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Meat in Modern Diet, Just as Bad as Sugar, Correlates with Worldwide Obesity: An Ecological Analysis

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Abstract

Background: The public have been educated that sugar intake should be minimized to avoid obesity, but no such recommendation regarding meat exists. We used FAO published comparable sugar and meat availability data to examine if they both contribute to obesity prevalence to the same extent.

Methods: Country-specific Body Mass Index (BMI) estimates of obesity and overweight were obtained. These were matched with country-specific per capita per day availability of major food groups (meat, sugar, starch crops, fibers, fats and fruits), total calories, per capita Gross Domestic Product (GDP PPP), urbanization and physical inactivity prevalence. Fisher's r-to-z transformation and Beta (B) range (B ± 2 Standard Errors) overlapping were used to test for potential differences between correlations and regressions results respectively. SPSS 22.0 was used for log-transformed data analysis.

Results: Pearson correlation showed that sugar and meat availability significantly correlated with obesity prevalence to the same extent (r=0.715, p<0.001 and r=0.685, p<0.001 respectively). These relationships remained in partial correlation analysis (r=0.359, p<0.001 and r=0.354, p<0.001 respectively) when controlling for calories availability, physical inactivity, urbanization and GDP PPP. Fisher's r-to-z transformation revealed no significant difference in Pearson correlation coefficients (z=-0.53, p=0.60), and partial correlation coefficients (z=-0.04, p=0.97) between sugar and meat availability with obesity prevalence.

Multiple linear regression analysis indicated that sugar and meat availability were the two most significant predictors of obesity prevalence in both Enter (B=0.455, SE=0.113, p<0.001 and B=0.381, SE=0.096, p<0.001, respectively) and Stepwise (B=0.464, SE=0.093, p<0.001 and B=0.433, SE=0.072, p<0.001, respectively) models. B ranges overlapping found in the Enter (0.289-0.573) and Stepwise (0.294-0.582) models showed sugar and meat availability correlated to obesity to the same extent with no statistically significant difference.

Conclusion: Sugar and meat availability comparably contribute to global obesity prevalence. Dietary guidelines should also advocate to minimize meat consumption to avoid obesity.

Keywords: Obesity; Sugar; Fructose; Meat; Meat protein; Fats; Insulin resistance; Energy surplus

Introduction

Obesity has been considered a major epidemic of the 21st century, and it has become a prelude to adverse health and premature death [1]. The World Health Organisation (WHO) estimates that obesity contributes significantly to the disease burdens of, among others, top causes of diseases, such as diabetes (44%), ischaemic heart disease (23%) and carcinogenesis (7-41%) [2]. Moreover, those considered overweight or obese have been subject to discrimination and prejudice [3].

Obesity and overweight are defined as abnormal or excessive fat accumulation that presents a risk to health. A crude measure of obesity is the body mass index (BMI). A person with a BMI of 30 kg/m^2 or more is generally considered obese. A person with a BMI equal to or more than 25 kg/m^2 is considered overweight (http://who.int/topics/obesity/en/).

Until the invention of food production in the Holocene, for several million years, human diet had relied on foods that could be found in natural environments. Since humans are unable to extract nutrition from cellulose, our food sources were limited to animals, fruits, nuts and tubers. This Palaeolithic diet contained large quantities of meat obtained through hunting [4] while it had fewer carbohydrates, especially simple carbohydrates. Besides large game that was hunted or scavenged, small vertebrates and invertebrates were gathered, and, where possible, fish were caught. Game meat does not contain much fat, so our metabolic system evolved to be efficient in using animal protein as a source of energy [5]. Deriving Acetyl CoA for use in the citric acid cycle from proteins is a complex process using a number of enzymes to obtain peptides, break them into separate amino acids and then deaminate those amino acids to obtain carbon skeletons-a source of pyruvates. Any pyruvates not used in the citric acid cycle to obtain energy can be converted via de novo lipogenesis into fats, and stored.

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Obtaining pyruvates from carbohydrates is a simpler metabolic process, especially when simple carbohydrates that are easily breakable into glucose are consumed. Therefore, when simple carbohydrates are available in the diet they, soon after their ingestion and absorption, can be used to provide energy in the citric acid cycle while additional pyruvates coming later from protein digestion may be surplus to direct need for energy, and therefore converted into fat [6]. Sucrose, being a compound of glucose and fructose provides easily accessible energy from glucose while fructose is not easily digested. Since the introduction of agriculture, and especially from the time of industrialised food production, sucrose became readily available in large quantities. In traditional agricultural economies meat was expensive to produce and thus was consumed in small quantities, rather rarely. Mass animal husbandry lowered cost of meat production and now meat is readily available and regularly consumed in significant quantities in developed economies. Diet patterns have been extensively considered as the contributing factor to obesity. Sugar and meat are now two major food groups in our daily diet. The prevailing dogma is that we should limit or avoid sugar intake, and eat a moderate amount of meat, preferably lean meat since it is a source of essential aminoacids. This dogma is supported by various dietary or nutrition guidelines published by the authorities. Numerous studies have reported that meat [7] and added sugar (sugar in short hereafter) [8] food groups were in significant correlations to obesity and/or body weight increase. However, the majority of the studies could not single out total sugar or all meat consumption in our diet for the correlation analysis. One of the concrete evidences that sugar consumption was correlated to obesity is that sugar-sweetened beverages (SSBs) intake is associated with obesity prevalence [9]. Despite the correlations between sugar food and beverage products and obesity are controversial, SSBs has been mostly consistently correlated to obesity prevalence [8]. However, sugar consumed via beverage is only part of the dietary sugar intake, and other sugar products, such as confectionery and bakery products were not included in the study designs. Similarly, meat containing food groups rather than pure meat are considered, for example processed meat [10] instead of total meat intake [11] have been linked to obesity prevalence. Another issue with meat food group is that data used for study may not be able to exclude bias from other food components, which may have been linked to body weight increase. For instance, wheat consumption has been correlated to obesity [12,13], and meat food groups containing wheat products (frankfurter and sausage) could be associated with obesity and central obesity [11] because of their wheat content. Likewise, the correlation between SSBs and obesity prevalence may be biased with other obesity associated additives in SSBs, such as preservatives. Therefore, these research results may not present the whole picture of the correlation between obesity prevalence and sugar or meat consumption. Using these data may not allow us to explore and compare the correlations between obesity prevalence and total intake of sugar and meat accurately.

The Food and Agriculture Organization (FAO) Food Balance Sheet presents the comparative per capita availability of major food items during the reference period by country after combining sources of supply and its utilization in terms of nutrient value. This study aimed to use empirical, macro-level nutrient availability data at the country level to evaluate and compare, from a global perspective, the correlation levels of obesity prevalence to sugar and meat availability.

Materials and Methods

Data

The country specific data were collected for this study:

1) The WHO Global Health Observatory (GHO) data on estimated prevalence rates of obesity and overweight (percent of population aged 18^+ with BMI ≥ 30 and 25 kg/m^2 respectively) of the population aged 18+ by country were obtained for the year 2010 (http://www.who.int/gho/database/en/). We did not use the most recent version of body weight status in 2014 because of other key variables of interest (described below). From GHO, we also captured the estimated prevalence rate of physical inactivity for each country for the people aged 18^+. The estimated prevalence rate of physical inactivity is defined as percent of a given population attaining less than 150 minutes of moderate-intensity physical activity per week, or less than 75 minutes of vigorous-intensity physical activity per week, or equivalent.

2) The FAOSTAT Food Balance Sheet (FBS) data on major food group availability per capita per day of: i) Sugar (total sugar and sweeteners); ii) Total meat; iii) Starch crops (mixed cereals and starchy root); iv) Fibers (vegetables, treenuts and pulses); v) Fats (plant oils and animal fats) and vi) Fruits. We also extracted the per capita per day availability of grand total calories (calories in short hereafter) as one of the potential confounders of our data analysis. Unfortunately, FAOSTAT does not contain data allowing separation of processed meats from “pure meat”. Because obesity develops after cumulative exposure to dietary risks (i.e., high intake of risk food groups today does not lead to immediate obesity, but a prolonged exposure to high intake of risk food type(s) is required [14-16]), we calculated the mean food availability per person per day over a 3-year period (2007-2009) in each of food categories to represent typical long-term exposure to each of these dietary components. The rationale for this decision is that studies have shown that three years is a practical period to develop metabolic syndrome leading to obesity after exposure to dietary risks. For instance, high intake of meat today does not lead to immediate obesity. Using the mean of three years of nutrients and food groups may also reduce the random errors during the data collection and calculation by FAO. The food items in each food groups were listed the Additional file 1: Food items in each food group.

3) The World Bank data on per capita GDP PPP (expressed in gross domestic product converted to international dollars using purchasing power parity rates) and country specific urbanization (the percent of population living in urban areas). Urbanization has been closely linked to human lifestyle change due to its process of modernization and industrialization.

How the above variables, such as food types (nutrients) and BMI were collected and how they lead to their robustness and to the subsequent validity of the current analysis have been described in details elsewhere [17,18].

WHO, FAO and the World Bank are intergovernmental organizations using specialized information relevant to their respective fields. Their professional personnel should have evaluated these data in consideration of their possible use, e.g. for scientific research and decision making, before they were published. Therefore, the data reporting is as free of bias and error as it can be with government statistics. This means that errors are reduced but some inaccuracies related to reporting quality may still be present in the data. Similar data from the same sources were recently used to analyse the relationships between nutrients and obesity [18,19] and diabetes [20-22] in a number of publications.

We obtained data for 170 countries after we matched the prevalence estimates of obesity and overweight to the year-and country-specific food groups and other variables. Each country was treated individually as the subject and all their availability for other variables information was analyzed. Data sources and summary statistics were further described in Additional file 2 Data descriptive summary and source.

For particular analyses, the number of countries included for variables may have differed somewhat because all information on other variables was not uniformly available for all countries due to unavailability from relevant UN agencies. All the data were extracted and saved in Microsoft Excel® for analysis.

Statistical analyses

It has been commonly believed that obesity is an affluence related medical condition [23], which is generally caused by eating too much (dietary) [24] and moving too little (lifestyle) [25]. Urbanization is a population shift from rural to urban areas. It causes changes in diet and exercise patterns of the population [26]. Therefore, in addition to the seven dietary predictors (availability of sugar, meat, fats, fruits, fibers, starch and calories), we also incorporated GDP PPP, urbanization and prevalence of physical inactivity for data analysis.

To assess the difference between relationships between obesity prevalence and availability of sugar and meat, the analysis proceeded in four steps.

Pearson correlation was used to evaluate the strength and direction of the associations between all variables.

2. Partial correlation of Pearson moment-product approach was used to find the relationship between obesity prevalence and each food group respectively while keeping calories availability, GDP PPP, physical inactivity and urbanization statistically constant. In order to show that meat and sugar availability contributed to obesity prevalence independent of each other, we controlled for availability of the other food groups (starch crops, fibers, fats and fruits) in addition to GDP PPP, urbanization, total calories availability, physical inactivity. Fisher's r-to-z transformation was performed to test significance of differences between correlation coefficients. The significance was reported when P-value was <0.01. We kept sugar and meat availability statistically constant respectively together with all the other variables to test if they were correlated to obesity prevalence significantly independent of each other in addition to all other variables.

3. Standard multiple linear regression (Enter) was conducted to describe the relationships between obesity prevalence and all independent variables, which include all the dietary, lifestyle and socioeconomic predictors. Standard multiple linear regression (Stepwise) was also performed to regress multiple variables while simultaneously retaining sugar and meat availability as the important predictors of obesity prevalence. Analysis results of multiple linear regression (Enter and Stepwise) model included both the indicative value of beta coefficient (B) and its standard error (SE). The actual B may fall into a range determined with its standard error. Therefore, we added twice the standard error (SE) to their respective B to obtain the upper bound of the range and subtracted two SEs from B to obtain the lower bound of the range. We compared the ranges of B's of obesity prevalence to sugar and meat availability to determine if the relationships were significantly different. If two B ranges have overlap, the difference between the B's would not be considered as significant. If there is no overlap, the difference would be considered significant.

4. We used scatter plots to explore and visualize the correlations between obesity and availability of sugar and meat. To compare the two relationships, we reversed x and y axes to allow the two correlations in one figure (chart).

Additional variables

We reassessed our models using overweight (BMI ≥ 25 kg/m^2 instead of obesity (BMI ≥ 30 kg/m^2) in case of sugar and meat availability as a late-stage predictor of obesity. The results were reported in tables aligning with those relationships between obesity prevalence and sugar and meat availability. To incorporate overweight data for analysis may allow us to reassure the quality of data which were used for this study.

SPSS v. 22 (SPSS Inc., Chicago Il USA) was used for data analysis. Prior to analysis data were log-transformed (natural logarithms) to bring their distributions close to normal.

Results

Pearson correlation analysis showed that both sugar and meat availability were significantly correlated with prevalence of obesity (r=0.715, p<0.001 and r=0.685, p<0.001, respectively) (Table 1). Spearman rho values were r=0.664 (p<0.001) and r=0.664 (p<0.001) respectively. Fisher's r-to-z transformation revealed no significant difference in Pearson correlations between sugar and meat availability with obesity (z=0.53, p=0.5961). The difference between two coefficients' values was negligible, indicating that both meat and sugar were related to obesity to the same extent.

When we controlled for availability of total calories, prevalence of physical inactivity, urbanization and GDP PPP in partial correlation analysis, sugar and meat availability were still in significant correlation with prevalence of obesity (r=0.359, p<0.001 and r=0.354, p<0.001, respectively) (Table 2). This indicates that it is not just the contribution of sugar and meat to the total caloric intake that relates to obesity, but specific contents of these two food groups that influence metabolic processes. Fisher's r-to-z transformation revealed no significant difference in partial correlations between sugar and meat availability with obesity prevalence based on the comparison of two correlations (z=0.04, p=0.9681). This means that both sugar and meat availability contributes to obesity to the same extent.

Table 2 also presented that fats availability was in strong and significant correlation (Pearson) with obesity prevalence (r=0.517, p<0.001), but the level of correlation was not retained in partial correlation analysis (r=0.057, p=0.537). Starch crops availability was in relative strong correlation with obesity prevalence, but this correlation almost disappeared in partial correlation analysis.

	BMI 30	BMI 25	Sugar	Meat	Fats	Fruits	Fibers	Starch crop	Calories	GDP	Urbanization	Physical Inactivity
BMI 30	1	0.931***	0.715***	0.685***	0.523***	0.477***	0.678***	-0.220**	0.619***	0.678***	0.497***	0.448**
BMI 25	-	1	0.776***	0.792***	0.644***	0.546***	0.806***	-0.290**	0.748***	0.798***	0.632***	0.458***
Sugar	-	-	1	0.718***	0.571***	0.470***	0.714***	-0.492***	0.650***	0.727***	0.529***	0.437***
Meat	-	-	-	1	0.614***	0.520***	0.826***	-0.431***	0.695***	0.831***	0.565***	0.406***
Fats	-	-	-	-	1	0.373***	0.696***	-0.223**	0.701***	0.684***	0.651***	0.300**
Fruits	-	-	-	-	-	1	0.565***	-0.215**	0.499***	0.560***	0.353***	0.230**
Fibers	-	-	-	-	-	-	1	-0.370***	0.779***	0.994***	0.625***	0.439***
Starch crop	-	-	-	-	-	-	-	1	-0.029	-0.394***	-0.150*	-0.425***
Calories	-	-	-	-	-	-	-	-	1	0.763**	0.643**	0.243**
GDP PPP	-	-	-	-	-	-	-	-	-	1	0.620***	0.437***
Urbanization	-	-	-	-	-	-	-	-	-	-	1	0.385***
Physical Inactivity	-	-	-	-	-	-	-	-	-	-	-	1

Numbers of countries included in the analysis range from 126 to 170. *p<0.05; **p< 0.01, ***P< 0.001

BMI ≥ 30 and BMI ≥ 25 are percentages of defined population with a body mass index (BMI) of no less than 30 kg/m^2 and 25 kg/m^2 respectively

Data sources: Dietary data from the FAO's FAOSTAT. BMI (≥ 30 and ≥ 25) and Physical Inactivity data from the WHO Global Health Observatory. GDP PPP and urbanization data from the World Bank

Table 1: Pearson correlation matrix for all variables.

When we controlled for availability of fats, fruits, fibers and starch, prevalence of physical inactivity, total calories, urbanization and GDP PPP in partial correlation analysis, both sugar and meat availability were still in significant correlation with prevalence of obesity (r=0.431, p<0.001 and r=0.339, p<0.001, respectively) (Table 2). Fisher's r-to-z transformation did not show a significant difference in the correlations between obesity and sugar and meat availability (z=0.81, p=0.4179). Therefore, sugar and meat contributions to obesity are independent of the availability of other food groups.

Interestingly, meat and sugar availability significantly correlated with each other in Pearson correlation (r=0.718, p<0.001) analysis (Table 1) but this correlation disappeared in partial correlation analysis when we controlled for availability of fats, fruits, fibers and starch crops, calories, GDP, urbanization and physical inactivity prevalence. Partial correlation coefficient became very weak and insignificant (r=0.144, p=0.124, not indicated in Table 2). This means that sugar and meat availability may contribute to obesity prevalence independent of each other.

The further investigation on this independence showed that both sugar (r=0.375, p<0.001) and meat (r=0.308, p<0.001) availability were still significantly correlated to obesity prevalence when we respectively controlled for sugar and meat availability together with all the other variables (fats, fruits, fibers and starch crops, calories, GDP, urbanization and physical inactivity prevalence) for testing each other's relationship with obesity prevalence (Table 2). Fisher's r-to-z transformation did not show significant difference between these two independent relationships (z=0.57, p=0.2843).

Table 3 presented the results of multiple linear regression analyses to identify dietary, lifestyle and socioeconomic predictors of prevalence estimates of obesity and overweight. We found that both sugar and meat were the significant predicators of estimates of obesity (B=0.455, SE=0.113 and B=0.381, SE=0.096, respectively) at the same significance level of p<0.001. The B ranges between obesity prevalence and availability of sugar (0.229-0.681) and meat (0.189-0.573) overlapped each other greatly (0.229-0.573). This meant that meat availability was no different from sugar availability to predict the estimates of prevalence of obesity.

Table 4 indicated that sugar (B=0.464, SE=0.093, p<0.001) and meat (B=0.433, SE=0.072, p<0.001) availability stood out as the significant predictor of obesity prevalence simultaneously in stepwise multiple linear regression analyses. Two overlapping B ranges (0.294-0.582) indicated that there was no difference between sugar and meat availability to predict obesity prevalence.

One of the highlights in our data analysis with linear regression was that fats availability was a minor predictor of obesity prevalence in both Enter method (B=0.053, SE=0.095, p=0.565) (Table 3) and Stepwise method (fats availability was a removed variable) (Table 4).

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	Pearson correlation				Partial Correlation										
Variable	**n**	**BMI ≥ 30**	**BMI ≥ 25**	**df**	**BMI ≥ 30**	**BMI ≥ 25**	**df**	**BMI ≥ 30**	**BMI ≥ 25**	**df**	**BMI 30**	**BMI 25**	**df**	**BMI ≥ 30**	**BMI ≥ 25**
Sugar	167	0.715***	0.776***	118	0.359***	0.372***	114	0.431***	0.399***	114	0.375***	0.363***	-	-	-
Meat	167	0.685***	0.792***	118	0.354***	0.418***	114	0.339***	0.370***	-	-	-	114	0.308***	0.341***
Fats	161	0.523***	0.644***	118	0.057	0.11	-	-	-	-	-	-	-	-	-
Fruits	167	0.477***	0.546***	118	0.112	0.159	-	-	-	-	-	-	-	-	-
Fibers	169	0.678***	0.806***	118	0.248**	0.269**	-	-	-	-	-	-	-	-	-
Starch crops	167	-0.220**	-0.290**	118	0.07	-0.036	-	-	-	-	-	-	-	-	-
Calories	167	0.619***	0.748***	-	-	-	-	-	-	-	-	-	-	-	-
GDP PPP	165	0.678***	0.798**	-	-	-	-	-	-	-	-	-	-	-	-
Urbanization	169	0.497***	0.632***	-	-	-	-	-	-	-	-	-	-	-	-
Physical Inactivity	131	0.448***	0.458***	-	-	-	-	-	-	-	-	-	-	-	-
*p<0.05, **P< 0.01, ***P< 0.001. -: Controlled variable															
BMI ≥ 30 and BMI ≥ 25 are percentages of defined population with a body mass index (BMI) of no less than 30 kg/m2 and 25 kg/m2 respectively															
Data sources: Dietary data from the FAO's FAOSTAT. BMI (≥ 30 and ≥ 25) and Physical Inactivity data from the WHO Global Health Observatory. GDP and urbanization data from the World Bank															

Table 2: Pearson and partial correlation analysis of different food groups to prevalence estimates of obesity and overweight.

	Obesity prevalence (%)				Overweight prevalence (%)			
	Model 1 (Enter), R^2=0.656				**Model 1 (Enter), R^2=0.823**			
Predictors	**B**	**SE**	**p**	**B range**	**B**	**SE**	**p**	**B range**
Sugar	0.455	0.113	<0.001	0.229-0.681	0.315	0.066	<0.001	0.183-0.447
Meat	0.381	0.096	0.001	0.189-0.573	0.307	0.056	<0.001	0.195-0.419
Fats	0.053	0.095	0.565	-	0.056	0.055	0.391	-
Fruits	0.034	0.07	0.633	-	0.054	0.041	0.29	-
Fibers	-0.17	0.314	0.777	-	0.214	0.182	0.618	-
Starch crops	0.349	0.215	<0.001	-	0.164	0.124	0.008	-
GDP PPP	0.37	0.272	0.525	-	0.002	0.157	0.997	-
Urbanization	-0.04	0.119	0.635	-	0.054	0.069	0.368	-
Physical Inactivity	0.163	0.098	0.015	-	0.081	0.057	0.09	-
Calories	-0.147	0.544	0.233	-	0.069	0.315	0.434	-
B: Beta; SE: Std. Error; p: Sig.								
BMI ≥ 30 and BMI ≥ 25 are percentages of defined population with a body mass index (BMI) of no less than 30 kg/m^2 and 25 kg/m^2 respectively								
Data sources: Dietary data from the FAO's FAOSTAT. BMI (≥ 30 and ≥ 25) and Physical Inactivity data from the WHO Global Health Observatory. GDP and urbanization data from the World Bank								

Table 3: Results of enter multiple linear regression analyses to identify dietary, lifestyle and socioeconomic predictors of prevalence estimates of overweight and obesity.

	Obesity prevalence (%)				Overweight prevalence (%)			
	Model 4 (Stepwise), Adjusted R^2=0.630				Model 4(Stepwise), Adjusted R^2=0.802			
Predictors	**B**	**SE**	**p**	**B Range**	**B**	**SE**	**p**	**B Range**
Sugar	0.464	0.093	<0.001	0.278-0.650	0.363	0.059	<0.001	0.245-0.481
Meat	0.438	0.072	<0.001	0.294-0.582	0.34	0.055	<0.001	0.230-0.450
Fats	-	-	-	-	-	-	-	-
Fruits	-	-	-	-	-	-	-	-
Fibers	-	-	-	-	0.359	0.034	<0.001	-
Starch crops	0.464	0.171	<0.001	-	0.187	0.097	<0.001	-
GDP PPP	-	-	-	-	-	-	-	-
Urbanization	-	-	-	-	-	-	-	-
Physical Inactivity	0.171	0.094	0.008	-	-	-	-	-
Calories	-	-	-	-	-	-	-	-
B: Beta; SE: Std. error; p: Sig.; -: Removed variable								
BMI ≥ 30 and BMI ≥ 25 are percentages of defined population with a body mass index (BMI) of no less than 30 kg/m^2 and 25 kg/m^2 respectively								
Data sources: Dietary data from the FAO's FAOSTAT. BMI (≥30 and ≥25 mean) and Physical Inactivity data from the WHO Global Health Observatory. GDP and urbanization data from the World Bank								

Table 4: Results of stepwise multiple linear regression analyses to identify dietary, lifestyle and socioeconomic predictors of prevalence estimates of overweight and obesity.

Figure 1 showed the unadjusted correlation between prevalence estimate of obesity and sugar and meat availability. The scatterplots are very similar. The relationships were noted to be best described by polynomial regression equations with strong correlation at very similar levels.

Our data analysis in different models showed the similar relationships between overweight prevalence and respective availability of sugar and meat when we substituted overweight prevalence for obesity prevalence. We did not describe the results in narrative form, but they were shown in Figure 2 and Tables 1-4, aligning with those with obesity prevalence.

Discussion

By examining the comparable per capita availability data of the sugar and meat for 170 countries we have shown that:

1. Sugar and meat consumptions may be two significant determinants of obesity prevalence.

2. The consumption of sugar and meat has statistically significant relations to obesity independent of the effect of other major food groups, socioeconomic and lifestyle factors.

3. Availability of sugar and meat availability are correlated to obesity prevalence independent of each other.

4. Statistically, there was no significant difference between sugar and meat relationship to global obesity prevalence at a population level.

Values of Pearson correlation coefficients may be influenced by non-homoscedasticity of distribution of correlated variables. We have tried to minimize such possibility by using logarithmically transformed data. Comparison of the values of Pearson correlation coefficients with Spearman rho values shows that effects of distributions are negligible. Thus, our partial correlation analysis produced acceptable results.

There is ample research on foods and diet patterns that contribute to body weight increase. Using the similar source of data, Siervo et al. reported that both meat and sugar availability were correlated to global obesity prevalence [18]. However, their study did not conduct in-depth investigation to compare the correlation levels of meat and sugar availability to obesity prevalence.

There are two similar mechanisms that may explain why sugar and meat availability contribute to obesity comparably.

1. Fructose and meat protein may produce energy surplus due to their slower digestion process.

Sucrose and high-fructose corn syrup (HFCS; 42% or 55% fructose) are two primarily consumed sugars, and they are very similar in their composition. HFCS is only consumed in the US, Canada, Japan, and some parts of Europe, while the rest of the world primarily consumes sucrose (50% fructose). Sucrose contains 50% fructose and 50% glucose. HFCS in common usage within the food industry comprises similar percentages (40-55%) of glucose and fructose, water and other carbohydrates which are readily hydrolysable polymers of glucose. Fructose, as the major component of sugar, is slow to absorb [27] and hard to assimilate and it can only be metabolized by the liver to have glycogen most of which may be converted into fat for storage [28-30].

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Meat is mainly composed of protein, fat and water. The absolute energy value of meat is determined by the protein and fat content [31]. Because meat of domesticated animals contains relatively large amount of fat, a number of studies have considered meat consumption as a higher risk of obesity and waist circumference (WC) [11,32]. Studies have already shown that dietary fat may not be a major determinant of obesity [33,34]. Animal breeding and butchering techniques in modern agriculture have significantly reduced meat fat content and increased protein content in the past few decades, so dietary meat is much leaner than ever [35,36]. The macronutrient energy values are 9.0 kcal/g for fat, 4.0 kcal/g for protein and carbohydrates [37]. Therefore, meat is not high in "energy and fat content" because it contains less fat and higher meat protein due to modern agriculture techniques.

Despite energy value of protein is not high (4.0 kcal/g), it has been postulated to contribute to the development of obesity because it may only be digested later than fats and carbohydrates [17,38,39]. Modern agriculture has been bringing the cost of availability of carbohydrates rich crops, such as cereals and starchy roots, and fat (oil), such as rape and soy significantly down. Cheap carbohydrates and fats in a meal can easily supply enough energy to meet human needs. This may make the energy from slow digested protein a surplus and stored as fat [17,38,39]. This postulation was supported by our data analysis result (Table 2) with the changes of correlations between food groups (fats and starch crops correlated to obesity and prevalence in Pearson r correlation, but not in partial correlation) and obesity and overweight in Pearson and partial correlations. In modern diet, foods rich in carbohydrates and fats have been able to provide enough energy to meet human daily energy requirements, so meat protein has been postulated to produce energy surplus, thus contributing to obesity may support our hypothesis in this study [17].

Plant protein is always mixed with fiber which makes it difficult to digest. Therefore, meat protein as the major source of digestible protein may contribute to the "energy surplus" significantly.

2. Sugar and meat consumption may cause insulin resistance, a metabolic syndrome contributing to obesity.

Insulin is an anabolic hormone in human body. It encourages the synthesis of carbohydrate, fat and protein, inhibits the production of glucose by the liver [40]. Insulin also increases the storage of fat in fat cells and prevents fat cells from releasing fat for energy [41-44]. The cells in insulin resistance patient become "resistant" to insulin, and sugars in blood cannot enter cells for calories production [45-50], but are metabolized into glycogen in their liver, which may be forced by insulin to metabolise into fat [28,51] and accelerates body weight gain [52] independent of excessive energy intake [53]. Insulin resistance is a major underlying cause of excess weight and obesity [54,55].

Many studies showed that sugar consumption is linked to insulin resistance in both children and adults, especially when it is consumed in large amounts [45,46].

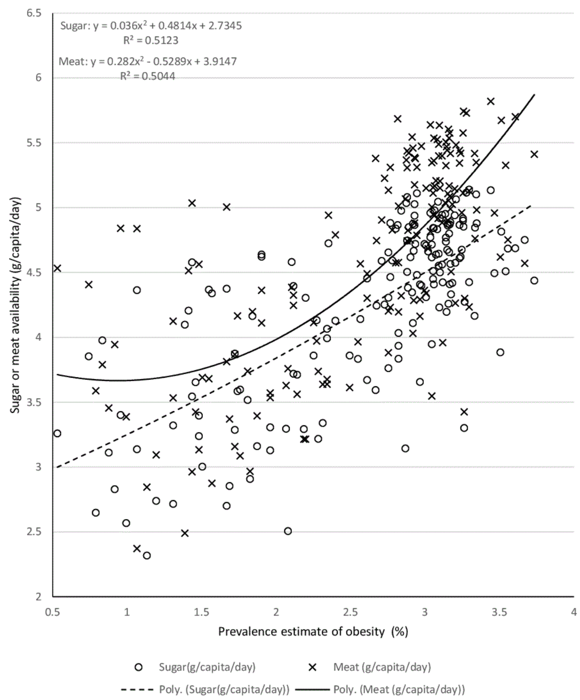

Figure 1: Polynomial correlation plot of obesity prevalence and sugar and meat availability.

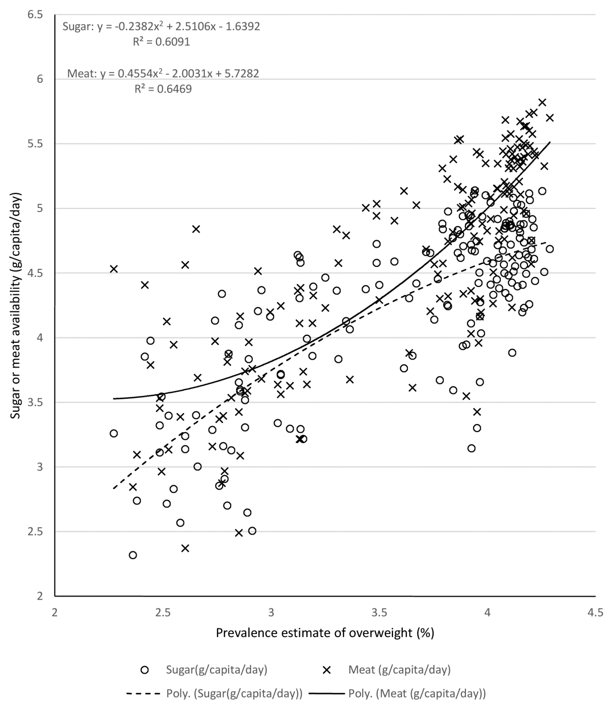

Figure 2: Polynomial correlation plot of overweight prevalence and sugar and meat availability.

High-dose fructose feeding can also cause insulin resistance in normal healthy human in as little as a week [56] and it can exacerbate insulin resistance in overweight and obese people [57].

Likewise, a number of studies have associated meat consumption as a risk factor for insulin resistance because: 1) Meat fat enhances intracellular lipid storage and impairs insulin metabolism [58,59]; 2) Heme iron from meat may damage pancreas cells [60,61] and 3) Meat sourced nitrites and sodium may impair the function of the pancreatic beta cells [62].

Leptin is a hormone made by adipose cells that helps to regulate energy balance by inhibiting hunger. A number of studies reported that sugar consumption was correlated to production of leptin, but the results were controversial [63,64].

The role of sugar consumption in the development of overweight and obesity has overly received scientific and policy attention. There are literally thousands of postings on the internet related to putative healthy diet guideline links between sugar and body obesity as well as insulin resistance. For instance, Morenga et al. [8] concluded that intake of sugar is a determinant of body weight after assessment of 6,557 relevant academic publications. Some authorities have taken action to limit young students' access to sugar products. Furthermore, taxation of sugar has been advocated or implemented in some countries/areas as a potential public health strategy to curb the obesity epidemic.

Meat, by contrast, has not been singled out as one of the worst dietary offenders. In terms of balanced diet components, what the public have been told overwhelmingly is that a moderate amount of meat (lean meat preferred) should be included in our daily diet as it contains essential protein and minerals. Although meat protein is nutritious and integral to our health, protein halo should not be prevailing. While recognizing that the evidence of harm to health against meat is statistically as strong as sugar, we should avoid the trap of waiting for absolute proof before allowing public health action to be taken. A survey of approximately 100,000 North American members of the Seventh Day Adventist Church [65] indicated that vegan members had the lowest BMI values, while mean BMI increased gradually with increasing amounts of animal protein consumed by lacto-ovo vegetarians, pesco-vegetarians and semi-vegetarians reaching the highest value in non-vegetarians.

A strength of this study is that we used comparable per capita availability data from 170 countries which enabled us to examine and compare relationships between obesity prevalence and different food groups (sugar and meat) at population level. However, there are several limitations in this study. Firstly, although we attempted to remove the potential confounding effects of variables such as GDP, caloric etc. by means of partial correlation analysis, some confounding factors may still influence correlations we found. Secondly, there may be some variables not included in our analysis that influence the correlation found in this study. It is however difficult to see what such variables may be. Thirdly, we could only use an international food group database that tracks the general market availability of different food types, not the actual human consumption. There are no direct measures of actual human consumption that can account for food wastage and provide precise measures of food consumption internationally. The database did not contain sufficient information to separate effects of "pure meat" from meat products that may contain other nutrients. Finally, the data analysed are calculated for per capita in each country, so we can only demonstrate a relationship between food group availability and obesity at a country level, which does not necessarily correspond to the same relationships holding true at the individual level. Prospective cohort studies are proposed to explore these associations further.

Conclusion

Both sugar and meat availability are correlated to obesity prevalence worldwide, and there is no significant difference between the levels of two correlations. Similar to the public campaign against excessive sugar consumption, considering the findings of adverse effects of meat on obesity and the environmental impact of meat production, the country authorities should also advise the public not to adopt a high-meat diet for long-term healthy weight management.

Declarations

Ethics approval and availability of data

All the data used in this study were freely downloaded from the United Nations (UN) agencies' websites. No ethical approval or written informed consent for participation was required.

Competing interests

The authors (WPY and MH) declare that there are no conflicts of interest, financial or otherwise, related to this paper.

Authors' contributions

MH conceived the idea for this study. WPY extracted the data. MH and WPY analysed and interpreted the data. WPY reviewed the literature and drafted the manuscript. WPY and MH edited and approved the manuscript for submission to the journal.

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Additional material

- Additional PDF 1 Food items in each food group
- Additional PDF 2 Data descriptive summary and source

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