《Original articles》

Associations of dietary diversity with the prevalence of depression and suicide: A 26-year global comparative study

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Abstract

Purpose: This study aimed to determine the associations of dietary diversity with depression and suicide rates by an ecological analysis using 26-years worldwide statistics.

Methods: Average food supply and energy supply by country, excluding loss between production and household, were obtained from the Food and Agriculture Organization of the United Nations Statistics Division database (FAOSTAT). Dietary diversity scores were calculated from food group classifications. Age-standardized depression prevalence and suicide rates per 100,000 people by country were obtained from the Global Burden of Disease (GBD) 2017 database. The association between food diversity scores and depression prevalence and suicide rates was analyzed by a mixed effects model controlling for covariates in 137 countries with populations of 1 million or greater.

Results: A significant negative association was found in the analysis of the relationship between dietary diversity and the prevalence of major depression in the model controlled for all covariates [β (se) = –225.6 (61.9), $p < 0.001$]. In addition, a significant negative association between dietary diversity and the suicide rate was also found in the model controlled for all covariates [β (se) = –3.08 (1.50), $p < 0.05$].

Conclusion: Dietary diversity was significantly negatively associated with the rates of major depression and suicide. Diets rich in foods may reduce the prevalence of depression and suicide rate.

Keywords: dietary diversity, depression, suicide, global statistics, FAOSTAT

1. Introduction

In 2018, the World Health Organization (WHO) estimated that over 300 million people worldwide were affected by depressed and 800,000 had died of suicide. Depression is the biggest factor in disability. However, in many countries around the world, there are only a limited number of patients who receive appropriate treatment for depression[1)].

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Although the causes of depression are not fully understood, abnormalities in the function of neurotransmitters such as noradrenaline, dopamine, and serotonin[2], changes in intestinal flora[3], chronic inflammation[4], oxidative stress[5], and changes in neuroplasticity[6] are thought to be involved. These abnormalities are mainly caused by aging, but sleep disturbances[7], lack of exercise[8], stress in daily life[9], and lack of sunlight[10] are also thought to be factors in the development of these abnormalities.

In recent years, the relationship between diet and depression has received considerable attention. In particular, a diverse diet rich in fruits and vegetables including antioxidants and anti-inflammatory components may have a beneficial effect on preventing depression[11]. Eating a wide variety of foods is called dietary diversity. Dietary diversity is an important requirement for a healthy diet[12] and has been reported to reduce mortality[13], dental disease[14], type 2 diabetes mellitus[15], and colorectal cancer[16]. It has also been suggested that dietary diversity may have a beneficial effect on depression[17-19]. However, these studies have been limited to certain regions, such as developing countries[17,18], and pre- and post-partum women[19]. The aim of this study was to determine the associations between dietary diversity and the prevalences of depression and suicide in a 26-year global comparative study from 1991 to 2017.

2. Methods

Variables

The annual prevalence of major depression and the suicide rate per 100,000 people in each country were obtained from the Global Burden of Disease Study (GBD) 2017 database using age-standardized country data from 1991 to 2017[20,21]. The GBD is a comprehensive regional or global disease burden research program on mortality from disease, injuries, and risk factors, as well as the burden of disease from disability, administered as an international collaborative study of more than 145 countries, led by the Institute for Health Metrics and Evaluation (IHME) at the University of Washington[21].

Food and energy supplies were obtained from the Food and Agriculture Organization of the United Nations (FAOSTAT) database of per capita food supplies by country; FAOSTAT's food supplies exclude depletion from production to delivery to consumers and reflect household consumption[22,23]. Data on average food supply (g/day/person) and energy supply (kcal/day/person) by country from 1991 to the most recent year 2017 were used in the analysis. The FAOSTAT dataset is a representative and objective measure of food consumption by people in 189 countries. Because data are collected by the same process in all countries, international comparisons are possible.

Each of the foods in the FAOSTAT database is divided into 12 food groups (potatoes, vegetables, beans, seeds, fruits, dairy products, cereals, meat, fish, eggs, fat, sugar, and confectionery). The Quantitative Index for Dietary Diversity (QUANTIDD) was used to calculate food diversity based on the relative contributions of different food groups[24]. The QUANTIDD is calculated as follow, where *prop*[j] is the proportion of food group *j* that contributes to total energy or nutrient intake, *n* is the number of food groups, and $j = 1, 2, \ldots, n$.

$$QUANTIDD = (1 - \sum_{j=1}^{n} prop[j]^2)/(1 - \frac{1}{n})$$

The numerator is the probability that the two foods taken out of an aggregation of consumed foods belong to different food groups. The denominator is its maximum value. The index ranges from 0 to 1.

With respect to socioeconomic and lifestyle indicators, the data for Gross Domestic Product (GDP) per capita (1000US$/capita), ageing rate (percentage of the population aged 65 years and over), unemployment rate (%) by International Labor Organization (ILO) standards, and total population by country were taken from the World Bank database for the period 1991–2017[25]. Years of education, current smoking rates (%), physical activity (1000 MET·min/week), and mean BMI (kg/m^2) were taken from age-standardized data from the GBD 2017 database for the years 1991 to 2017[20]. Because depression and

suicide are more common in countries with higher latitudes with fewer hours of daylight, absolute values of latitude at the center of each country from the GBD 2017 database were used to control for the effect of latitude[20].

Statistical analysis

A total of 137 countries with a population of more than 1 million for which all data were available were included in the analysis. Differences in the mean values of the variables by year in 1991, 2004, and 2017 were tested by analysis of variance (ANOVA). The trend by year was tested with a linear model.

To determine the association between dietary diversity and the prevalences of depression and suicide, a linear mixed-model analysis was conducted with the prevalences of depression and suicide in each country for 26 years from 1991 to 2017 as the dependent variable and the QUANTIDD in each year as the independent variable. In Model 1, only the year was used as an independent control variable; in Model 2, the year and GDP were used as independent control variables; and in Model 3, in addition to the year and GDP, aging rate, years of education, smoking rate, average BMI, energy supply, unemployment rate, and latitude were used as independent control variables. All independent variables were mean-centered. The random effects of the mixed model were the intercept for each country and the slope for year. In addition, a Compound Symmetry structure was specified for the covariance matrix by year for each country. Models were fit by maximizing the log-likelihood. Akaike's Information Criterion (AIC) and the Bayesian information criterion (BIC) were used to determine the suitability of the model. R 4.0.1 was used for the analysis[26], and p values <0.05 were considered significant. The generalized linear mixed-effects model was fitted using the 'lme' function of the 'nlme' package[27].

3. Results

Table 1 shows the means and standard deviations of socio-economic indicators (GDP, population, aging population, unemployment rate, and years of education), lifestyle (smoking rate, mean BMI, physical activity, and total energy supply), QUANTIDD, depression prevalences, and suicide rates per 100,000 people for 1991, 2004, and 2017 in countries with a population of more than 1 million people included in the analysis. In 1991, 107 countries were

Table 1. Characteristics of countries by year

	Year			p-value	
	1991	2004	2017	ANOVA	Trend
n	107	136	137		
Population (million)	43.89 (142.06)	45.82 (149.95)	52.85 (168.05)	NS	NS
Aging rate (%)	6.17 (4.37)	7.64 (5.21)	9.17 (6.53)	p<0.001	p<0.001
GDP (1,000US$/capita)	5.63 (8.90)	8.75 (13.56)	12.92 (17.27)	p<0.001	p<0.001
Education (years)	6.18 (3.52)	7.95 (3.62)	9.20 (3.42)	p<0.001	p<0.001
Unemployment rate (%)	7.65 (6.19)	8.24 (5.95)	6.89 (5.12)	NS	NS
Smoking (%)	17.69 (8.54)	16.53 (7.87)	15.13 (7.28)	0.040	0.012
Physical activity (1,000 MET·min/week)	5.32 (1.64)	5.63 (1.78)	5.73 (1.77)	NS	NS
BMI (kg/m^2)	23.83 (1.80)	24.73 (1.90)	25.42 (1.97)	p<0.001	p<0.001
Energy supply (1,000 kcal/capita/day)	2.32 (0.46)	2.48 (0.43)	2.64 (0.41)	p<0.001	p<0.001
Dietary diversity (QUANTIDD)	0.84 (0.07)	0.86 (0.06)	0.86 (0.06)	NS	NS
Prevalence of depression (100,000/year)	2321.19 (576.50)	2275.04 (627.80)	2192.56 (594.13)	NS	NS
Suicide rate (100,000/year)	11.66 (6.41)	12.03 (7.54)	9.98 (5.29)	0.023	0.044

Mean (standard deviation)

QUANTIDD: Quantitative Index for Dietary Diversity, GDP: Gross Domestic Product, BMI: Body Mass Index, NS: not significant.

included in the analysis; in 2004, 136 countries were included in the analysis; and in 2017, 137 countries were included in the analysis. Socio-economic indicators showed that the aging rate, GDP, and years of education increased significantly with year, whereas population and unemployment did not change. As for the lifestyle variables, smoking rates decreased, and BMI and energy supply increased. There was no change in physical activity levels. The prevalence of depression did not change by year, but the suicide rate decreased slightly. There was no change in dietary diversity (QUANTIDD) by year.

First, the association between QUANTIDD and depression prevalence was examined (Table 2). In Model 1, there was a significant negative association between QUANTIDD and depression prevalence controlling for year [β (se) = –222.1 (62.7), $p <$ 0.001]. The fixed effect of QUANTIDD was also significant in Model 2 in which GDP per capita was controlled [β (se) = –203.6 (62.5), $p < 0$ .01]. In addition, a significant negative association between QUANTIDD and depression prevalence was also found in Model 3, in which the aging rate, years of education, unemployment rate, energy supply, smoking rate, mean BMI, and absolute values of latitude were controlled [β (se) = –225.6 (61.9), $p < 0.001$].

The associations between QUANTIDD and the suicide rate were similar to those of depression (Table 3). There was a significant negative association between QUANTIDD and the suicide rate in Model 1, adjusting for year only [β (se) = –4.73 (1.52), $p <$ 0.01]. The fixed effect of QUANTIDD was significant in Model 2, in which GDP per capita and year were controlled [β (se) = –4.41 (1.52), $p < 0.01$]. Furthermore, a negative association between QUANTIDD and suicide rate was also found in Model 3, which included aging rate, years of education, unemployment rate, energy supply, smoking rate, mean BMI, physical activity, and absolute values of latitude [β (se) = –3.08 (1.50), $p < 0.05$].

4. Discussion

The present study using 26-year international data showed significant associations between dietary diversity and the prevalence of depression and the suicide rate. This is the first study to demonstrate global associations of depression and suicide with dietary diversity using long-term international data.

Previous studies have shown an association between diet and depression. A systematic review and meta-analysis of 24 cohorts has shown that a higher quality of diet is associated with a lower risk for the onset of depressive symptoms[28]. A systematic review and meta-analysis of observational studies, including 20 longitudinal and 21 cross-sectional studies, also concluded that a healthy diet, such as the Mediterranean diet, has a preventive effect on depression[29]. We have already reported that high dietary diversity may increase healthy life expectancy[30]. Diets with greater dietary diversity are more likely to be healthier. Dietary diversity has been shown to be associated with the sufficiency of necessary nutrients[31,32]. High dietary diversity was associated with higher intake of dairy products, vitamin A-rich vegetables, dark green leafy vegetables, eggs, legumes, and seeds, and lower intake of meat and seafood. In terms of nutrients, the intake of B vitamins, especially vitamins B_6, B_{12}, and folic acid, was higher[33].

A high intake of folic acid, which is high in vegetables, has been shown to reduce the frequency of depression[34]. A meta-analysis of 43 studies reported significantly lower serum folic acid levels in people with depression[35]. Deficiencies in folic acid and vitamin B_{12} increase blood levels of homocysteine and increase oxidative stress, resulting in vascular endothelial cell damage, which can damage nerve cells and cause depression[36]. Magnesium is abundant in unrefined cereals, vegetables, and other plant foods. Magnesium decreases the chronic inflammatory response and lowers blood levels of C-reactive protein, an indicator of inflammation[37]. The antioxidant vitamins, including vitamin C, vitamin E, beta-carotene, and folic acid are found in a highly diverse diet[33], and these vitamins may reduce oxidative stress, protect nerve cells, and prevent depression[38].

Serotonin, a neurotransmitter synthesized in the

Table 2. Fixed effects of dietary diversity (QUANTIDD), year, and covariables on the prevalence of depression in the three linear mixed effect models

	Model 1	Model 2	Model 3
	β (SE)	β (SE)	β (SE)
(Intercept)	–7.158 (51.23)	–7.17 (51.32)	–5.85 (50.48)
QUANTIDD	–222.101 (62.74) ***	–203.60 (62.46) **	–225.57 (61.92) ***
Year	–4.405 (0.85) ***	–3.61 (0.84) ***	3.87 (1.64) *
GDP		–2.06 (0.33) ***	–1.25 (0.33) ***
Aging rate			6.85 (2.83) *
Education			–51.72 (13.60) ***
Energy supply			–6.81 (11.14)
Smoking			1.98 (1.27)
BMI			–42.94 (8.09) ***
Physical activity			–190.71 (19.93) ***
Latitude			6.49 (3.69)
Unemployment rate			1.07 (0.49) *
AIC	39996.58	39959.24	39783.72
BIC	40046.04	40014.89	39888.79

QUANTIDD: Quantitative Index for Dietary Diversity, GDP: Gross Domestic Product, BMI: Body Mass Index, AIC: Akaike's Information Criterion, BIC: Bayesian Information Criterion, SE: Standard Error
* p <0.05, ** p<0.01, *** p<0.001.

Table 3. Fixed effects of dietary diversity (QUANTIDD), year, and covariables on the suicide rate in the three linear mixed effect models

	Model 1	Model 2	Model 3
	β (SE)	β (SE)	β (SE)
(Intercept)	0.078 (0.576)	0.078 (0.578)	0.085 (0.548)
QUANTIDD	–4.728 (1.515) **	–4.405 (1.515) **	–3.079 (1.495) *
Year	–0.133 (0.022) ***	–0.122 (0.021) ***	–0.116 (0.031) ***
GDP		–0.027 (0.008) ***	–0.019 (0.008) *
Aging rate			0.302 (0.064) ***
Education			0.547 (0.214) *
Energy supply			–0.415 (0.269)
Smoking			–0.028 (0.030)
BMI			–1.461 (0.176) ***
Physical activity			–0.527 (0.272)
Latitude			0.015 (0.045)
Unemployment rate			0.045 (0.012) ***
AIC	13173.62	13170.83	13052.72
BIC	13223.08	13226.48	13157.78

QUANTIDD: Quantitative Index for Dietary Diversity, GDP: Gross Domestic Product, BMI: Body Mass Index, AIC: Akaike's Information Criterion, BIC: Bayesian Information Criterion, SE: Standard Error
* p <0.05, ** p<0.01, *** p<0.001.

brain, is involved in the control of mood, appetite, sleep, and pain. Serotonin is synthesized from tryptophan in the brain because it cannot pass through the blood-brain barrier. Tryptophan is often found in beef, pork, liver, dairy products, and vegetables and fruits. The synthesis of serotonin from tryptophan

also requires vitamin B_6 and carbohydrate. Vitamin B6 is partly synthesized by intestinal bacteria, but it is also abundant in fruits such as bananas. Consuming a diverse diet high in carbohydrates and vitamins, in addition to tryptophan, may increase serotonin in the brain and prevent depression[2,39].

This was an ecological study by countries and does not take into account individual differences in age, sex, and lifestyle habits. The limitation of this study is that, although it was a long-term study, the causal relationship between dietary diversity and the development of depression in individuals is unknown, and the causal relationship cannot be clearly established.

Depression is the largest contributor to suicide. Depression is also strongly associated with chronic illnesses and a factor that shortens healthy life expectancy[1]. On a global scale, age-standardized suicide rates have been decreasing since 1990, but suicide remains a major cause of death[40]. Depression and suicide rates vary widely across countries and regions, and appropriate national and regional responses will be required. Lifestyle habits, especially eating habits, may have an impact on a person's physical and mental health every day. A diet rich in a variety of foods has a healthy impact on the body and mind and may prevent depression and suicide.

5. Conclusion

The results of this long-term study over a 26-year period on a global scale study support the depression-preventing effect of dietary diversity. It is hoped that improving dietary habits will prevent depression and increase healthy life expectancy in countries around the world.

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《原著》

食生活の多様性とうつ病および自殺の有病率との関連
―26年間の国際比較研究―

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要旨

【目的】本研究は、26年間の世界的な統計を用いた生態学的分析により、食生活の多様性とうつ病や自殺率との関連を明らかにすることを目的とした。
【方法】生産と家庭間の喪失を除く国別平均食料供給量とエネルギー供給量を国連食糧農業機関統計局データベース（FAOSTAT）から入手した。食物群分類から食事多様性スコアを算出した。年齢標準化された国別の人口10万人当たりのうつ病有病率と自殺率は、Global Burden of Disease（GBD）2017データベースから取得した。人口100万人以上の137カ国を対象に、食品多様性スコアとうつ病有病率および自殺率との関連を、共変量を制御した混合効果モデルで解析した。
【結果】食生活の多様性とうつ病の有病率との関係を分析したところ、すべての共変量を調整したモデルにおいて、有意な負の関連が認められた［β（se）＝－225.6（61.9）、$p < 0.001$］。さらに、食生活の多様性と自殺率との間の有意な負の関連も、すべての共変量を調整したモデルで認められた［β（se）＝－3.08（1.50）、$p < 0.05$］。
【結論】食生活の多様性は、うつ病および自殺の発生率と有意に負の関連があった。食物を豊富に含む食事は、うつ病や自殺を減少させる可能性がある。

キーワード：食生活の多様性、うつ病、自殺、国際比較、FAOSTAT

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