Original Article

Choline and betaine food sources and intakes in Taiwanese

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Choline and betaine are involved in several similar health-relevant metabolic pathways, but the foods sources are different. We have assessed their intakes (individual, sums and ratios) from a dominantly Chinese food cultural point of view. A representative free-living Taiwanese population aged 13-64 years was drawn from the Nutrition and Health Survey in Taiwan (NAHSIT) 1993-1996. Food intake was derived from interviews as 24-hour recalls. The USDA database, with adaptations for Taiwan, provided choline and betaine food compositions. Major food contributors of these nutrients were identified and compared with data from the US Framingham offspring study. Mean and variance reduced median nutrient intakes were calculated. Top ten major food contributors of choline in Taiwan were eggs, pork, chicken, fish, soybean and its products, dark leafy vegetables, dairy, fruit, wheat products and light leafy vegetables in sequence. For betaine, the top ten were dark leafy vegetables, wheat products, fish, pork, bread, chicken, cake/cookies, grain-based alcoholic beverages, rice and its products and sauces. The main contributors of choline in Taiwan and the USA were, respectively, eggs and red meat; and for betaine, greens were similarly best contributor. The rankings of the main food contributors of choline and betaine differed substantially between Taiwan and the USA. The total daily intakes (mean±SE, mg) in Taiwan for choline were 372±19 (median=348) in men and 265±9 (median 261) for women; for betaine, values were 101±3 (median 93) in men and 78±8 (median 76) for women. These allow for health outcome considerations.

Key Words: USDA food composition, gender, eggs, pork, soy, green leafy vegetables, wheat, choline, betaine

INTRODUCTION

Choline and betaine are both quaternary ammonium compounds. They are metabolically linked to both lipid and one-carbon metabolism. There has been an increased appreciation of their contribution to neurodevelopment and the progress of some chronic diseases. Hence, their roles in risk assessment and disease prevention are of interest.[1] Choline, as acetylcholine, plays a role in neurotransmission.[2] Betaine is a cellular osmolyte and regulates cell volume to maintain tissue integrity.[3] High intakes of choline and betaine have been related to low homocysteine status.[4,5] Even in individuals with low folate intake or consuming alcohol, an inverse association between plasma concentrations of betaine and homocysteine is found.[6] Choline deficiency causes fatty liver,[7] liver and muscle damage,[8-10] and is probably related to neoplasia and cognitive impairment.[11] The importance of choline and betaine are evident from experimental studies of normal physiology and in their apparent pathogenetic contribution to common chronic metabolic and degenerative diseases.[1]

Moreover, their combined contributions to epigenetics as methyl donors is likely to be of growing relevance to the understanding of intergenerational health and to the dietary and other environmental determinants of genomic expression.[12] Nevertheless, whether the net effects of dietary choline and betaine intakes are health favorable or unfavourable may depend on gut microbiome, since a vasculotoxic derivative of choline, trimethylamine *N*-oxide (TMAO), may be generated by intestinal microflora, be absorbed and achieve measurable blood concentrations. Both circulating TMAO and betaine may augment the development of cholesterol-laden macrophages or foam cells in atherosclerotic lesions and predict cardiovascular disease.[13]

Available food composition data for choline and betaine have stimulated studies on relationships between choline-betaine status and health.[4] So far, human intake data are sparse and the number of studies has been limited,[1] particularly for oriental diets with information only

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Manuscript received 24 February 2012. Initial review completed 26 March 2012. Revision accepted 4 June 2012.

for some Korean foods.[23] In the present study, we utilized a nationally representative cohort study, the Nutrition and Health Survey in Taiwan (NAHSIT) 1993-1996, to document the food sources and intakes of choline and betaine.

METHODS

Population

The Nutrition and Health Survey in Taiwan (NAHSIT) 1993-1996 was conducted from July 1993 to June 1996. Details of this survey have been published previously.[14] Briefly, a representative and season-balanced sample of Taiwan was obtained from 5,834 individuals (2,923 men and 2,911 women) aged 13-64 years. These participants were from 21 townships, 3 each in 7 geographical or cultural strata. The study was granted ethics approval by the Institutional Review Boards of the National Health Research Institutes and Academia Sinica in Taiwan.

Estimation of choline and betaine intakes

Choline and betaine food composition information was introduced into the Taiwanese Food Composition Tables which have not heretofore provided these data. The concentrations were obtained and customized for Taiwanese foods from the US Department of Agriculture's (USDA) choline and betaine database.[15] Total choline intake included intakes of free choline, phosphocholine, glycerophosphocholine, phosphatidylcholine (lecithin), and sphingomyelin. Only one form of betaine was included.

We used the 24-hour dietary recall method to obtain participants' food intakes. There were 3,837 food items (52 categories) in the NAHSIT 1993-1996. This extensive list of food items was formed from a limited availability of food choline and betaine composition from the USDA. We therefore combined and encoded similar food items as though they had the same choline and betaine concentrations. This was based on: 1) the same or similar food names; 2) similar nutrient profiles; 3) comparable physical properties; and 4) similar ingredients and preparation. With these food composition data, we estimated daily choline and betaine intakes for all participants.

Statistical analysis

Statistical analyses were performed using SAS software (version 9.1, SAS Institute, Inc., Cary, NC). All data were weighted to represent the population in Taiwan. For the effect of multi-staged complex sampling design in the population, SUDAAN software (version 9.0, Research Triangle Institute, Research Triangle Park, NC) was used.

Data were presented as percentages and means±SE (standard error). Choline and betaine intake difference were tested by one-way ANOVA. However, large within-person or day-to-day variation is seen when using the 24-hour dietary recall method. In order to reduce any over-estimated standard deviation for choline and betaine intakes, we calculated the within person/between person ratio using the repeated 24-hour recall data of a sub-set of the study population. This provided for variance-reduction.[16] Stepwise regression analysis was used to determine the food predictors of choline and betaine intakes in Taiwan. Statistical significance was two-sided and was determined at $p<0.05$.

RESULTS

The leading food contributors of choline and betaine in Taiwan with comparison to available US data from the Framingham Offspring study [4] are shown in Tables 1 and 2. In our study population, a total of 3,837 food items were grouped into 52 categories. The top ten major food contributors of choline in Taiwan were eggs, pork, chicken, fish, soybean and its products, dark leafy vegetables, dairy, fruit, wheat products and light leafy vegetables in sequence. For betaine, the top ten were dark leafy vegetables, wheat products, fish, pork, bread, chicken, cake/cookies, grain-based alcoholic beverages, rice and its products and sauces. To compare food contributors of choline and betaine in the East and West, comparable USA data during a similar period in the USA[4] are also shown in Tables 1 and 2. The corresponding rank in the USA for choline was: red meat, poultry, milk, eggs, fish, coffee, beer, potatoes, oranges/orange juice, and broccoli. For betaine in the USA, the rank for the top 10 was: spinach, pasta, white bread, cold breakfast cereal, English muffins/bagels/rolls, dark bread, beer, pizza, beets and red meat. In Taiwan, the top ten foods contributed more than 75% for both choline and of betaine. In the USA, the top ten foods contributed 65% and 81% for choline and betaine, respectively.

Table 1. Major food contributors of total choline in Taiwan and USA†

Rank	NAHSIT 1993-1996 (13-64 years)			Framingham Offspring Study (USA, 1991-1994) (28-82 years)		
	Food	Percentage	Cumulative percentage	Food	Percentage	Cumulative percentage
1	Eggs	25.4	25.4	Red meat	14.3	14.3
2	Pork	18.8	44.1	Poultry	13.0	27.3
3	Chicken	8.36	52.5	Milk	9.52	36.8
4	Fish	6.09	58.6	Eggs	7.57	44.4
5	Soybean and its products	5.87	64.5	Fish	5.22	49.6
6	Dark leafy vegetables	4.00	68.5	Coffee	4.00	53.6
7	Dairy	2.96	71.4	Beer	3.29	56.9
8	Fruit	2.50	73.9	Potatoes	4.03	60.9
9	Wheat products	2.29	76.2	Oranges and orange juice	2.27	63.2
10	Light leafy vegetables	2.27	78.5	Broccoli	1.88	65.0

†Data derived from Cho et al.'s study (Reference 4)

Table 2. Major food contributors of betaine in Taiwan and USA†

Rank	NAHSIT 1993-1996 (13-64 years)			Framingham Offspring Study (USA, 1991-1994) (28-82 years)		
	Food	Percentage	Cumulative percentage	Food	Percentage	Cumulative percentage
1	Dark leafy vegetables	21.7	21.7	Spinach	25.1	25.1
2	Wheat products	15.2	36.9	Pasta	11.8	36.9
3	Fish	10.2	47.1	White bread	9.35	46.3
4	Pork	8.84	56.0	Cold breakfast cereal	8.05	54.4
5	Bread	5.10	61.1	English muffins, bagels, or rolls	7.07	61.5
6	Chicken	3.84	64.9	Dark bread	5.95	67.5
7	Cake and cookies	3.51	68.4	Beer	3.97	71.5
8	Grain-based alcoholic beverages	3.12	71.5	Pizza	3.39	74.9
9	Rice and its products	3.04	74.6	Beets	2.91	77.8
10	Sauces	2.70	77.3	Red meat	2.83	80.6

†Data derived from Cho et al.'s study (Reference 4)

The demography of dietary intakes of choline and betaine are shown in Tables 3 and 4, separately. For both choline and betaine, there were significant differences in terms of intake among men and women. The daily intakes (mean) for choline were 372 mg in men and 265 mg in women; for betaine, they were 101 mg in men and 78 mg in women. Among men, the 19-30 yrs group had the highest choline intake (424 mg), but it was highest in the 31-44 yrs group for women (293 mg); for both genders, the 45-64 yrs group had the lowest choline intakes (men: 306 mg; women: 229 mg). However, no significant differences were found among different age groups for betaine intake, either among men or women. Similarly, there were no significant differences in the intakes of choline between regions for either men or women. For different ethnicities (major Han Chinese sub-ethnicities, those born in Mainland China, and Indigenes), only choline intakes was significantly different among men, though the Mainlanders had a relatively higher and Hakkas relatively lower intakes. Both choline and betaine intakes were positively correlated with education level in a dose response manner. Choline intakes were almost doubled in those with college education compared to those who were illiterate (384 vs 194 mg). Similar pattern for betaine intakes were observed (105 vs 62.7 mg).

Table 5 shows the combination of daily choline and betaine intakes as sums and ratios. The sum intakes were 472 mg/day in men and 343 mg/day in women, a significant gender difference. But the intake ratios of betaine to choline were not significantly different between genders. For men, the 19-30 yr age group had the highest daily sum intake (535 mg). However among women there was no significant difference between age groups. For men, the 45-64 yr age group had the highest ratio (0.34), but for women it was the 13-18 yr age group (0.39). For both genders, there were no significant differences in the sum intakes among regions. But people who lived in the Penghu islands had the highest ratio (0.38). Mainlanders had the highest sum intakes for both men (543 mg) and women (437 mg). However, there were no significant differences in intake ratios among ethnicities. There were positive relationships between sum intakes and education level.

The top 3 food predictors of total choline (eggs, spices and pork) and total betaine (dark leafy vegetables, wheat products and fish) intakes among the population explain 63.3% and 64.3% of the variance, respectively, while the top 10 explain 85.8% and 86.5% of the variance (Table 6).

On the basis of data from a single 24-hour dietary recall, the variation of choline and betaine intakes would be greater than the "true intake". In Figure 1, gender-specific probability density (distribution) (Figures 1a and 1b) and cumulative distribution (Figures 1c and 1d) curves of choline intake are shown. The distribution curve of variance reduced choline intake (solid line) is more symmetric than the original curve (dotted line). Similarly, it can be seen in Figure 2 for betaine. Table 7 shows the variance-reduced medians, gender-specific distributions for choline and betaine intakes. The 50^{th} percentiles for daily dietary choline intakes among men and women are 348 and 261 mg, respectively. For daily dietary betaine intakes, the 50^{th} percentiles are 93 and 76 mg for men and women, respectively. Only less than 25% of the men and less than 5% of the women reached the AI values in Taiwan.

DISCUSSION

To the best of our knowledge, we provide here the dietary choline and betaine intakes for the Taiwanese population for the first time. We find that the food contributors of choline and betaine are rather different between Taiwan and the USA.[4] Eggs are the most important contributor of choline for the Taiwanese, as they contribute more than 25% to the total intake, but less than 8% in the USA. Interestingly, soybean and its products are also an important contributor of choline in Taiwan, but not in the USA.[4] Coffee ranks 6^{th} in the USA[4] and not in Taiwan's top 10. In both Taiwan and the USA, dark leafy vegetables rank as the major contributor of betaine. However, in Taiwan, the top ten food contributors of betaine include 3 animal sources (fish, pork and chicken) and their contribution for total betaine intake is near 23%. Conversely, only one animal source, red meat (2.83%), is ranked in the top ten food contributors of betaine in USA.[4] In both Taiwan and USA, most choline and betaine intakes in the general population come from only a few food sources.

Table 3. The distributions of dietary intake of total choline (mg/day) by demography in NAHSIT 1993-1996†

	Total			Men			Women		
	n	%	Mean±SE	n	%	Mean±SE	n	%	Mean±SE
Total	5834		325±10.1	2923	56.4	372±18.8[a]	2911	43.6	265±9.17[a]
Age (years)									
13-18	1919	15.2	338±12.0[a]	960	14.3	398±12.8[ab]	959	16.5	272±13.2[a]
19-30	807	34.0	358±17.7[b]	415	35.8	424±34.9[cd]	392	31.7	260±16.1
31-44	1169	30.5	319±15.4[c]	588	30.8	339±21.3[ac]	581	30.0	293±15.5[b]
45-64	1939	20.3	270±8.51[abc]	960	19.1	306±11.4[bd]	979	21.8	229±9.11[ab]
Region									
Hakka	850	2.25	329±13.3	430	2.27	376±15.7	420	2.23	268±12.5
Mountain areas	840	0.95	345±37.9	416	1.04	392±43.1	424	0.83	270±33.5
Eastern	840	1.70	354±28.4	429	1.89	393±38.1	411	1.41	288±14.1
Penghu	817	0.39	310±7.91	402	0.41	351±11.8	415	0.37	251±12.0
Metropolitan areas	796	17.8	362±16.8	394	16.4	407±12.4	402	19.5	313±25.0
Provincial cities and class I townships	829	42.3	319±13.8	420	42.1	370±35.7	409	42.5	254±16.6
Class II rural townships	862	34.7	312±22.5	432	35.9	356±31.2	430	33.1	251±9.99
Ethnicity									
Fukienese	3275	81.1	322±12.4[a]	1615	81.8	368±22.6[a]	1660	80.1	261±7.06
Hakka	1248	10.8	314±9.01[b]	663	10.5	362±15.7[b]	585	11.2	256±20.9
Mainlander	325	6.14	380±15.7[ab]	179	5.93	431±18.6[ab]	146	6.40	318±26.0
Indigenes	977	1.91	355±39.4	463	1.71	391±55.7	514	2.16	318±29.5
Education level									
Illiterate or informal	494	4.66	194±6.73[abc]	126	2.17	234±11.9[abc]	368	7.88	180±10.5[abc]
Primary school	1542	22.7	267±9.26[ade]	713	20.5	286±10.6[ade]	829	25.4	247±15.0[a]
High school	3287	57.9	344±8.02[bd]	1759	60.9	390±17.9[bd]	1528	54.0	278±15.2[b]
College and above	501	14.6	384±34.2[ce]	320	16.2	432±47.4[ce]	181	12.6	304±29.8[c]

†Percentage and means are weighted to reflect their representation in the population.
Means in a demographic category share a common superscript are significantly different at $p<0.05$.

Table 4. The distributions of dietary intake of betaine (mg/day) by demography in NAHSIT 1993-1996[†]

	Total			Men			Women		
	n	%	Mean±SE	n	%	Mean±SE	n	%	Mean±SE
Total	5834		90.8±3.67	2923	56.4	101±3.40^{a}	2911	43.6	77.7±7.67^{a}
Age (years)									
13-18	1919	15.2	85.8±4.87	960	14.3	92.6±3.30	959	16.5	78.2±8.48
19-30	807	34.0	97.3±4.55	415	35.8	111±5.89	392	31.7	77.4±7.66
31-44	1169	30.5	89.6±5.50	588	30.8	96.8±5.85	581	30.0	80.0±10.1
45-64	1939	20.3	85.2±4.94	960	19.1	94.6±5.88	979	21.8	74.7±6.28
Region									
Hakka	850	2.25	76.3±3.52^{ab}	430	2.27	86.4±6.15	420	2.23	63.0±2.09^{a}
Mountain areas	840	0.95	91.7±4.52^{a}	416	1.04	103±4.28	424	0.83	72.7±8.36^{b}
Eastern	840	1.70	95.9±8.91	429	1.89	107±12.1	411	1.41	77.9±10.4
Penghu	817	0.39	96.5±10.3	402	0.41	111±9.36	415	0.37	75.7±13.4
Metropolitan areas	796	17.8	104 ±6.37^{bc}	394	16.4	114±9.86	402	19.5	93.6±3.17^{abc}
Provincial cities and class I townships	829	42.3	91.8±7.62	420	42.1	101±2.61	409	42.5	80.0±17.5
Class II rural townships	862	34.7	83.1±3.71^{c}	432	35.9	95.0±7.58	430	33.1	66.5±5.04^{c}
Ethnicity									
Fukienese	3275	81.1	90.4±2.40^{a}	1615	81.8	101±3.41	1660	80.1	76.2±6.45
Hakka	1248	10.8	77.0±8.45^{b}	663	10.5	92.2±10.4	585	11.2	58.5±8.61
Mainlander	325	6.14	115 ±8.99^{ab}	179	5.93	112±8.67	146	6.40	119±16.9
Indigenes	977	1.91	103 ±21.1	463	1.71	98.1±11.8	514	2.16	109±43.0
Education level									
Illiterate or informal	494	4.66	62.7±5.35^{abc}	126	2.17	71.5±12.4^{a}	368	7.88	60.0±6.50^{ab}
Primary school	1542	22.7	80.7±5.23^{ad}	713	20.5	89.6±6.19^{b}	829	25.4	71.5±5.69
High school	3287	57.9	93.6±5.26^{bd}	1759	60.9	103 ±2.91^{ab}	1528	54.0	79.7±12.0^{a}
College and above	501	14.6	105 ±9.53^{c}	320	16.2	112 ±12.2	181	12.6	93.3±9.86^{b}

†Percentage and means are weighted to reflect their representation in the population.
Means in a demographic category share a common superscript are significantly different at $p<0.05$.

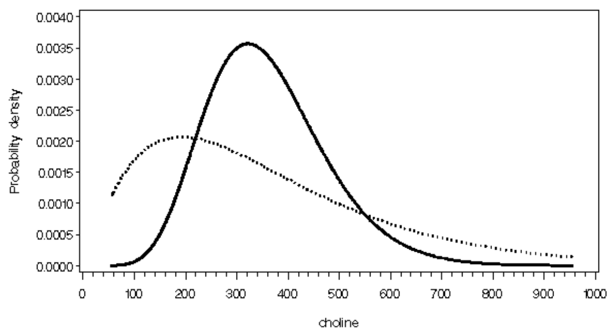
Table 5. The distributions of the combinations of dietary betaine and total choline intakes by demography in NAHSIT 1993-1996†

	Total				Men				Women			
	n	%	Sum‡	Ratio§	n	%	Sum‡	Ratio§	n	%	Sum‡	Ratio§
Total	5834		416	0.33	2923	56.4	472[a]	0.31	2911	43.6	343[a]	0.35
Age (years)												
13-18	1919	15.2	424[a]	0.34	960	14.3	490[a]	0.28[a]	959	16.5	351	0.39[a]
19-30	807	34.0	455[b]	0.32	415	35.8	535[bc]	0.31	392	31.7	337	0.35[b]
31-44	1169	30.5	409[c]	0.31	588	30.8	436[b]	0.32	581	30.0	374	0.30[ab]
45-64	1939	20.3	355[abc]	0.36	960	19.1	400[ac]	0.34[a]	979	21.8	304	0.38
Region												
Hakka	850	2.25	406[a]	0.26[abcd]	430	2.27	463	0.26[abcd]	420	2.23	331	0.26
Mountain areas	840	0.95	437	0.31	416	1.04	495	0.29	424	0.83	343	0.35
Eastern	840	1.70	450	0.32[a]	429	1.89	499	0.33[a]	411	1.41	366	0.31
Penghu	817	0.39	407[b]	0.38[b]	402	0.41	462	0.37[b]	415	0.37	327	0.40
Metropolitan areas	796	17.8	466[abcd]	0.36[c]	394	16.4	521	0.33[c]	402	19.5	407	0.38
Provincial cities and class I townships	829	42.3	411[c]	0.33	420	42.1	471	0.31	409	42.5	334	0.36
Class II rural townships	862	34.7	395[d]	0.31[d]	432	35.9	451	0.31[d]	430	33.1	317	0.32
Ethnicity												
Fukienese	3275	81.1	412[a]	0.33	1615	81.8	469[a]	0.32	1660	80.1	337[a]	0.35
Hakka	1248	10.8	391[b]	0.27	663	10.5	455[b]	0.28	585	11.2	314[b]	0.26
Mainlander	325	6.14	495[ab]	0.37	179	5.93	543[ab]	0.34	146	6.40	437[ab]	0.40
Indigenes	977	1.91	317	0.38	463	1.71	490	0.36	514	2.16	427	0.39
Education level												
Illiterate or informal	494	4.66	257[abc]	0.36	126	2.17	305[abc]	0.31	368	7.88	240[abc]	0.39
Primary school	1542	22.7	348[ade]	0.35	713	20.5	376[ade]	0.38[ab]	829	25.4	319[a]	0.32
High school	3287	57.9	438[bd]	0.32	1759	60.9	493[bd]	0.30[a]	1528	54.0	357[b]	0.34
College and above	501	14.6	488[ce]	0.32	320	16.2	543[ce]	0.28[b]	181	12.6	397[c]	0.39

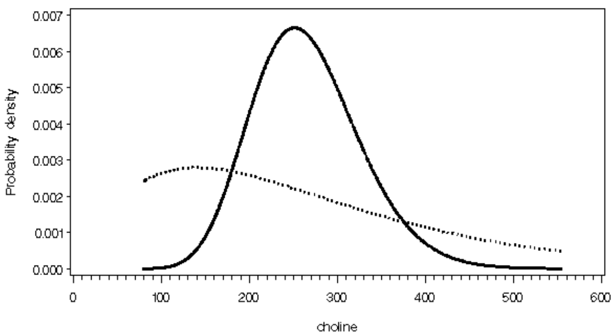
†Percentage and means are weighted to reflect their representation in the population.
‡Sum=daily betaine intake + daily choline intake (mg/day)
§Ratio= daily betaine intake/ daily choline intake
Means in a demographic category share a common superscript are significantly different at $p<0.05$.

Table 6. The food predictors of total choline and betaine intakes in NAHSIT 1993-1996 by stepwise regression

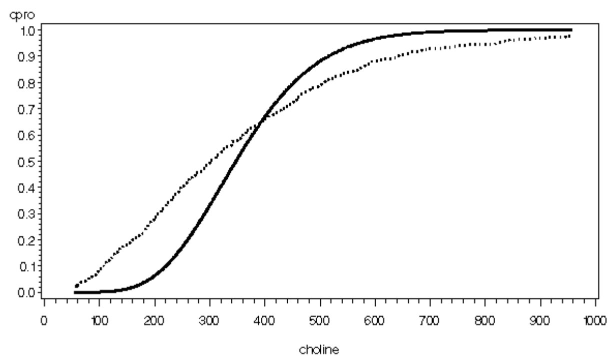
Rank	Choline				Betaine			
	Food	Partial R^2	Model R^2	Cumulative percentage of food source	Food	Partial R^2	Model R^2	Cumulative percentage of food source
1	Eggs	0.278	0.278	25.4	Dark leafy vegetables	0.478	0.478	21.7
2	Spices (garlic, ginger, chili)	0.201	0.479	27.2	Wheat products	0.084	0.562	36.9
3	Pork	0.154	0.633	46.0	Fish	0.081	0.643	47.1
4	Chicken	0.082	0.715	54.4	Grain-based alcoholic beverages	0.075	0.718	50.2
5	Fish	0.049	0.764	60.5	Pork	0.040	0.758	59.1
6	Dark leafy vegetables	0.034	0.798	64.5	Sauce	0.026	0.784	61.8
7	Soybean and its products	0.028	0.826	70.4	Rice and its products	0.025	0.809	64.8
8	Fruit	0.012	0.838	72.9	Bread	0.020	0.829	69.9
9	Dairy	0.011	0.849	75.8	Fast food	0.020	0.849	72.1
10	Wheat products	0.009	0.858	78.1	Cake and cookies	0.016	0.865	75.6



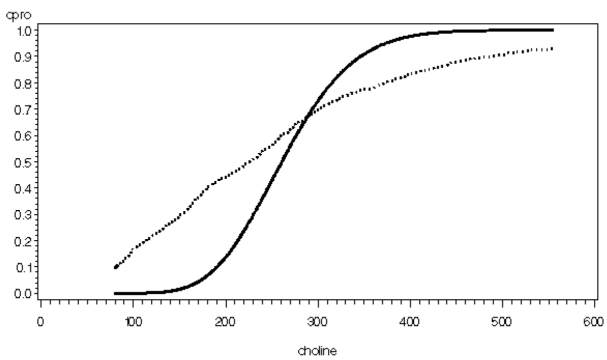
(a) probability density in men



(b) probability density in women



(c) cumulative distribution in men



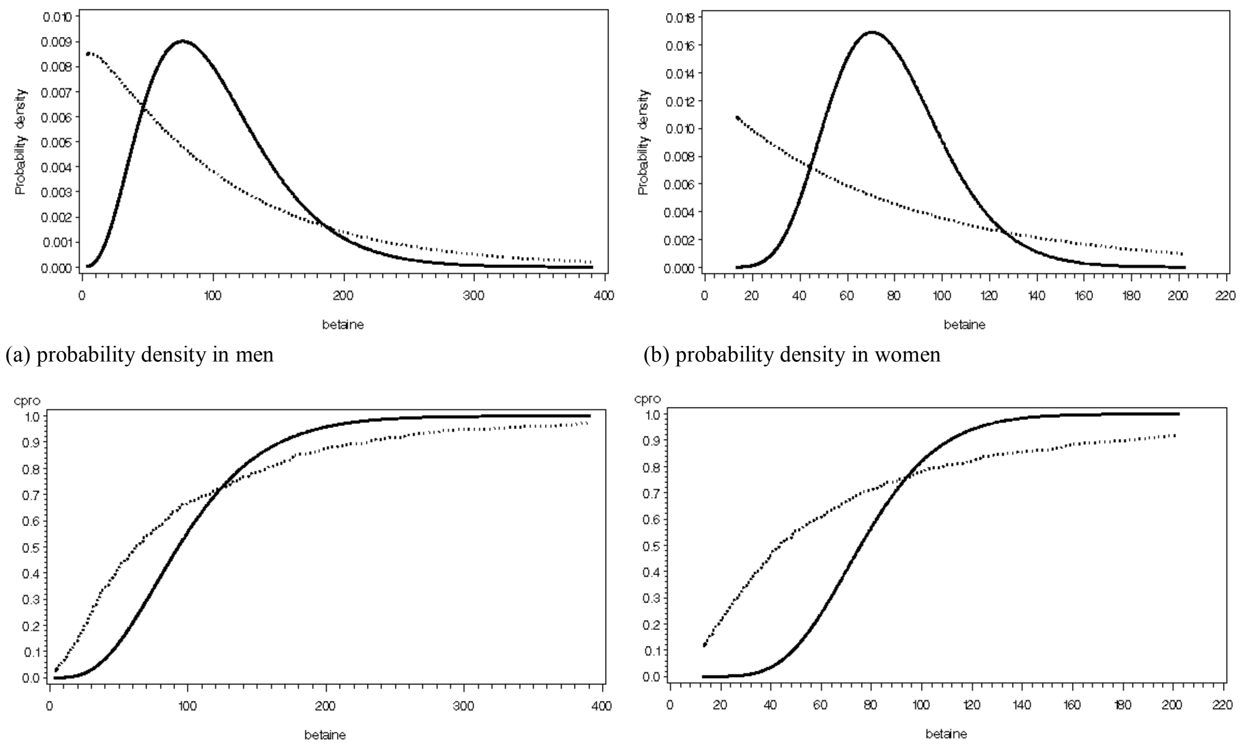
(d) cumulative distribution in women

Figure 1. (a)(b) probability density (distribution) and (c)(d) cumulative distribution of original (dotted line) and variance reduced (solid line) dietary choline intake for (a)(c) men and (b)(d) women in NAHSIT 1993-1996 (aged 19-64 years, cpro is cumulative probability)

The differences in food contributors to these nutrients between the two countries reflect dietary patterns and raise questions about the assessment of their requirements and related food policy.

In terms of methyl group intake, 60% (about 50 mmol/day) in a USA diet is estimated to come from choline,[17] the remainder coming from betaine and methionine–rich foods (with folate intake being a modulator of methyl donor status). Thus, 6 food categories, as combined choline and betaine contributors, will probably account for the majority of the methyl group intake in a Taiwanese diet.

In Taiwan, the Adequate Intake (AI) of choline is reckoned to be 450 and 390 mg per day for men and women, respectively.[18] In the USA, the AI is 550 and 425 mg per day for men and women, respectively.[19] In the American Atherosclerosis Risk in Communities (ARIC) repeatability study of 1987-9 and 1990-2, 94% of middle age men and 89% of middle age women had inadequate intakes of choline based on AIs for the USA. The average daily choline intakes were 324 mg for men and 288 mg for women.[20] In the present Taiwanese study, the mean dietary choline intakes (intakes of 372 and 265 mg per day in men and women, respectively) were similar to the USA and also lower than the recommended values. Less than a quarter of men and less than 5% of women reached the recommendation. Current reference values of dietary choline intake may or may not be valid and need review in light of the present findings.[21] However, the possibility that choline and betaine intakes of the Taiwanese may have been underestimated needs consideration. In 2008, Konstantinova *et al.* reported that plasma free choline



(a) probability density in men

(b) probability density in women

(c) cumulative distribution in men

(d) cumulative distribution in women

Figure 2. (a)(b) probability density (distribution) and (c)(d) cumulative distribution of original (dotted line) and variance reduced (solid line) dietary betaine intake for (a)(c) men and (b)(d) women in NAHSIT 1993-1996 (aged 19-64 years, cpro is cumulative probability)

Table 7. Gender-specific distributions of variance reduced total choline and betaine intakes (mg/day) in NAHSIT 1993-1996 (aged 19-64 years)

	Percentiles							
	1st%	25th%	50th%	75th%	80th%	90th%	95th%	99th%
Choline								
Men	145	277	348	432	455	516	572	687
Women	144	222	261	304	316	347	375	430
Betaine								
Men	21.9	65.0	93.2	129	139	167	194	250
Women	32.7	60.8	76.0	93.7	98.2	111	123	147

was positively related to intake of eggs and cholesterol, but not to other rich-choline food items in a Norwegian study. Only a few food items were the determinants of plasma choline and betaine.[22] The most striking finding was that betaine intake was negatively associated with a Western dietary pattern (meat, pizza, sugar, and fat were highly proportional), but choline was not significantly related to any dietary pattern.[22] One implication of the Norwegian study is that choline and betaine intakes themselves, without information about bioavailability, together with measures of de novo synthesis in tissues, may be inadequate as health predictors.

We have compared the food contributors of choline and betaine in Taiwan and the US, and not the sums and ratios in this paper. However, the sum has been used in the Framingham Offspring study [4] to explain homocysteine status and we consider the ratio to be of potential value in the assessment of the risk and benefits of these 2 related molecules, especially given potential choline toxicity (denominator) and the relative safety that might accrue to betaine as a methyl donor (numerator).

Our study has several strengths, including its large sample size, fully representative of the general population and is conducted on free living participants. But some limitations must be considered. Choline food composition data were dependent on USDA analyses. Primary Taiwanese food compositional data for choline and betaine are not available. There are some foods where this might be especially problematic, like green leafy vegetables for betaine, where there are many varieties and cultivars, and most likely a wide range of nutrient contents. Since dietary patterns and food culture-in-general differ between Taiwan and the USA, the criteria by which USDA foods are selected for compositional analysis, basically for common American foods, may prejudice their utility in Taiwan. It is most likely that this would result in underestimation of choline and betaine intakes in Taiwan through neglect of local foods for which no useful American analysis had been made. It is difficult to say what proportion of local foods are explicitly the same as those for which choline and betaine concentrations have been measured for US food composition tables. However, we have confidently assigned North American values to 57% of the Taiwanese foods used by study participants. For the remainder, we used a biologically similar food for 21% of the foods. This resulted in a small group of foods (22%) without assignation, but which are unlikely to contain appreciable amounts of either choline (7%) or betaine (7%). Thus, there remains a possibility that the Taiwanese intake data have underestimated intakes compared with the US. At the same time, major contributors of these nutrients will have been covered by approaches used in the separate locations.

Our estimates of intakes may also suffer from inaccuracy on account of our use of a single 24-hour dietary recall method to assess choline and betaine intakes. However, we have applied the within person/between person ratios using repeated 24-hour recall data from a sub-set of the study population to reduce the variance. Yet another limitation is that participants were aged 13 to 64 years, so that we cannot comment on intakes of children or the elderly who are likely to represent age groups vulnerable to inappropriate choline and betaine intakes.

There are two major issues which arise with the present study. One is that the intakes of choline and betaine in Taiwan, like the USA, are relatively low, if current recommendations are valid. However, since the spectrum of principal sources of these nutrients are different, the recommendations may need to acknowledge related differences in bioavailability, assimilation into metabolic pathways and relative differences in impact where health profiles also differ, both intragenerationally and intergenerationally (if the epigenetic potential of these nutrients is realized). The second issue is the problem of ascertainment of optimal intakes in a population where few foods account for most of the nutrient intake, the intakes are food-culturally sensitive, when the ranges of optimal intakes may be narrow, when the physiological relationships between them may be important and expressed mathematically (e.g. in addition or as ratios), and when bioavailabities are in question. We need to be particularly cautious about low and high dietary recommended values, especially given recent data, to which reference is made in the Introduction, in regard to toxic derivatives of choline.[13] In the meantime, the availability of choline and betaine food compositional data and intakes in various food cultures should allow issues like these to be explored.

ACKNOWLEDGEMENTS

Data analyzed in this paper were collected in the research project "Nutrition and Health Survey in Taiwan (NAHSIT)" sponsored by the Department of Health in Taiwan (DOH-88-FS, DOH89-88shu717, DOH90-FS-5-4, DOH91-FS-5-4). This research project was carried out by the Institute of Biomedical Sciences of Academia Sinica, directed by Dr. Wen-Harn Pan. The Office of Nutrition Survey, The Center for Survey Research of Academia Sinica, is responsible for data distribution.

AUTHOR DISCLOSURES

There is no conflict of interest.

REFERENCES

1. Ueland PM. Choline and betaine in health and disease. J Inherit Metab Dis. 2011;34:3-15.
2. Canty DJ, Zeisel SH. Lecithin and choline in human health and disease. Nutr Rev. 1994;52:327-39.
3. Lang F. Mechanisms and significance of cell volume regulation. J Am Coll Nutr. 2007;26:613S-23S.
4. Cho E, Zeisel SH, Jacques P, Selhub J, Dougherty L, Colditz GA, Willett WC. Dietary choline and betaine assessed by food-frequency questionnaire in relation to plasma total homocysteine concentration in the Framingham Offspring Study. Am J Clin Nutr. 2006;83:905-11.
5. Alfthan G, Tapani K, Nissinen K, Saarela J, Aro A. The effect of low doses of betaine on plasma homocysteine in healthy volunteers. Br J Nutr. 2004;92:665-9.
6. Holm PI, Hustad S, Ueland PM, Vollset SE, Grotmol T, Schneede J. Modulation of the homocysteine-betaine relationship by methylenetetrahydrofolate reductase 677 C->t genotypes and B-vitamin status in a large-scale epidemiological study. J Clin Endocrinol Metab. 2007;92:1535-41.
7. Buchman AL, Dubin MD, Moukarzel AA, Jenden DJ, Roch M, Rice KM, Gornbein J, Ament ME. Choline deficiency: a cause of hepatic steatosis during parenteral nutrition that can be reversed with intravenous choline supplementation. Hepatology. 1995;22:1399-403.
8. Shronts EP. Essential nature of choline with implications for total parenteral nutrition. J Am Diet Assoc. 1997;97:639-46, 49; quiz 47-8.
9. Zeisel SH, Da Costa KA, Franklin PD, Alexander EA, Lamont JT, Sheard NF, Beiser A. Choline, an essential nutrient for humans. FASEB J. 1991;5:2093-8.
10. Fischer LM, daCosta KA, Kwock L, Stewart PW, Lu TS, Stabler SP, Allen RH, Zeisel SH. Sex and menopausal status influence human dietary requirements for the nutrient choline. Am J Clin Nutr. 2007;85:1275-85.
11. Poly C, Massaro JM, Seshadri S, Wolf PA, Cho E, Krall E, Jacques PF, Au R. The relation of dietary choline to cognitive performance and white-matter hyperintensity in the Framingham Offspring Cohort. Am J Clin Nutr. 2011;94: 1584-91.
12. Martin DI, Cropley JE, Suter CM. Environmental influence on epigenetic inheritance at the Avy allele. Nutr Rev. 2008; 66(Suppl 1):S12-4.
13. Wang Z, Klipfell E, Bennett BJ, Koeth R, Levison BS, Dugar B et al. Gut flora metabolism of phosphatidylcholine promotes cardiovascular disease. Nature. 2011;472:57-63.
14. Pan WH, Kao MD, Tzeng MS, Yen LL, Hung YT, Li LA, Hsiao SY, Yeh WT, Huang PC. Nutrition and Health Survey in Taiwan (NAHSIT) 1993-1996: design, contents, and operations. Nutr Sci J. 1999;24:1-10.
15. USDA. USDA database for the choline content of common foods release two, vol. 2009: US Department of Agriculture, 2008.
16. Chang HY, Suchindran CM, Pan WH. Using the overdispersed exponential family to estimate the distribution of usual daily intakes of people aged between 18 and 28 in Taiwan. Stat Med. 2001;20:2337-50.
17. Niculescu MD, Zeisel SH. Diet, methyl donors and DNA methylation: interactions between dietary folate, methionine and choline. J Nutr. 2002;132:2333S-5S.
18. DOH. Daily Reference Intakes, DRI. In: DOH, ed., vol. 2011 Taipei, ROC: Department of Health, 2011.
19. Food and Nutrition Board IOM. Dietary Reference Intakes: Thiamin, Riboflavin, Niacin, Vitamin B-6, Vitamin B-12, Pantothenic Acid, Biotin, and Choline. National Academy of Sciences. In: Food and Nutrition Board IOMNA, ed. Washington, DC: Food and Nutrition Board, Institute of Medicine National Academic, 1998:390-422.

20. Bidulescu A, Chambless LE, Siega-Riz AM, Zeisel SH, Heiss G. Repeatability and measurement error in the assessment of choline and betaine dietary intake: the Atherosclerosis Risk in Communities (ARIC) study. Nutr J. 2009; 8:14.
21. Zeisel SH, Caudill MA. Choline. Adv Nutr. 2010;1:46-8.
22. Konstantinova SV, Tell GS, Vollset SE, Ulvik A, Drevon CA, Ueland PM. Dietary patterns, food groups, and nutrients as predictors of plasma choline and betaine in middle-aged and elderly men and women. Am J Clin Nutr. 2008; 88:1663-9.
23. Cho H, Na J, Jeong H, Chung Y. Choline Contents of Korean Common Foods. Korean J Nutr. 2008;41:428-38.

Original Article

Choline and betaine food sources and intakes in Taiwanese

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臺灣民眾膽鹼與甜菜鹼的食物來源及攝取情形

膽鹼與甜菜鹼皆參與數個與健康有關的代謝路徑，但它們的食物來源卻不同。我們以中華食物文化的角度來評估兩者攝取情形(個別的、兩者總和、兩者比例)。從具代表性的 1993-1996 國民營養健康調查中選取 13-64 歲台灣民眾作為研究對象。食物攝取量以面訪方式獲得的 24 小時回憶記錄來計算；食物中膽鹼與甜菜鹼含量之估算，是以美國農業部(USDA)食物成分資料庫為根據，再調整成適用於台灣的食物。這兩個營養素的主要來源被確認後，與美國佛來明罕子代研究的結果比較。並且計算營養素攝取量的平均值與降低變異中位數。在臺灣，提供膽鹼的前十項主要食物依序為蛋類、豬肉、雞肉、魚肉、黃豆及其製品、深色葉菜、奶類、水果、小麥製品、淡色葉菜。提供甜菜鹼的前十項主要食物依序為深色葉菜、小麥製品、魚肉、豬肉、麵包、雞肉、蛋糕/餅乾、酒(以穀類為原料)、米及其製品、醬汁。膽鹼的主要提供者，在臺灣與美國，分別是蛋類與紅肉。但在兩地，青菜都是甜菜鹼的主要供應者。臺灣與美國的膽鹼與甜菜鹼主要食物來源順序大不相同。臺灣男性膽鹼每日平均攝取量為 372±19 毫克(中位數為 348)，女性為 265±9 毫克(中位數為 261)；臺灣男性甜菜鹼每日平均攝取量為 101±3 毫克(中位數為 93)，女性為 78±8 毫克(中位數為 76)。這些資料可作為影響健康結果的參考因素。

關鍵字：美國農業部食物成分表、性別、蛋類、豬肉、黃豆、綠葉蔬菜、小麥、膽鹼、甜菜鹼