Concentrations of Choline-Containing Compounds and Betaine in Common Foods[1]

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ABSTRACT Choline is important for normal membrane function, acetylcholine synthesis and methyl group metabolism; the choline requirement for humans is 550 mg/d for men (Adequate Intake). Betaine, a choline derivative, is important because of its role in the donation of methyl groups to homocysteine to form methionine. In tissues and foods, there are multiple choline compounds that contribute to total choline concentration (choline, glycerophosphocholine, phosphocholine, phosphatidylcholine and sphingomyelin). In this study, we collected representative food samples and analyzed the choline concentration of 145 common foods using liquid chromatography-mass spectrometry. Foods with the highest total choline concentration (mg/100 g) were: beef liver (418), chicken liver (290), eggs (251), wheat germ (152), bacon (125), dried soybeans (116) and pork (103). The foods with the highest betaine concentration (mg/100 g) were: wheat bran (1339), wheat germ (1241), spinach (645), pretzels (237), shrimp (218) and wheat bread (201). A number of epidemiologic studies have examined the relationship between dietary folic acid and cancer or heart disease. It may be helpful to also consider choline intake as a confounding factor because folate and choline methyl donation can be interchangeable. J. Nutr. 133: 1302–1307, 2003.

KEY WORDS: • *food composition* • *choline* • *phosphatidylcholine* • *sphingomyelin* • *betaine*

Choline is required for synthesis of the phospholipids in cell membranes, methyl group metabolism and cholinergic neurotransmission (1). Betaine, a derivative of choline, is also important because of its role in the donation of methyl groups to homocysteine to form methionine (2,3). Humans have a requirement for choline; the U.S. Institute of Medicine recently made recommendations for choline intake in the diet (4). Due to insufficient data with which to assess choline and betaine intake and to derive an estimated average requirement for choline, only an Adequate Intake of ~550 mg/d for men could be estimated. Healthy men fed a choline-deficient diet, with normal folate and vitamin B-12 intake, became choline depleted and developed liver steatosis and damage (elevated plasma alanine aminotransferase) (5). Some humans (both men and women) receiving total parenteral nutrition solutions devoid of choline developed fatty liver and liver damage that resolved when a source of dietary choline was provided (6–11). Animals fed a choline-deficient diet may also develop growth retardation, renal dysfunction and hemorrhage, or bone abnormalities (12–14). Folate and choline metabolism are highly interrelated, and epidemiologic studies indicate a strong inverse association between dietary folate intake or blood folate levels and the risk of developing colorectal adenomas or cancer (15) and heart disease (16). Knowledge of choline intake could well enhance these analyses.

Some humans with a defect in the flavin-containing monooxygenase 3 gene, FM03, develop fishy body odor because they accumulate trimethylamine, a breakdown product formed from choline by bacteria in the gut (17–19). An 1999 NIH sponsored workshop on trimethylaminuria estimated that as much as 1% of the U.S. population may suffer from this genetic defect, but its true incidence is not known. A choline-restricted diet is useful in these patients because it diminishes body odor (20). These diets have heretofore been constructed without sufficient information, and clinical care could be enhanced if the choline concentration of foods were better described.

There are some data, generated using outdated methods, on the unesterified choline in foods (21,22) and there is limited information about the phosphatidylcholine (PtdCho,[3] also called lecithin) in foods (23). Almost no information is available concerning the other esterified forms of choline in foods. More is known about the betaine concentration of some foods (24–26). In this study, we collected representative food samples and analyzed the choline concentration of common foods using liquid chromatography-mass spectrometry. This study

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[3] GPCho, glycerophosphocholine; PCho, phosphocholine; PtdCho, phosphatidylcholine; SM, sphingomyelin.

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TABLE 1

Choline and betaine concentrations of common foods[1]

	USDA NDB #[2]	Choline	GPCho	PCho	PtdCho	SM	Total choline[3]	Betaine
		mg choline moiety/100 g food						*mg/100 g food*
Dairy and eggs								
2% Milk (2)	01079	2.82	9.98	1.58	1.15	0.87	16.40	0.84
Cheese	01009	1.59	2.30	0.64	7.37	4.59	16.50	0.59
Eggs (15)	01123	0.62	0.60	0.61	238.43	10.74	251.00	0.53
Creamer (3)	01069	0.54	1.44	ND	0.05	0.26	2.28	0.08
Cottage cheese	01012	3.64	8.39	1.34	2.54	2.51	18.42	0.66
Cream cheese	01017	3.58	9.26	1.50	7.29	5.57	27.21	0.65
Half & half (2)	01050	3.92	8.48	1.17	1.71	1.55	16.82	0.61
Sour cream	01056	4.73	8.08	1.26	3.51	2.75	20.33	0.67
Yogurt, fruit (2)	01121	2.08	7.79	1.59	1.52	1.06	14.04	0.74
Yogurt, plain (2)	01117	2.32	9.10	1.65	1.04	1.09	15.20	0.76
Butter with salt[4]	01001	0.55	1.18	0.68	10.99	5.37	18.77	0.24
Whole milk[4]	01077	3.67	7.52	1.85	0.61	0.65	14.29	0.54
Skim milk	01085	2.81	9.70	1.66	0.75	0.71	15.63	1.70
Cheese nachos	21078	4.77	10.79	0.73	9.24	0.81	26.35	0.62
Spices and herbs								
Mustard seeds	02024	46.21	0.90	0.44	75.10	ND	122.66	1.65
Fats and oils								
Olive oil	04053	0.02	0.28	ND	ND	ND	0.29	0.10
Fat-free dressing	04021	1.49	1.38	0.24	0.48	0.38	3.97	1.61
Imitation mayonnaise[4]	04027	0.30	1.08	ND	12.58	0.63	14.59	0.31
Italian dressing, regular	04114	1.62	2.93	ND	7.42	0.42	12.40	0.01
Mayonnaise, regular	04025	0.23	ND	ND	45.79	ND	46.02	ND
Chickens								
Chicken roasted (w/skin)[4]	05009	5.27	1.20	3.45	44.44	11.48	65.83	4.95
Chicken roasted (no skin)[4]	05013	5.67	1.12	3.72	53.71	14.52	78.74	5.09
Chicken liver	05028	47.87	8.80	4.86	213.70	14.8	290.03	11.43
Soups, sauces and gravies								
Chicken noodle soup (2)	06419	3.27	0.93	0.35	5.88	0.77	11.22	10.56
Salsa	06164	7.30	1.03	1.31	2.01	0.05	11.70	0.22
Tomato product (4)	06931	12.88	1.10	2.51	3.50	0.08	20.07	0.38
Soy sauce	16123	31.01	ND	ND	2.02	ND	33.03	35.21
New England clam chowder	06205	1.96	0.94	0.36	3.49	0.15	6.89	21.28
Sausages and luncheon meats								
Chicken hot dogs (4)	07024	6.17	0.93	1.75	35.20	7.31	51.36	4.53
Pork sausage	07065	7.39	7.41	0.78	52.50	5.00	73.07	2.15
Breakfast cereals								
Wheat germ, toasted	08084	69.19	33.78	4.19	44.92	ND	152.08	1240.48
Farina with wheat germ[4]	08105	1.57	0.72	ND	1.17	ND	3.45	6.09
Plain oats[4]	08121	1.25	1.64	ND	4.53	ND	7.42	2.72
Fruits and fruit products								
Apples	09003	0.33	ND	ND	3.11	ND	3.44	0.09
Avocados (2)	09037	8.64	0.73	2.47	2.22	0.11	14.18	0.58
Blueberries	09050	3.00	0.61	0.66	1.76	ND	6.04	0.16
Bananas	09040	3.20	5.60	0.51	0.44	ND	9.76	0.07
Cantaloupe	09181	4.12	0.71	1.13	1.62	ND	7.58	0.07
Grapefruit (2)	09111	3.56	1.16	0.25	2.55	ND	7.53	0.13
Grapes (2)	09132	4.80	ND	0.62	0.21	ND	5.63	0.12
Oranges (2)	09200	4.68	1.10	0.51	2.09	ND	8.38	0.11
Peaches, raw	09236	0.78	1.11	0.48	3.73	ND	6.10	0.24
Peaches, canned	09241	0.43	0.94	0.53	1.29	0.20	3.40	0.24
Pears (2)	09252	2.26	0.33	ND	2.52	ND	5.11	0.14
Prunes	09288	6.30	0.91	ND	2.45	ND	9.66	0.39
Raisins (2)	09298	9.37	0.31	1.14	0.32	ND	11.14	0.27
Strawberries	09316	0.63	0.86	ND	4.17	ND	5.65	0.14
Watermelon	09326	3.08	ND	0.66	0.20	0.12	4.07	0.25
Orange juice (3)	09215	4.16	2.65	0.44	3.81	ND	11.05	0.23
Apple juice	09016	0.71	0.69	ND	0.44	ND	1.84	0.11
Canned pears[4]	09257	0.55	1.05	ND	0.34	ND	1.94	0.23
Pork products								
Bacon, cooked (12)	10124	12.06	14.52	2.68	85.58	10.05	124.89	3.14
Pork loin cooked (4)	10046	2.19	22.51	1.18	70.45	6.42	102.76	1.39
Vegetables and vegetable products								
Alfalfa seeds	11001	11.02	0.60	1.76	1.01	ND	14.40	0.35
Broccoli	11091	8.45	1.32	9.30	20.98	ND	40.06	0.11

TABLE 1 *(continued)*

Choline and betaine concentrations of common foods[1]

	USDA NDB #[2]	Choline	GPCho	PCho	PtdCho	SM	Total choline[3]	Betaine
		mg choline moiety/100 g food						*mg/100 g food*
Carrots	11124	6.82	ND	1.13	0.84	ND	8.79	0.34
Cooked carrots	11125	0.44	0.44	1.08	6.81	ND	8.77	0.11
Cabbage (2)	11110	6.87	3.47	1.34	3.76	ND	15.45	0.31
Celery (2)	11143	5.25	ND	0.71	0.18	ND	6.14	0.09
Cucumber	11205	3.99	0.48	0.91	0.58	ND	5.95	0.07
Iceberg lettuce (2)	11252	4.80	ND	1.53	0.37	ND	6.70	0.08
Romaine lettuce (3)	11251	7.63	ND	1.61	0.69	ND	9.92	0.08
Onions	11282	4.39	0.57	0.68	0.47	ND	6.10	0.07
Peppers	11333	3.62	ND	1.19	0.74	ND	5.54	0.07
Spinach, raw (3)	11457	2.25	0.21	1.40	18.23	ND	22.08	599.81
Spinach, cooked (2)	11458	1.69	ND	1.13	21.97	ND	24.78	645.06
Sauerkraut (2)	11439	8.68	0.94	ND	0.61	0.16	10.39	0.43
Sweet potatoes (2)	11602	0.89	1.97	2.56	7.69	ND	13.11	30.76
Tomatoes (2)	11529	4.40	ND	1.83	0.50	ND	6.74	0.06
Beets (canned)[4]	11084	0.40	0.61	0.89	4.10	0.09	6.10	296.73
Beet, raw[4]	11080	4.12	0.55	0.89	0.44	ND	6.01	114.42
Catsup[4]	11935	6.54	1.59	1.83	0.57	ND	10.53	0.15
Raw mushrooms[4]	11260	5.93	5.11	1.34	4.47	ND	16.86	9.52
Brussels sprouts[4]	11101	23.37	3.18	ND	14.06	ND	40.61	0.13
Cauliflower[4]	11136	24.53	0.74	1.79	12.05	ND	39.10	0.11
Yellow corn[4]	11179	8.93	0.64	1.68	10.70	ND	21.95	0.15
Kelp[4]	11445	0.10	ND	ND	0.33	ND	0.43	0.22
Mashed potatoes[4]	11657	8.44	1.28	0.79	3.85	ND	14.36	0.38
Peas[4]	11313	2.16	0.79	0.68	23.88	ND	27.51	0.13
Snap beans[4]	11061	4.00	0.79	1.36	7.31	ND	13.46	0.08
Yellow squash[4]	11644	2.08	0.62	2.60	5.28	ND	10.57	0.18
Zucchini[4]	11478	0.53	0.69	2.43	5.72	ND	9.36	0.23
French fries, frozen, baked[4]	11403	7.22	4.53	1.35	7.07	ND	20.17	0.28
Beverages								
White wine	14106	3.56	1.59	ND	ND	ND	5.15	0.13
Brewed tea	14355	0.37	ND	ND	ND	ND	0.37	0.90
Coffee (3)	14209	1.89	0.67	ND	0.03	0.03	2.62	0.07
Vanilla shake	14347	4.58	9.52	1.42	1.46	1.23	18.21	1.04
Beer, regular[4]	14003	4.65	5.06	ND	ND	ND	9.71	8.65
Beer, light[4]	14006	4.07	2.98	ND	ND	ND	7.06	6.20
Coca Cola[4]	14400	0.06	0.62	ND	ND	ND	0.67	0.08
Diet Coca Cola	14416	ND	ND	ND	ND	ND	ND	0.06
Orange crush[4]	14150	ND	0.57	ND	ND	ND	0.58	0.05
Cranberry juice[4]	14242	0.43	0.70	ND	ND	ND	1.13	0.08
Decaf. coffee powder[4]	14219	93.7	8.19	ND	ND	ND	101.93	0.65
Finfish and shellfish								
Shrimp, canned (2)	15152	5.56	5.69	1.13	58.22	ND	70.60	218.74
Finfish-Atlantic cod[4]	15016	17.73	30.04	1.57	32.90	1.38	83.63	8.58
Salmon[4]	15086	8.62	5.89	1.07	48.02	1.84	65.45	1.87
Fish sticks[4]	15027	11.55	6.80	0.60	8.88	0.48	28.32	29.32
Legumes and legume products								
Peanuts (4)	16089	17.59	1.27	1.79	31.81	ND	52.47	0.56
Peanut butter (4)	16098	25.04	1.25	1.64	35.09	ND	63.02	0.70
Beans, navy (2)	16039	14.02	0.78	0.56	11.57	ND	26.93	0.07
Soybean, raw	16108	47.27	2.92	1.12	64.56	ND	115.87	1.85
Tofu, soft	16127	9.72	0.71	ND	16.94	ND	27.37	0.36
Baked products								
Wheat bread (2)	18064	17.98	4.93	0.29	3.33	ND	26.53	201.41
White bread	18069	6.04	3.33	0.24	2.56	ND	12.17	93.20
Chocolate chip cookie	18159	8.90	1.43	0.50	6.21	ND	17.05	38.03
Tortillas	18363	4.10	2.42	0.21	6.54	ND	13.27	0.34
English muffins (2)	18258	10.26	5.08	ND	2.61	ND	17.95	95.42
Wheat cracker (5)	18232	17.71	10.94	0.55	2.60	ND	31.80	198.71
Graham cracker, plain (5)	18173	13.15	3.56	0.40	5.16	ND	22.27	172.59
Danish pastry (4)	18246	8.72	2.21	0.68	9.54	0.69	21.84	12.68
Apple pie[4]	18301	4.66	1.03	ND	1.50	ND	7.19	14.57
Biscuit-plain[4]	18009	6.85	1.25	0.57	0.21	ND	8.89	38.24
Pancakes-plain[4]	18290	5.44	1.47	ND	11.38	0.92	19.21	23.12
Saltine crackers[4]	18228	12.63	6.30	ND	0.65	ND	19.59	49.14
Frosted cake[4]	18140	4.63	1.33	ND	28.90	1.51	36.38	16.59
Plain muffins[4]	18273	14.48	2.86	0.70	23.93	1.44	43.40	82.12

TABLE 1 *(continued)*

Choline and betaine concentrations of common foods[1]

	USDA NDB #[2]	Choline	GPCho	PCho	PtdCho	SM	Total choline[3]	Betaine
		mg choline moiety/100 g food						*mg/100 g food*
Sugar and sweets								
Corn chips	19003	1.86	0.72	ND	9.48	ND	12.07	0.10
Potato chips	19411	4.57	ND	ND	7.50	ND	12.07	0.15
Ice cream (2)	19095	4.78	13.23	1.81	3.62	2.60	26.04	0.94
Ice cream, vanilla/sherbet, orange	—	1.80	6.18	1.64	3.27	2.69	15.59	0.53
Popcorn[4]	19035	5.17	1.73	ND	7.07	ND	13.98	0.32
Milk chocolate	19120	9.12	21.92	2.25	10.89	1.93	46.11	2.33
Yogurt, frozen (2)	19293	4.38	11.30	1.60	4.26	1.48	23.01	0.77
Snickers candy bar (2)	19155	10.20	18.04	2.40	9.09	0.99	40.72	0.98
Strawberry preserve (3)	19297	2.57	6.70	0.49	0.44	ND	10.21	0.09
Pretzel, hard, (2) plain, salted	19047	16.23	18.68	0.53	2.95	ND	38.40	236.45
Cereal grains, pastas and snacks								
Oat bran, raw	20033	4.41	33.25	0.68	20.23	ND	58.57	31.73
Rice (2)	20045	0.72	0.95	ND	0.42	ND	2.08	0.27
Pasta/rice	20121	4.20	0.66	ND	1.80	ND	6.66	89.86
Wheat bran[4]	20077	50.89	4.36	2.06	17.77	ND	74.39	1339.35
Brown rice[4]	20037	4.66	1.17	ND	3.38	ND	9.22	0.43
Grains	20010	6.79	0.81	0.71	5.15	ND	13.47	37.26
Fast food								
Cheese pizza	21049	6.68	1.42	0.81	4.17	0.90	13.98	23.01
Chicken nuggets (12)	21037	3.87	1.53	1.11	30.19	5.17	41.87	15.06
French fries	21138	12.14	3.94	0.81	5.18	ND	22.06	0.66
Fast food hamburger (13)	21107	5.66	4.50	0.88	20.34	2.85	34.23	29.61
Fast food sandwich (3)	21089	5.37	6.15	0.95	23.22	3.59	39.27	26.23
Tacos/burritos (6)	21082	9.55	1.01	0.87	13.80	1.65	26.88	13.22
Lasagna	—	5.21	1.14	0.91	8.55	1.16	16.98	5.42
Hot dog and bun	21118	4.51	1.88	0.81	20.72	2.14	30.06	39.39
Beef products								
Beef, trim-cut, cooked	13004	3.57	3.86	0.53	62.43	7.77	78.15	10.12
Beef liver, pan fried	13327	56.67	77.93	11.77	247.75	24.10	418.22	5.63
Ground beef, 75% lean, broiled (12)	23568	2.22	2.95	0.33	68.97	7.88	82.35	7.54
Ground beef, 85% lean, broiled (12)	23578	2.30	2.57	0.32	65.98	8.16	79.32	8.49

[1] Data are means of duplicate determinations.

[2] USDA NDB # refers to the United States Department of Agriculture nutrient database number. ND, not detected.

[3] Total choline is the sum of choline, phosphocholine (PCho), glycerophosphocholine (GPCho), phosphatidylcholine (PtdCho), and sphingomyelin (SM) in the food. In parentheses after the food item name is indicated the number of samples (different brands or regions) assayed in duplicate and averaged to generate provided value.

[4] Denotes food items purchased locally in Chapel Hill, NC; all others were national samplings.

will provide choline data for products analyzed under the USDA National Food and Nutrition Analysis Program (NFNAP). These data will also be used to establish a special choline database to be posted on the USDA Nutrient Data Laboratory web site (http://www.nal.usda.gov/fnic/foodcomp).

MATERIALS AND METHODS

Sample preparation. Food items for this study were obtained either locally or through a nation-wide pick-up of 12 retail outlets in accordance with the national sampling plan developed for the NFNAP (27) and shipped to the Food Analysis Laboratory Control Center, Virginia Polytechnic Institute and State University, Blacksburg, VA, for preparation and compositing (**Table 1**). For each composite, the maximum amount was taken from each sample unit to be included, with a minimum subsample size of 1 serving (according to typical serving sizes) and preferably whole units (i.e., cans, fruits, bottles). Appropriate cooking methods were used. Packaged foods were prepared according to package directions. Both fresh and frozen vegetables were cooked in boiling water for 8–10 min and then drained and cooled (except mushrooms and alfalfa seed, which were processed directly without cooking). Salmon and Atlantic cod were baked at 218°C for 20 min. Grains were boiled in 2 parts water and then simmered for 20 min. Brown rice was boiled in 1 part water then simmered for 20 min. Whole chicken was roasted in a preheated oven at 218°C for at least 25–30 min or until an internal temperature of 82°C was reached; no-fat medium or nonstick spray was added. One half of the bird was analyzed with skin, the other without. Ground beef samples were blended for 2 min in a Hobart mixer (Hobart, Troy, OH), pressed into a patty mold (112 g), then broiled in a preheated conventional oven to an internal temperature of 72°C. Beef liver samples were browned in a nonstick Rival skillet (Holmes Group, Kansas City, MO) preheated to 162° C for 5 min, then cooked to an internal temperature of at least 74°C (6–10 min). Chicken livers were simmered in a nonstick Rival skillet for 6–10 min to a minimal internal temperature of 79°C. Plain muffins were prepared according to a recipe (NDB# 18273). Mashed potatoes were prepared by boiling minced potatoes and adding whole milk and mashing until a smooth texture was achieved; no salt or butter was added.

After cooling, foods were finely chopped using a food processor. Dry foods were ground with a mortar and pestle. Canned vegetables and soups were mixed in a blender. Fresh produce, fast food sandwiches, cheese, dried fruits, nuts, chocolate candy and muffins were immediately frozen in liquid nitrogen before blending, and kept frozen during and after homogenization. Liquids (e.g., fruit juices, milk, oil), as well as spice composites, were homogenized after storage at room temperature (shelf-stable products) or at 28°C (perishables) by stirring thoroughly in a large stainless steel bowl. Salad dressings and whole eggs were blended with a hand-held blender (Cuisinart). Whole kernel popcorn was processed in the grain mill attachment of a KitchenAid mixer (model #KSM5PSWW, KitchenAid U.S.A.; Greenville, OH). Food items that were picked up locally were processed in a similar manner. Foods were stored in a glass container at −20°C overnight and then stored at −80°C until analyzed.

Homogenates of foods were shipped to the University of North Carolina on dry ice. All of the samples were either analyzed immediately or stored at −80°C until the time of analysis. Frozen food samples were thawed at room temperature for ~2–4 h, the sample was mixed for 30 s with a stainless steel spatula and an aliquot was taken. Choline compounds were extracted from foods using the procedure of Bligh and Dyer (28), spiked with deuterium-labeled internal standards of all the analytes and analyzed using liquid chromatography-electrospray ionization-isotope dilution mass spectrometry as previously described (29). Quality assurance was monitored through the use of duplicate sampling, in-house control materials, and Standard Reference Materials.

RESULTS AND DISCUSSION

Foods contained choline, phosphocholine (PCho), glycerophosphocholine (GPCho), sphingomyelin (SM) and PtdCho as well as the choline metabolite betaine (Table 1). When choline is taken up by most tissues it is either converted to betaine and then used as an osmolyte and methyl donor, or it is phosphorylated and then used for the synthesis of phospholipids (see **Fig. 1**). Because there are metabolic pathways for the interconversion of choline, PCho, GPCho, SM and PtdCho (1), we present the sum of the concentrations of these compounds as total choline concentration. The conversion of choline to betaine is irreversible (1); thus, we present this value separately.

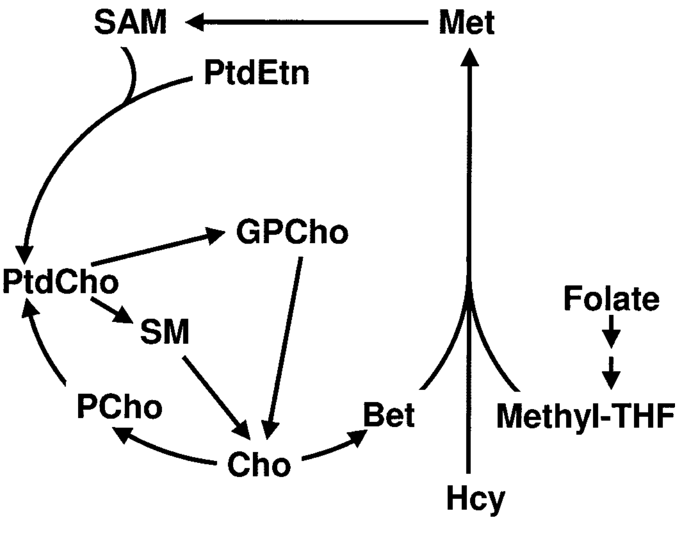

FIGURE 1 Metabolic pathways for choline and betaine. Phosphocholine (PCho), phosphatidylcholine (PtdCho), glycerophosphocholine (GPCho), and sphingomyelin (SM) are formed from choline (Cho) and can be hydrolyzed to form Cho. The formation of betaine (Bet) from Cho is irreversible. Betaine can donate a methyl group to homocysteine (Hcy) to form methionine (Met). Met is converted to *S*-adenosylmethionine (SAM), which is an important methyl donor. PtdCho can be formed from SAM and phosphatidylethanolamine (PtdEtn). Folate and Cho metabolism intersect because methyltetrahydrofolate (Methyl-THF), a product of folate metabolism, can also donate a methyl group for the formation of Met from Hcy.

We present the values for individual choline compounds because these choline sources may have differing bioavailability from foods (30). We did not measure acetylcholine or cytidinediphosphocholine (CDP)-choline concentrations in foods because they are present in minor amounts. The water-soluble compounds (choline, PCho, and GPCho) have different kinetics for uptake and metabolism than the lipid soluble compounds (PtdCho and SM). Choline and PtdCho are absorbed by mediated transport in the small intestines (31,32). We know little about the absorption of the other choline compounds found in foods. We do know that water-soluble choline compounds are absorbed via the portal circulation, whereas the lipid- soluble compounds present in foods are partially hydrolyzed by phospholipases and then absorbed via the thoracic duct and by-pass the liver (1).

When both cooked and raw vegetables were analyzed, we observed that total choline content of the foods per 100 g remained similar (Table 1). Free choline concentration was lower when the food was cooked, whereas the choline in PtdCho was proportionately higher. We discovered that when raw vegetables were finely minced, phospholipase D was activated, resulting in the conversion of PtdCho to phosphatidic acid and choline (assessed using TLC, data not shown). This enzyme activity can be inhibited by boiling the raw vegetable in water before mincing (at least 3 min; data not shown) or by homogenizing the fresh vegetable in hot (82°C) isopropanol (33). We present values for raw vegetables despite this mincing artifact, because chewing foods should produce the same result, i.e., a conversion of PtdCho to choline.

Methyltetrahydrofolate and choline are major dietary methyl donors that are metabolically interrelated (1). Both regulate the formation of *S*-adenosylmethionine, and thereby influence methylation reactions. Diminished folate availability increases demand for choline as a methyl donor (34), and decreased choline availability increases demand for folate methyl groups (35). For this reason, both methyl donors must be considered in any attempts to understand how methyl status could be mechanistically related to disease processes. Epidemiologists have been interested in methyl metabolism as it relates to chronic diseases. For example, >20 epidemiologic studies indicate a strong inverse association between dietary folate intake or blood folate levels and the risk of developing colorectal adenomas or cancer (15). Others have examined dietary folate intake and heart disease (16), and clinical trials indicated efficacy for increased diet folic acid intake in hypertension and restenosis of coronary arteries (36,37). These studies focused on the folate and methionine content of diet, but did not include dietary choline intake as a variable because data were not available on the choline concentration of common foods. Reanalysis of these studies, using the food data we now provide, may identify important interactions between dietary choline and folic acid. Perhaps the most affected groups will be those consuming diets low in both methyl donors. In such analyses, both total choline and betaine should be considered as fungible sources of methyl groups. In other studies in which the suspected mechanism of action is not methyl donation, but rather via the role of choline as a neurotransmitter precursor or membrane precursor, the value for total choline without betaine might be preferred because betaine cannot be converted into acetylcholine or membrane phospholipids. Similarly, betaine does not contribute to trimethylamine formation in trimethylaminuria.

In conclusion, data from this study will be used to establish a choline database to facilitate research relating choline intake to risk for diseases. Furthermore, it will provide the basic information for estimating dietary requirements and for developing nutrient recommendations.

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