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Aluminum Levels in Foods Cooked and Stored in Aluminum Pans, Trays and Foil

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ABSTRACT

The aluminum content of 26 different foods was determined before and after the foods were cooked in uncoated new, conditioned and old aluminum pans, in stainless steel pans or in disposable aluminum trays and foil. All the foods tested contained small amounts of aluminum naturally. Some foods (i.e., potatoes boiled in new aluminum pans; cabbage and beef roasts cooked in aluminum pressure cookers; applesauce and eggs cooked in conditioned aluminum pans; tomatoes cooked in old aluminum pans; and mashed potatoes frozen and heated in TV dinner trays) accumulated significant ($P<0.05$) amounts of aluminum during preparation. However, the actual amounts of aluminum that were added to foods through the use of aluminum utensils were quite small as compared to the average dietary intake of aluminum by Americans.

During the last 16 years, medical researchers have debated the importance of exposure to aluminum in the etiology of dialysis osteodystrophy, dialysis encephalopathy and Alzheimer's disease (*6*). These reports aroused interest in dietary sources of aluminum (*8,9*).

Food composition tables on the aluminum content of foods have been prepared by Sorenson et al. (*18*) and Schelettwein-Gsell and Mommsen-Straub (*17*). However, these tables are limited in regard to the number of foods included and probably the accuracy of data. Estimates of the amounts of aluminum in plasma have decreased by more than 50-fold during the last 20 years because of improvements in methodology (*21*). It is likely that many old values on the aluminum content of foods may be artificially high too.

Another limitation of composition tables on the aluminum content of foods is that the effect of cooking and storing foods in aluminum utensils has been studied with a limited number of foods (*1,7,11-16,20*). Furthermore, the significance of these data can be questioned in some cases because of unusual cooking conditions, i.e., boiling pieces of aluminum foil with food in a pan (*20*).

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Many factors that could effect translocation of aluminum from utensils to foods have not been assessed. For example, differences in aluminum alloys, in types of utensils (i.e., foil, disposable trays, pans), in the presence of coatings, and in the use of the utensils (i.e. boiling, frying, pressure cooking), could all affect aluminum accumulation in foods. The purposes of these studies were: (a) to determine the aluminum content of common foods; (b) to assess the aluminum contents of foods cooked in a variety of aluminum utensils by a variety of methods; (c) to assess whether previous usage of pans can affect aluminum translocation from the pans into foods; and (d) to assess whether freezing foods in aluminum foil affected the aluminum content of foods.

MATERIALS AND METHODS

Experimental design

Three studies were done to determine the amount of aluminum translocated from aluminum pans and foil into food during preparation. The types of foods prepared in the three studies, the types of aluminum utensils used, the methods of cooking, and the lengths of the processing periods are listed in Table 1.

In the first study, three foods (i.e., ground beef, potatoes and tomatoes) were cooked in new aluminum pans, conditioned aluminum pans and stainless steel pans. Tomatoes were cooked also in 30-year old aluminum pans. These pans had been used in a home previously. In the second study, 15 foods were cooked in conditioned aluminum pans and stainless steel pans. In both studies, each type of food was prepared three times in each of two aluminum pans ($n=6$ replicates) and three times in one stainless steel pan ($n=3$ replicates); three samples of unprocessed foods were collected for analysis also.

In the third study, eight different foods were cooked in disposable aluminum trays or aluminum foil. Five of these foods (i.e., beef round roast, flounder and TV dinner components) were frozen also in the aluminum foil or trays before cooking. One food, beef round roast, was refrigerated after cooking and then reheated in aluminum foil. Three replicates of each food, except flounder ($n=6$ replicates), were prepared. Two foods, i.e., beef round roast and flounder, were sampled for analysis after freezing as well as after cooking. Three samples of the unprocessed foods were collected for analysis also.

TABLE 1. *Foods prepared in aluminum pans, trays and foil.*

Food	Type of original food	Type of aluminum pan, tray or foil	Type of preparation	Average length of cooking (min)
Study 1				
Beef, ground	Fresh	Fry pan[a]	Frying	8
Potatoes	Fresh & peeled	Saucepan[a]	Simmering	30
Tomatoes	Fresh	Saucepan[a]	Simmering	10
Study 2				
Applesauce	Fresh & peeled	Saucepan[b]	Simmering	33
Beans, green	Frozen	Saucepan[b]	Simmering	5
Beef rump roast	Fresh	Pressure cooker[c]	Pressure cooking	40
Cabbage	Fresh	Pressure cooker[c]	Pressure cooking	8
Cauliflower	Frozen	Saucepan[b]	Simmering	6
Chicken	Fresh	Fry pan[b]	Frying	32
Cod	Frozen	Fry pan[b]	Frying	10
Eggs	Fresh	Fry pan[b]	Frying	14
Grits	Dried	Saucepan[b]	Simmering	25
Ham	Smoked	Fry pan[b]	Frying	20
Peas	Frozen	Saucepan[b]	Simmering	5
Pudding, chocolate	Dried	Saucepan[b]	Simmering	10
Rice	Dried	Saucepan[b]	Simmering	16
Spaghetti	Dried	Saucepan[b]	Simmering	12
Tomato sauce	Fresh & peeled	Saucepan[b]	Simmering	180
Study 3				
Beef chuck roast	Fresh	Roasting pan[d]	Baking	66
Beef round roast	Fresh	Foil[e]	Freezing[g]	--
			Baking	120
			Refrigerating	--
			Reheating[g]	30
Flounder	Fresh	Foil[e]	Freezing[g]	--
			Baking	66
Potatoes	Fresh	Foil[e]	Baking	70
Turkey	Fresh	Foil[e]	Baking	120
TV dinner-ham	Smoked	Tray & foil[f]	Freezing-thawing cycle[h]	--
			Baking	45
TV dinner-peas	Frozen	Tray & foil[f]	Freezing-thawing cycle[h]	--
			Baking[g]	45
TV dinner-potatoes	Mashed	Tray & foil[f]	Freezing-thawing cycle[h]	--
			Baking	45

[a]Pan of alloy 3003 conditioned in autoclave.
[b]Pan of alloy 3003 conditioned through prescribed cooking pattern.
[c]Pan of alloy 3004 conditioned through prescribed cooking pattern.
[d]Disposable roasting pan of alloy 8079.
[e]Heavy duty foil of alloy 8111.
[f]Three compartment, uncoated tray of alloy 1100 with uncoated hooding foil, alloy 1235.
[g]Food sampled for analyses after this process as well as after cooking.
[h]Freeze-thaw cycle consisted of quick freezing to -40°C, warming to 4°C and refreezing to -18°C three times.

Sample preparation

Twenty-one different foods were purchased from commercial sources and 26 different dishes were prepared according to directions in a standard cookbook (*3*), with the exception of the following three factors: foods were prepared with deionized water; reagent grade sodium chloride was used because cooking salt contains aluminum-containing food additives (*2*); and pepper, herbs and spices were omitted from recipes because they often naturally contain high levels of aluminum (*17*). To reduce the risk of sample contamination, care was taken to prevent contact of foods with aluminum or glass during food preparation and storage.

Enough food to serve four people was prepared in each pan or foil package for each replicate, with one exception, i.e., TV dinner trays contained only one serving of each of the three foods studied. Thus, the contents of each food from four trays were combined to create one replicate for analyses. All the food needed for the replicates of any recipe were from the same lot. Different sets of pans were used for each type of food prepared in Studies 1 and 2. All pans were hand-washed before each use with a mild detergent (Ivory), rinsed with hot tap water and deionized water, and air-dried.

The methods used to condition aluminum pans in Studies 1 and 2 differed. In Study 1, pans were conditioned by filling them with deionized water, covering the pan securely with high-density polyethylene and heating in an autoclave at 100°C for 72 h. Afterwards, it was decided that this method of conditioning might not simulate a household situation. Thus, in

Study 2 pans were conditioned by filling the pans with canned tomatoes to 1 cm from the top, cooking for 30 min, discarding the tomatoes, washing the pans with mild detergent, rinsing the pans, filling the pans with peeled and quartered potatoes and water to 1 cm from the top, cooking for 45 min, discarding the potatoes, washing and rinsing the pans again, and air-drying the pans for 16 h.

Analyses

All replicate samples of vegetable, fruit and cereal products were homogenized in stainless steel blenders; meat and fish were processed in stainless steel grinders. The homogenized and uniformly ground samples were frozen in double-polyethylene bags.

All foods simmered in added water were drained of excess water before they were homogenized. However, some cooked samples did differ from some raw products in terms of hydration. Hence, the percentages of moisture in all products are listed in Tables 2, 3 and 4. Duplicate moisture analyses were done on each sample replicate.

TABLE 2. *Aluminum content of foods cooked in new, conditioned and old aluminum pans.*

	Uncooked			Cooked in aluminum pans				Cooked in stainless steel pans		
	Mean %	μg Al/g wet wt.		Type of	Mean %	μg Al/g wet wt.		Mean %	μg Al/g wet wt.	
Foods	moisture	Mean ± SD[a,b]	Range	pan	moisture	mean ± SD[b,c]	Range	moisture	Mean ± SD[a,b]	Range
Beef, ground	68	0.14 ± 0.04	<0.10-0.18	New	64	0.46 ± 0.54	0.22-1.6	62	0.22 ± 0.08	0.14-0.31
				Simulated use[d]	63	0.38 ± 0.15	0.14-0.54			
Potatoes	80	0.16 ± 0.06	<0.10-0.20	New	80	0.41 ± 0.05[e]	0.34-0.46	80	0.10 ± 0.00	<0.10
				Simulated use[d]	80	0.12 ± 0.03	<0.10-0.18			
Tomatoes	91	0.12 ± 0.04	<0.10-0.17	New	91	3.1 ± 1.4	1.8 -5.4	91	0.11 ± 0.01	<0.10-0.12
				Simulated use[d]	90	0.32 ± 0.17	0.13-0.56			
				Old[f]	91	0.63 ± 0.17[e]	0.5 -0.9			

[a]n = 3.
[b]Values of <0.10 μg Al/g were rounded to 0.10 μg Al/g for calculations.
[c]n = 6 (3 replicates cooked in each of 2 pans).
[d]Pans conditioned in autoclave.
[e]Products differed (P<0.05) from those that were uncooked or cooked in stainless steel pans.
[f]30-year-old pans.

TABLE 3. *Aluminum content of foods before and after being cooked in conditioned aluminum and stainless steel pans.*

	Uncooked			Cooked in aluminum pans[a]			Cooked in stainless steel pans		
	Mean %	μg Al/g wet wt.		Mean %	μg Al/g wet wt.		Mean %	μg Al/g wet wt.	
Food	moisture	Mean ± SD[b,d]	Range	moisture	Mean ± SD[c,d]	Range	moisture	Mean ± SD[b,d]	Range
Applesauce	79	0.13 ± 0.02	0.12-0.16	76	7.1 ± 0.8[e]	6.3 -8.2	77	0.12 ± 0.04	<0.10-0.17
Beans, green	93	3.8 ± 0.5	3.4-4.2	94	3.8 ± 0.3	3.4 -4.0	94	3.4 ± 0.1	3.3 -3.4
Beef, rump roast	82	0.19 ± 0.08	<0.10-0.26	80	0.85 ± 0.14[e]	0.60-0.96	79	0.21 ± 0.03	0.18-0.24
Cabbage	92	0.13 ± 0.05	<0.10-0.18	92	3.6 ± 0.7[e]	2.8 -4.2	93	0.20 ± 0.11	<0.10-0.32
Cauliflower	92	0.19 ± 0.10	<0.10-0.30	93	0.72 ± 0.49	0.24-1.65	93	0.19 ± 0.14	<0.10-0.35
Chicken	68	0.47 ± 0.15	0.30-0.58	51	1.00 ± 0.51	0.54-2.05	49	0.66 ± 0.05	0.61-0.70
Cod	81	0.35 ± 0.04	<0.30-0.37	68	0.47 ± 0.16	0.30-0.64	68	0.40 ± 0.18	0.30-0.60
Eggs	72	0.10 ± 0.00	<0.10	70	1.6 ± 0.5[e]	0.82-2.2	69	0.13 ± 0.02	0.10-0.14
Grits[f]	9	0.62 ± 0.17	0.44-0.78	83	0.60 ± 0.34	0.31-1.1	83	0.17 ± 0.06	<0.10-0.22
Ham	73	0.85 ± 0.61	0.46-1.6	60	1.2 ± 0.5	0.66-1.8	63	1.2 ± 0.6	0.72-1.9
Peas	81	1.9 ± 0.1	1.8 -2.0	80	1.9 ± 0.1	1.8 -2.0	80	1.9 ± 0.1	1.8 -2.0
Pudding[f]	2	21.3 ± 0.2[g]	21.1 -21.6	70	4.2 ± 0.4	3.8 -4.6	70	4.0 ± 0.3	3.8 -4.4
Rice[h]	67	1.5 ± 0.2	1.4 -1.8	63	1.7 ± 0.1	1.6 -1.8	63	1.7 ± 0.1	1.6 -1.8
Spaghetti[f]	10	1.7 ± 0.2[g]	1.4 -1.8	69	0.78 ± 0.21	0.54-1.1	72	0.45 ± 0.04	0.42-0.50
Tomato sauce	92	0.10 ± 0.01	<0.10-0.11	84	57.1 ± 36.6	29.7-125	79	0.16 ± 0.03	0.13-0.19

[a]Pans conditioned through standardized cooking procedures.
[b]n = 3.
[c]n = 6 (three replicates cooked in each of two pans).
[d]Values of <0.10 μg Al/g were rounded to 0.10 μg Al/g for calculations.
[e]Products cooked in aluminum pans contained significantly (P<0.05) more aluminum than unprocessed products or products cooked in stainless steel pans.
[f]Uncooked products were dry; cooked products were hydrated. Pudding mixes without milk analyzed as uncooked samples.
[g]Dry product had significantly (P<0.05) higher concentration of aluminum than either cooked product.
[h]Uncooked rice was soaked in water.

TABLE 4. *Aluminum content of foods before and after being frozen, refrigerated and/or cooked in aluminum foil or disposable aluminum trays.*

	Uncooked food			Prepared food			
	Mean %	μg Al/g wet wt.		Type of	Mean %	μg Al/g wet wt.	
Food	moisture	Mean ± SD	Range	processing	moisture	Mean ± SD	Range
Beef, chuck roast[a]	71	0.30±0.00	<0.30	Baking	58	0.33±0.02	<0.30-0.36
Beef, round roast[a,f]	69	0.39±0.16	<0.30-0.58	Freezing	71	0.47±0.15	<0.30-0.56
				Baking	58	0.54±0.19	0.33-0.68
				Reheating	56	0.74±0.11	0.62-0.82
Flounder[b,f]	80	0.55±0.20	0.32-0.84	Freezing	80	0.70±0.33	0.30-1.1
				Baking	76	0.76±0.26	0.52-1.2
Potato[a]	80	2.0 ±0.6	1.3 -2.5	Baking	76	2.4 ±1.0	1.6 -3.4
Turkey[a,c]	71	0.32±0.03	<0.30-0.36	Baking	62	0.38±0.07	<0.30-0.44
TV dinner - ham[d,f]	71	1.1 ±0.6	0.49-1.6	Heating	60	2.1 ±0.3	1.8 -2.4
TV dinner pea[d,f]	81	2.4 ±0.2	2.2 -2.7	Heating	76	4.1 ±0.6	3.4 -4.6
TV dinner - mashed potatoes[d,f]	75	0.18±0.04	0.16-0.22	Heating	71	0.97±0.01[e]	0.95-0.98

[a]n=3; values of <0.30 μg Al/g were rounded to 0.30 μg Al/g for calculations.
[b]n=6.
[c]Cooked with skin but only flesh analyzed.
[d]n=3; food from four trays were combined to create each replicate.
[e]Processed product differed (P<0.05) from uncooked product.
[f]Food frozen in aluminum foil before cooking.

Duplicate aluminum analyses were performed on each sample replicate at Hazleton Laboratories America, Inc., under the supervision of one author (D.S.). Each food sample (10 to 50 g) was weighed into platinum dishes, charred on a hot plate, and ashed at 500°C for 6 to 8 h. The samples were then fused with a mixture of sodium carbonate and sodium borate [3 (vol):1(vol)] at 1000°C for 10 min. Aluminum contamination had been removed from the sodium carbonate and borate mixture by extracting it with 8-hydroxyquinoline in chloroform. The fused samples were boiled in 5 ml of concentrated nitric acid and transferred to a 50-ml volumetric flask. Aluminum standards were prepared with the same fusion flux and acid composition.

Each sample and standard were injected three times into a Model 4000 atomic absorption spectrophotometer (Perkin-Elmer Corporation, Norwalk, CT) equipped with a HGA-400 graphite furnace and a Model AS-40 autosampler. L'vov platforms and pyrolytically-coated graphite tubes were used to increase sensitivity. A deuterium arc lamp was used to correct for background noise. The programmed cycle on the spectrophotometer included: drying at ambient temperature to 150°C in 15 s and at 150°C for 15 s; charring at 150 to 1000°C in 20 s and at 1000°C for 15 s; atomizing at 2600°C for 3 s; cleaning the tube at 2600°C for 3 s; cooling at 20°C in 2 s; and holding at 20°C for 8 s.

Aluminum at levels that were equivalent to 0.5, 1.0 and 2.0 times the amount of aluminum naturally present in the food was added to at least six replicates of 14 different foods. The calculated recoveries of the added aluminum to various foods were: 107% ± 4 (S.D.) applesauce; 97% ± 13 ground beef; 102% ± 5 cabbage; 108% ± 4 cauliflower; 91% ± 6 chicken; 108% ± 4 eggs; 100% ± 9 flounder; 95% ± 12 green beans; 100% ± 8 grits; 104% ± 16 ham; 112% ± 12 peas; 100% ± 13 pudding; 102% ± 9 rice; and 111% ± 9 spaghetti.

Means and standard deviations were calculated. Means were compared through Student 't' tests that assumed observations were unpaired and variances were unequal (*19*).

RESULTS AND DISCUSSION

Aluminum content of foods

Most of the foods cooked in stainless steel pans contained on the average less than 0.5 μg Al/g wet wt. (Tables 2 and 3). The only foods that contained more than 1 μg Al/g food after being cooked in stainless steel utensils were green beans, peas, unpeeled potatoes, pudding, rice and ham. The two foods with the highest aluminum content (i.e., pudding and green beans) would provide only 0.4 and 0.3 mg of aluminum per 100-g serving, respectively.

Our estimates of the aluminum content of foods are similar to or somewhat lower than earlier estimates by other investigators (*17,18*). These differences in the data may reflect improvements in analytical procedures and in prevention of random contamination (*21*) and/or may reflect real differences in the aluminum content of foodstuffs due to differences in plant varieties, and soil and growing conditions (*5*).

Aluminum accumulation in foods during cooking and storage

Mattsson (*13*) observed that some, but not all foods, cooked in new aluminum pans accumulated more aluminum than foods cooked in conditioned aluminum pans. We prepared different foods than Mattsson did but obtained similar results. In the first study, ground beef cooked in both new and conditioned aluminum fry pans contained similar levels of aluminum as beef cooked in a stainless steel fry pan (Table 2). However, peeled potatoes boiled in new aluminum sauce pans contained about 0.30 μg/g more aluminum than potatoes boiled in stainless steel or conditioned aluminum sauce pans. These differences were significant (P<0.05).

Tomatoes were used to determine if the laboratory (autoclave) method used to condition pans in Study 1 would establish a surface finish that would be equivalent to that of an aluminum pan that had been used in a household 30 years. The autoclave-conditioned pans appeared to be more resistant than the 30-year-old pan to the acidic action of the tomatoes. Thus, it was decided that this particular conditioning procedure was not appropriate to simulate household use of pans. A practical kitchen-like procedure as described in the Materials and Methods section was used in Study 2.

Despite the large increases in the average aluminum contents of tomatoes cooked in new aluminum pans, the increases were not statistically significant because of the large variation between the replicates cooked in each two new aluminum pans. (Duplicate analyses performed on three samples from one pan were very similar). However, the tomatoes cooked in the 30-year-old aluminum pans had significantly (P<0.05) higher levels of aluminum than the raw ones or those cooked in stainless steel pans.

In Study 2, the aluminum content of some foods were similar when cooked in stainless steel and aluminum pans (Table 3). However, some foods seemed to accumulate aluminum when cooked in aluminum rather than stainless steel pans. Ranked in order of increasing aluminum migration, these foods were: grits, cauliflower, beef, eggs, cabbage, applesauce and tomato sauce.

These observations are consistent with those of previous studies (*1,14,16*). Acidic foods, such as tomatoes, tomato sauces and applesauce, especially those cooked for more than 15 min, tended to accumulate more aluminum than other foods.

Despite these observations, only a few of the changes in the aluminum content of foods were significant (P< 0.05). For example, although differences in aluminum contents of applesauces cooked in aluminum and stainless steel pans were significant, differences in the aluminum content of tomato sauces were not. The variations among replicates were large for the tomato sauce prepared in aluminum pans, although duplicate analyses performed on the same replicate were similar.

Aluminum contents of both foods (beef chuck roast and cabbage) cooked in aluminum pressure cookers were significantly greater than the aluminum content of those samples cooked in stainless steel pressure cookers (see Table 3). Cabbage is acidic but beef is not. The aluminum content of eggs fried in aluminum fry pans was significantly greater than the aluminum content of eggs cooked in stainless steel fry pans (Table 3).

In practical terms, the amount of aluminum added to foods by cooking in aluminum utensils would amount to <0.1 mg aluminum per 100-g serving for most foods, i.e., green beans, fresh meats, grits, pea, pudding, rice and spaghetti. However, several foods would accumulate more aluminum during cooking. Typical 100-g servings of cabbage and applesauce would accumulate 0.3 and 0.7 mg aluminum, respectively. A 100-g serving of tomato sauce cooked in an aluminum pan for 180 min might contain as much as an additional 5.7 mg of aluminum. This is similar to Lione's (*11*) estimate.

In Study 3, the baked potatoes, meat and fish products did not accumulate significant amounts of aluminum when frozen and cooked in disposable aluminum trays or foil (Table 4). In fact, beef roasts that were frozen, cooked, refrigerated and reheated in aluminum foil, accumulated only 0.35 μg Al/g food (<0.04 mg/100 g-serving).

The TV dinners in aluminum trays were frozen and then thawed and refrozen three more times before they were cooked. This processing resulted in almost a 2-fold increase in aluminum content of the ham and peas, and more than a 4-fold increase in the aluminum content of the mashed potatoes (Table 4). Only the mashed potatoes accumulated significant (P<0.05) amounts of aluminum during processing. A TV dinner that consisted of 100-g servings of each of these three foods would accumulate <0.35 mg aluminum if handled in this manner. These thawing and refreezing cycles represented an abusive test.

Americans probably consume about 20 to 40 mg of aluminum in food daily (*4*) and can consume 1 to 5 g of aluminum in antacids daily (*10*). Thus the amount of aluminum added to foods by cooking in aluminum utensils is relatively small. It is unlikely that the amount of aluminum entering food during preparation is sufficient to have any effect of the metabolism of adults (*4a,4b*).

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