Chemistry behind the News

Trans Fatty Acids

by Ellin Doyle

Fats and their various fatty acid components seem to be a perennial concern of nutritionists and persons concerned with healthful diets. Advice on the consumption of saturated, polyunsaturated, monounsaturated, and total fat bombards us from magazines and newspapers. One of the newer players in this field is the group of trans fatty acids found predominantly in partially hydrogenated fats such as margarines and cooking fats. The controversy concerning dietary trans fatty acids was recently addressed in an American Heart Association (AHA) science advisory (*1*) and in a position paper from the American Society of Clinical Nutrition/American Institute of Nutrition (ASCN/AIN) (*2*). Both reports emphasize that the best preventive strategy for reducing risk for cardiovascular disease and some types of cancer is a reduction in total and saturated fats in the diet, but a reduction in the intake of trans fatty acids was also recommended. Although the actual health effects of trans fatty acids remain uncertain, experimental evidence indicates that consumption of trans fatty acids adversely affects serum lipid levels. Since elevated levels of serum cholesterol and triacylglycerols are associated with increased risk of cardiovascular disease, it follows that intake of trans fatty acids should be minimized.

Trans fatty acids, as the name indicates, have one or more double bonds in which the adjacent hydrogen substituents are attached on opposite sides of the hydrocarbon chain, as in elaidic acid (*trans*-Δ9-C18:1) (see illustration at right). Most naturally occurring fatty acids, such as oleic acid (*cis*-Δ9-C18:1), are cis isomers, with the hydrogen atoms attached on the same side of the hydrocarbon chain. The configuration of the hydrogen atoms in cis fatty acids causes a bend in the carbon chain, whereas in saturated fatty acids such as stearic acid the carbon chain is straight (see illustration). In a trans fatty acid, the carbon chain is relatively straight, so that in this respect the trans isomer resembles the corresponding saturated fatty acid (in this case, stearic acid, C18:0); but the chain is twisted slightly, which affects its sectional area and therefore its space requirements. These differences in geometry allow saturated fatty acids to be packed together more tightly than the trans monounsaturated isomer, while the cis isomer will be the most loosely packed. As a consequence, reported melting points of these substances vary from 72 °C (stearic acid) to 44 °C (elaidic acid) to 13 °C (oleic acid) (*3*). Trans fatty acids, then, appear to have characteristics intermediate between those of the corresponding saturated and cis fatty acids.

Small amounts of trans fatty acids are present in some plants, including pomegranates, peas, and cabbage. Resident bacteria in the digestive tract of ruminant animals can also produce trans fatty acids by an enzymatic reaction that hydrogenates unsaturated fatty acids present in grass and feed. Therefore, approximately 3–5% of fatty acids in milk and meat from cows, sheep, and goats are trans isomers, primarily *trans*-vaccenic acid (*trans*-Δ11-C18:1) (*3*). (An important intermediate in the hydrogenation of linoleic acid is the mixture of isomers known as conjugated linoleic acid or CLA, which is predominantly *trans*-Δ10,*cis*-Δ12-C18:2 and *cis*-Δ9,*trans*-Δ11-C18:2. Unlike other trans fatty acids, CLA has a wide range of beneficial effects [*4*]).

The predominant source of dietary trans fatty acids is the partially hydrogenated vegetable oil used in producing cooking fats and margarines. Hydrogenation involves use of high temperatures, pressure, and a catalyst (usually nickel). Unsaturated fatty acids in the vegetable oil bind to the surface of the catalyst and a double bond is opened. Addition of hydrogen at this site saturates the bond. However, binding to the catalyst is not stable, and if the fatty acid is released before saturation the double bond may be regenerated in either the cis or trans configuration. Since formation of the trans isomer is favored energetically, this structure tends to dominate. Partial hydrogenation also produces positional isomers (*3*). By varying the temperature, pressure, catalyst, processing time, and type of oil, fats with different characteristics can be produced. In recent years, these parameters have been manipulated to produce cooking fats with lower levels of trans fatty acids. Between the 1960s and the 1980s, the content of trans fatty acids in household shortenings decreased from 26% to 17% (*2*).

Deodorization of vegetable oils, a process utilizing high temperatures to drive off compounds with undesirable flavors or odors, also induces the cis-to-trans isomerization of fatty acids. Isomerization begins at 220 °C, and as much as 10% of fatty acids may be converted to the trans isomer after exposure to 280 °C. Under the usual conditions for deodorization, 3–6% trans fatty acids would be formed (*5*).

Hydrogenated fats account for an estimated 80–90% of the intake of trans fatty acids by Americans (*2*). Margarines contain 11–49% trans fatty acids, while some cooking fats have even higher percentages. Soft margarines packaged in tubs have lower levels of trans fats than the harder, stick margarines. Other major contributors to trans fatty acid intake include doughnuts, pastries, fried chicken, French-fried potatoes, snack chips, and imitation cheese; these foods contain 35–38% trans fatty acids (*2*).

Average intakes of trans fatty acids are difficult to calculate but have been estimated to range from 2.6 to 12.8 g/day in the U.S.A. (*1*). The lower estimates were calculated from food-frequency questionnaires, which are relatively narrow in scope and do not reflect the wide variations in dietary habits. The higher values are estimated from market availability and disappearance data, which do not consider such factors as the disposal of hydrogenated frying fat after use. Although the level of trans fatty acids in margarines has declined, overall intake has probably remained stable because greater quantities of hydrogenated fats are being consumed as a replacement for saturated fats (lard, butter).

Is this level of trans fatty acid consumption harmful to

ABOUT CHEMISTRY BEHIND THE NEWS

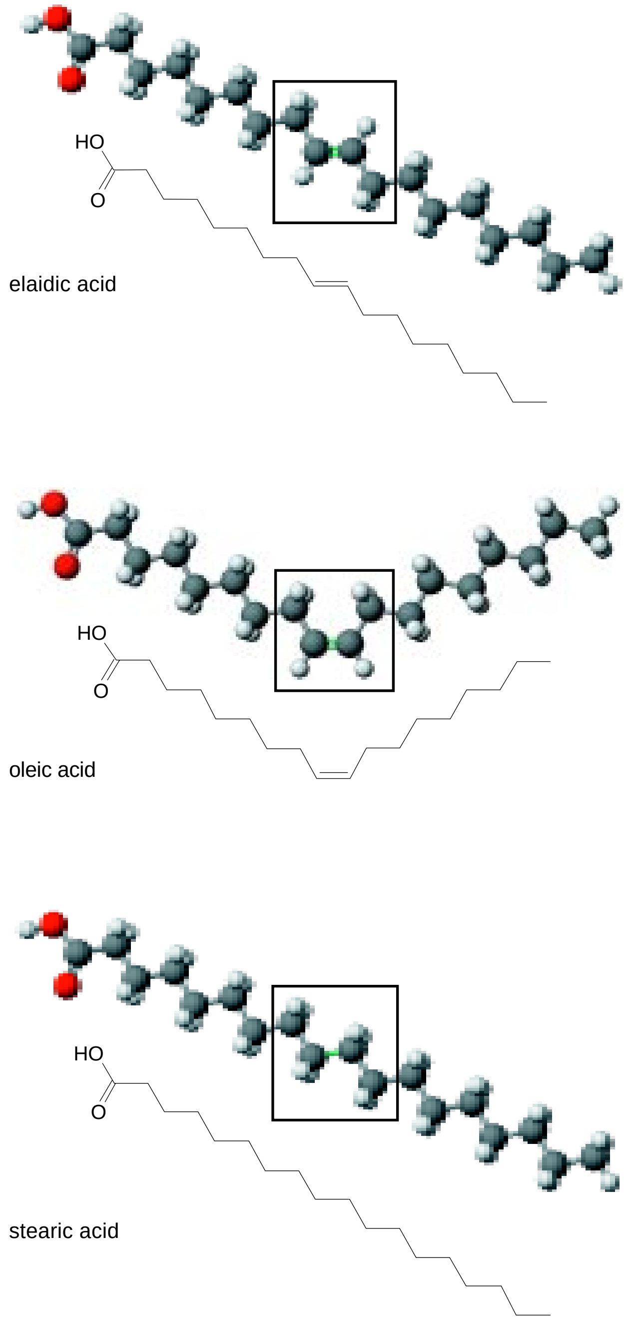
This column, as its name implies, features articles highlighting the chemistry behind selected topics in the news. Because the topics are news, much information is preliminary. Our intent is to summarize the state of knowledge on these developing subjects in a way that will be useful to classroom teachers, not to take a position on one side or the other regarding any of the issues involved.

health? The answers from research range from “probably not” to “yes, to a small extent”. Results of research into the effects of trans fatty acids on cancer development were recently reviewed and it was concluded that the data do not support a carcinogenic role for these fats (*6*). Epidemiological studies, which can indicate associations but not necessarily causation, have demonstrated a slight increase in risk of coronary heart disease with increasing margarine intakes in some populations (*7*), but no association between margarine intake and the prevalence of previously undiagnosed coronary heart disease in other populations (*8*).

Another approach to assessing adverse effects of trans fatty acids on cardiovascular health is to determine their effects on serum levels of low-density lipoprotein (LDL) cholesterol, high-density lipoprotein (HDL) cholesterol, and lipoprotein a, Lp(a). LDL cholesterol and Lp(a) participate in the development of arteriosclerosis, whereas HDL cholesterol is sometimes considered “good” cholesterol because in this form cholesterol is transported to the liver for metabolism and elimination. Data from numerous experiments have consistently demonstrated that relative to diets rich in cis-unsaturated fats, high-saturated- and high-trans-fat diets increase total and LDL cholesterol and Lp(a) (*1–3*). Some research has found a decrease in HDL cholesterol in response to trans fatty acids, but the data are inconsistent. The mechanisms by which these changes in serum lipids are induced are unknown, but the similar geometry of trans and saturated fatty acids may explain their similar physiological effects.

It is notable that dietary changes to improve serum lipid profiles normally replace saturated, not unsaturated, fats with trans fats. An appropriate question thus may be, “Is there any advantage to using margarine in place of butter?” In human experiments comparing the effects of substituting stearic (C18:0) and elaidic (*trans*-C18:1) acids for dairy fats high in palmitic (C16:0) and myristic (C14:0) acids, both C18 compounds decreased serum total and HDL cholesterol but the trans fat had a greater depressive effect on HDL. Moreover, stearic acid (but not elaidic) decreased LDL cholesterol levels (*9*). Experiments with monkeys demonstrated that elaidic and palmitic acids did not differ significantly in their effects on total and LDL cholesterol, but elaidic acid caused a greater decrease in HDL cholesterol (*10*). These results indicate that the trans-for-saturated fat (margarine for butter) substitution not only fails to improve the serum lipid profile but may actually worsen it. Another conclusion that can be drawn is that “all saturated fatty acids are not equal” in their effects on cholesterol levels: chain length (C14 + C16 vs. C18) is also important.

More basic research is needed to completely understand the physiological effects of trans fatty acids. Geometric differences between trans and cis isomers undoubtedly affect their interactions with enzymes involved in lipid metabolism. Because their melting point is higher, trans fats incorporated into cell membranes undoubtedly alter membrane fluidity and affect permeability. As an interesting aside, *Pseudomonas putida*, an omnivorous bacterium capable of degrading toxic pollutants such as phenol, possesses an isomerase enzyme that can convert cis fatty acids to their geometric trans isomers. When exponentially growing cells are challenged with high temperatures or salt concentrations or the presence of certain alcohols, more saturated fatty acids are incorporated into the cell membrane. But when cells enter the stationary phase (are no longer actively growing), the isomerase is activated and cells protect themselves by converting cis fatty acids to trans (*11*).



Structures and ball-and-stick models of three C18 fatty acids common in foods. Top: elaidic acid [(*E*)-9-octadecenoic acid *or trans*-Δ9-C18:1], a major monounsaturated trans fatty acid component of partially hydrogenated vegetable oils. Center: oleic acid [(*Z*)-9-octadecenoic acid or *cis*-Δ9-C18:1], the predominant monounsaturated fatty acid in olive oil. Bottom: stearic acid (octadecanoic acid or C18:0), a saturated fatty acid abundant in animal fats. The regions of interest are shown the boxes. The overall similarity in shape between the trans and saturated fatty acids is evident and helps to explain their similar effects in organisms. More subtle differences in geometry can account for other differences in the properties of cis and trans monounsaturated isomers and the corresponding saturated fatty acids. Figure by *Journal* staff.

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Although all the answers are not available, it appears prudent to follow the AHA and ASCN/AIN recommendations to use liquid oils when frying and tub (soft) margarines as spreads in order to limit intake of trans fatty acids.

Literature Cited

1. Lichtenstein, A. H. *Circulation* **1997,** *95*, 2588–2590.
2. Feldman, E. B.; Kris-Etherton P. M.; Kritchevsky, D.; Lichtenstein, A. H. *Am. J. Clin. Nutr.* **1996,** *63*, 663–670.
3. Stender, S.; Dyerberg, J.; Hølmer, G.; Ovesen, L.; Sandström, B. *Clin. Sci.* **1995,** *88*, 375–392.
4. Steinhart, C. *J. Chem. Educ.* **1996,** *73*, 302–303.
5. Pudel, F.; Denecke, P. *OCL—Oleagineaux Corps Gras Lipides* **1997,** *4*(1), 58–61.
6. Ip, C.; Marshall, J. R. *Nutr. Rev.* **1996,** *54*, 138–145.
7. Gillman, M. W.; Cupples, L. A.; Gagnon, D.; Millen, B. E.; Ellison, R. C.; Castelli, W. P. *Epidemiology* **1997,** *8*, 144–149.
8. Bolton-Smith, C.; Woodward, M.; Fenton, S.; Brown, C. A. *Eur. Heart J.* **1996,** *17*, 837–845.
9. Aro, A.; Jauhiainen, M.; Partanen, R.; Salminen, I.; Mutanen, M. *Am. J. Clin. Nutr*. **1997,** *65*, 1419–1426.
10. Khosla, P.; Hajri, T.; Pronczuk, A.; Hayes, K. C. *J. Nutr.* **1997,** *127*, 531S–536S.
11. Loffeld, B.; Keweloh, H. *Lipids* **1996,** *31*, 811–815.

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