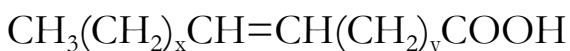


Fatty Acids—Monoenoic

In his classic studies on fatty acids from pork fat, Chevreul (1823) recognized the nature of oleic acid but it was not prepared in pure condition for a long time. Its structure was not definitively elucidated by a series of complex chemical reactions until later (*Baruch J, Ber 1894, 27, 172*). Much simpler proof of the now accepted structure of oleic acid was given by means of oxidation techniques (*Edmed FG, J Chem Soc 1898, 73, 627*). The ozonisation method for the determination of the position of the unsaturated linkage was used for the first time in lipidology in 1903 (*Molinari E, Annuario della Soc Chimica di Milano 1903, 9, 507*). Oleic acid synthesis was realized in 1934 (*Noller CR et al., J Am Chem Soc 1934, 56, 1563*).

Mono-unsaturated normal fatty acids are widespread in the living world where they occur mostly as the cis-isomer. Over a hundred naturally occurring monoene fatty acids have been identified. They have the general structure:



The most frequently they have an even number of carbon atoms and the unique double bond may be in a number of different positions.

The double bond can exist in two stereo isomeric forms :

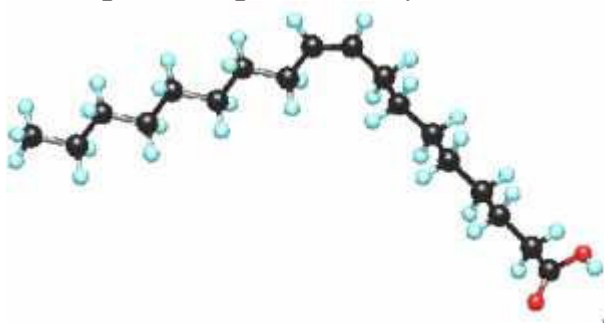
- the cis (or Z) configuration
- the trans (or E) configuration

CIS-MONOENOIC FATTY ACIDS

The commonest cis-monoenes are of the n-9 series, as oleic acid from olive oil (cis-9-octadecenoic acid) and from quite all seed oils. Some important monoenoic acids are found below:

Systematic name	Trivial name	Shorthand designation	Molecular wt.	Melting point (°C)
cis-4-decenoic	obtusilic	10:1(n-6)	170.3	
cis-9-decenoic	caproleic	10:1(n-1)	170.3	
cis-5-lauroleic	lauroleic	12:1(n-7)	198.4	
cis-4-dodecenoic	linderic	12:1(n-8)	198.4	
cis-9-tetradecenoic	myristoleic	14:1(n-5)	226.4	-
cis-5-tetradecenoic	physeteric	14:1(n-9)	226.4	
cis-4-tetradecenoic	tsuzuic	14:1(n-10)	226.4	
cis-9-hexadecenoic	palmitoleic	16:1(n-7)	254.4	0.5
cis-6-hexadecenoic	sapienic	16:1(n-10)	254.4	
cis-6-octadecenoic	petroselinic	18:1(n-12)	282.4	30
cis-9-octadecenoic	oleic	18:1(n-9)	282.4	16.2
tr-9-octadecenoic	elaidic	tr18:1(n-9)	282.4	43.7
cis-11-octadecenoic	vaccenic (ascleplic)	18:1(n-7)	282.4	39
cis-9-eicosenoic	gadoleic	20:1(n-11)	310.5	25
cis-11-eicosenoic	gondoic	20:1(n-9)	310.5	-
cis-11-docosenoic	cetoleic	22:1(n-11)	338.6	
cis-13-docosenoic	erucic	22:1(n-9)	338.6	33.4
cis-15-	nervonic	24:1(n-9)	366.6	39

- Oleic acid is probably the most common fatty acid (olive oil has a high content of this acid: about 60-70%, but it is also found in a large range of nuts). The major sources for human food are palm, rapeseed, soybean, butter, lard and tallow.



While this common fatty acid is mainly found acylated in glycerides, it may be found sometimes as ethyl esters in organs of animal treated with ethanol (*Hungund BL et al., J Chem Pharmacol 1988, 37, 3001*) and may serve as markers of ethanol intake. (*Laposata M, Prog Lipid Res 1998, 37, 307*).

The first synthesis of oleic acid appeared in the literature in 1934 (*Noller CR et al., J Am Chem Soc 1934, 56, 1563*).

Ethyl oleate was identified as a primer pheromone in honey bees in causing a delayed onset of foraging in younger individuals (*Leoncini I et al., PNAS 2004, 101, 17559*).

- Myristoleic acid is found in most animal depot fats from marine or terrestrial origin. It represents a major component of seed oil from Myristicaceae, some plant species containing up to 30 per cent of this fatty acid in addition to more important amounts of myristic acid. An isomeric form of myristoleic acid was discovered in dolphin and whale head oils (*Tsujimoto M, Chem Umschau 1925, 32, 202*) and was proved to be the 5-tetradecenoic acid. This uncommon (n-9) fatty acid was more recently described in the retina, acylating an NH₂ terminus of a

protein (recoverin) related to signal transduction in photoreceptors (*Dizhoor AM et al., J Biol Chem 1992, 267, 16033*). Furthermore, more recently, the presence of this fatty acid in plasma was shown to be of diagnostic value in patients with defects of long-chain fatty acid oxidation (*Onkenhout W et al., Clin Chem 1995, 41, 1467*).

- Palmitoleic acid is found mainly in animal fats, particularly in fish and marine mammals. This acid was first noticed in 1854 by Hofstädter PG (*Ann 1854, 91, 177*) in sperm whale oil and named physetoleic acid. Its exact molecular composition ($C_{16}H_{30}O_2$) was proposed in 1906 by Bull H (*Ber 1906, 39, 3570*) at the time when its actual name was given by Lewkowitsch. Its structure was established in 1925 (*Armstrong EF et al., J Soc Chem Ind 1925, 44, 180T*). It has been determined to be abundant in the Asclepediaceae *Asclepis syriaca* seed oil (10%) (*Chisholm MJ et al., Can J Chem 1960, 38, 2500*), in the Australian *Macademia ternifolia* seed oil (20%) (*Bridge RE et al., J Chem Soc 1950, 2396*), and in the Connaraceae *Roureopsis obliquifoliata* (32%) seed oil (*Spencer GF et al., JAOCS 1978, 55, 689*). Later, it was shown to characterize the seeds of all plants of the Proteaceae family (*Badami RC et al., Prog Lipid Res 1981, 19, 119*). The berry oil of *Hippophae rhamnoides* (Sea buckthorn) is known to be rich in palmitoleic acid (16-22%).
- Petroselinic acid is present as a major component (from 15 to 60%) in many species of Umbelliferae (parsley or coriander oilseeds) and Araliaceae (*Hedera helix*). Its presence was first noted in 1909 in parsley seed oil (*Vongerichten et al., Ber deutsch chem Ges 1909, 42, 1638*) and in the seeds of ivy (*Hedera*) (*Steger A et al., Rec Trav Chim 1928, 47, 471*) and its exact structure was determined. Within the Umbelliferae, it was shown that the genus *Thapsia* should be regarded as a useful source of petroselinic acid, which represents an important oleochemical material for the food, cosmetics, chemistry and pharmaceutical industries (*Avato P et al., Lipids 2001, 36, 845*). Petroselinic acid was also shown to be an important constituent of *Geranium sanguineum* (Geraniaceae) seed oil (about 48%) (*Tsevegsuren N et*

- al.*, *Lipids* 2004, 39, 571) and of sweet cicely (*Myrrhis odorata*, Umbelliferae) (82%).
- Vaccenic acid (from *Vacca* : cow), named also asclepic acid, was discovered in 1928 (*Bertram SH, Biochem Z* 1928, 197, 433) in animal fats and butter.
 - Gadoleic acid was first noted in cod liver oil (*Bull H, Ber* 1906, 39, 3570), present in marine fish, it originates from dietary crustacea. Its structure was given in 1933 (*Takano M J, Soc Chem Ind Japon* 1933, 36, 1317).
 - Nervonic acid, with 24 carbon atoms, was first believed to be characteristic of fats of Elasmobranch fish (first name: selacholeic acid) where it was discovered (*Tsujimoto M, J Soc Chem Ind Japon* 1927, 30, 868). In the same year, Klenk E (*Z physiol Chem* 1927, 166, 287) isolated this fatty acid from cerebrosides of brain tissue, and established its structure. This acid is also present in a Cruciferae (*Lunaria annua*) in high amounts (22-25%) where it can be suitable (together with erucic acid) for production of high-temperature lubricants and engineering nylons.
 - Erucic acid, with 22 carbon atoms, is found in high amounts (up to 50%) in seed oils of the Cruciferae such as *Nasturtium*, rape, mustard, *Lunaria* (38-48%) and of the Tropaeolaceae. Other species have been proposed as sources of erucic acid for nonfood applications, crambe (*Crambe abyssinica*) (about 60%) and meadowfoam (*Limnanthes alba*) (about 15%) but there has been no sustained production of these plants. This acid is used in the manufacture of polyethylene film.

Sapienic acid (16:1n-10), a 16-carbon fatty acid with a single cis double bond at the sixth carbon from the carboxyl end, is the most abundant fatty acid in human wax sebum, and among hair-bearing animals is restricted to humans (*Nicolaidis N, Science* 1974, 186, 19). Notably, this fatty acid has been implicated in the pathogenesis of acne (*Downing DT et al., J Am Acad Dermatol* 1986, 14, 221). Further works characterized its biosynthesis by a D-6 desaturase acting on palmitic acid (*Ge L et al., J Invest Dermatol* 2003, 120, 707).

An unusual 20 carbon fatty acid (20:1 n-15) is found in high concentration (about 60%) in seeds of *Limnanthes alba* (meadowfoam), an herbaceous winter annual plant native to the Pacific Northwest area of the United States.

Seeds of *Androsace septentrionalis* (Primulaceae) were shown to contain an unusual fatty acid : 16:1 n-5 (Tsevegsuren N *et al.*, *Lipids* 2003, 38, 1173).

An unusual monoene, lauroleic acid (12:1n-3) has been described as a natural metabolite of lauric acid (12:0) in rat hepatocytes (Legrand P *et al.*, *Lipids* 2002, 37, 569). This compound was formerly known to be present in milk lipids. An isomer (12:1n-8, linderic acid) has been found as the major fatty acid (47%) in the seed oil of a Lauraceae, *Lindera umbellata* (Hopkins CY *et al.*, *Lipids* 1961, 1, 118). This fatty acid is not known to occur in any other plant family.

No fatty acid exists naturally with the double bond close to the terminal methyl group, only one is chemically synthesized from ricinoleic acid, the undecylenic acid (11:1n-10).

TRANS-MONOENOIC FATTY ACIDS

One geometrical and several positional isomers of oleic acid exist with a trans double bond. Among the naturally occurring trans isomers, the double bond is in the (n-13), (n-12), (n-9) or (n-7) position.

Vegetable oils and fats are almost trans free, if not warmed at high temperature in the presence of active components. In contrast, trans fatty acids occur in most animal fats especially in butter and ruminant fats.

Among the most common, Elaidic acid (t9-octadecenoic acid) and t-vaccenic acid (t11-octadecenoic acid) are found in the rumen and in lipids of ruminant animals. Trans-vaccenic acid which is the major trans-monounsaturated fatty acid present in several food products

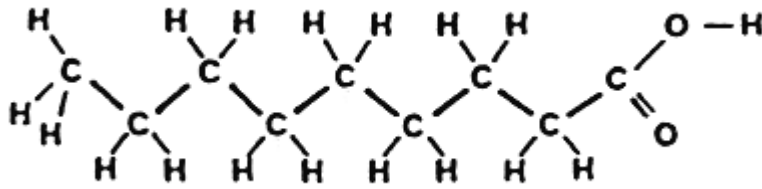
(milk, yoghurt, cheese, butter and meats) results from the bio-hydrogenation of rumenic acid.

The elaidinization reaction was first obtained by a French pharmacist, Poutet JJE (*Ann Chim Phys* 1819, 12, 58), who observed that trioleine could be converted to the consistency of pork lard when treated with the oxides of nitrogen derived from mercurous nitrate (mainly nitrous acid). Later, Boudet F (*Ann Chim Phys* 1832, 50, 391; *J Pharm* 1832, 18, 469) studied accurately the reaction and isolated after saponification of “elaidine” (obtained from triolein) a fatty acid melting at 36°C which he named “acide élaidique” (elaidic acid), from the Greek name of olive (elais, elaidos) .

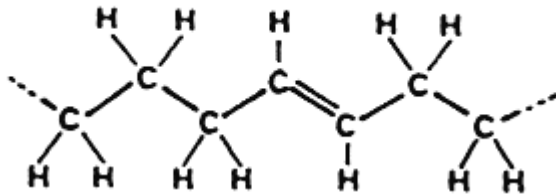
Until 1952, elaidic acid was known only as a laboratory isomerization product of oleic acid. This trans fatty acid was demonstrated by infrared analysis to be present in substantial quantities in beef fat (*Swern D et al., JAOCS* 1952, 29, 44). Later, it was shown that trans fatty acids arise in the first stomach of ruminants as products of catalytic hydrogenation of dietary unsaturated fatty acids (conjugated by an isomerase) during bacterial fermentation. As a result, butter, cheese, milk, beef and mutton fats contain approximately 2-8% trans fatty acids by weight.

Trans-fatty acids are also formed in varying amounts during the industrial hydrogenation of plant or fish oils. This hydrogenation improves the thermal stability and prevents any oxidative process in unsaturated oils. The natural kick found in cis-fatty acids disappears and the molecule becomes linear and thus has physical properties similar to saturated fatty acids as it was observed by Poutet in 1819.

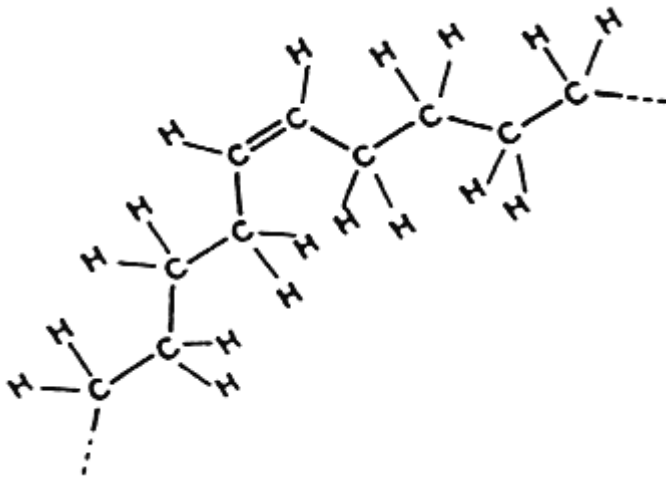
Trans-fatty acids are also formed under the action of thiyl radicals.
Saturated fatty acids



Trans-fatty acid



cis-fatty acid



An unusual trans fatty acid, t3-hexadecenoic acid (trans-16:1 n-13), occurs in eukaryotic photosynthetic membranes (mainly in phosphatidylglycerol) from higher plants and green algae. As this fatty acid is absent from etiolated tissue, it has been inferred that it has a specific role associated with the light reactions of photosynthesis (*Gounaris K et al., Biochem J 1986, 237, 313*).

Trans fatty acids are formed by some bacteria (predominantly gram

negative and under anaerobic conditions) via double-bond migration and isomerization.

The predominant 18:1 trans isomers in partially hydrogenated vegetal oils have their double bond in position t9, t10, t11 and t12, but their distribution (10-22% for t8, t9, t10, t11, t12 or t13 isomer) is distinct from that of milk fat, which contains (2-6% of the total fatty acids) vaccenic acid (t11-18:1) as the predominant isomer (about 60% of t11 and 4-8% for each of the others). The trans-18:1 acid content of beef meat fat and tallow are about 2 % and 5 %, respectively. Its presence in ruminant fats is explained by a biohydrogenation of linoleic acid occurring in the rumen.

The trans isomers account for about 4.5 % of total fatty acids in ewe milk fat and 3 % in goat milk fat. While the contribution of these two milk sources may be estimated as negligible in most EEC countries, in Greece ewe and goat milk fat contribute for about 45 % of the daily consumption of vaccenic acid.

The daily per capita intake of trans-18:1 acids from ruminant fats was estimated to be about 1.5 g for people from most countries of the EEC, Spain and Portugal being exceptions (about 0.8 g/person/day) (review in *Wolff RL, AOCS 1995, 72, 259*). An estimation of the trans fatty acid content of foods and intake levels in France has been reported in 2007 (*Laloux L et al., Eur J Lipid Sci Technol 2007, 109, 918*). A review of the possible effects of trans fatty acids on heart health and the recommendations for the UK population has been reported (*Denny AR, Nutr Bull 2008, 33, 124*).