

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

4,800

Open access books available

122,000

International authors and editors

135M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.

For more information visit www.intechopen.com



Fatty Acids and Emotional Behavior

Carlos M. Contreras^{1,2}, Ana G. Gutiérrez-García^{2,3}
and Diana Idania Vásquez-Hernández²

¹*Unidad Periférica Xalapa, Instituto de Investigaciones Biomédicas,
Universidad Nacional, Autónoma de México,
Xalapa, Veracruz,*

²*Laboratorio de Neurofarmacología, Instituto de Neuroetología,
Universidad Veracruzana,*

³*Facultad de Psicología, Universidad Veracruzana,
Xalapa, Veracruz,
Mexico*

1. Introduction

Fatty acids are widely distributed in nature. In addition to being found in plants and seeds, these organic compounds are present in other organisms, from unicellular protists to mammals, including humans. The anabolic and catabolic pathways of fatty acids have been identified. They have a well-known function as energy sources in metabolic processes and constitute a fundamental part of cellular membrane structures. Long-chain fatty acids also play a role in inflammatory process. Fatty acids exert their actions by modifying the fluidity of membranes, exerting marked actions on membrane ionic channels, and leading to a reduction in the excitability of cardiac myocytes, thus prompting interest in the study of fatty acids as protectors of cardiac function. Fatty acids exert similar actions on membrane neurons and the modulation of neurotransmission. The role of fatty acids in several psychiatric and neurologic conditions is a topic of current research. Fatty acid deficiency appears to be related to alterations in development, but the results from supplementary diet studies are far from conclusive. Interestingly, fatty acids are present in amniotic fluid, colostrum, and maternal milk in at least two mammalian species (i.e., pigs and humans) and according to both anecdotal and experimental reports appear to produce anxiolytic effects. Additionally, fatty acids exert effects when applied by the olfactory route. Odorant carrier proteins to olfactory receptors are present in maternal fluids and nasal mucosa epithelia. In newborns, fatty acids may also act as olfactory cues for feeding source seeking after exposure during prenatal life, which may constitute an additional function.

2. Overview

Lipids are organic compounds that are insoluble in water but soluble in nonpolar solvents, such as ether and chloroform. Some of these lipids naturally occur in the marine food chain. From an evolutionary ecological perspective, their presence in dinoflagelates, teleosts, amphibians, reptiles, birds, mammals, and humans is important (Crawford et al., 2009).

In mammals, the highest lipid concentrations occur in adipose tissue, followed by the central nervous system (Carrié et al., 2000). However, lipids are present in all cell types, where they contribute to cell structure and energy storage and participate in many biological processes, such as gene transcription, the regulation of metabolic pathways, and other physiological processes (Gurr et al., 2002).

The biological functions of lipids are as diverse as their chemistry. Fats and oils are the main forms of energy storage in many organisms, and phospholipids and sterols are the major structural elements of biological membranes. Other lipids, although present in relatively small amounts, play a crucial role in the composition of enzymatic cofactors, electron carriers, light pigments, membrane protein folding, digestive tract emulsifiers, hormones, and intracellular messengers (Nelson & Cox, 2005). Fatty acids are the main component of phospholipids, triglycerides, and cholesterol esters (Agostoni & Bruzzese, 1992).

2.1 Definition and classification

Fatty acids are aliphatic carboxylic acids composed of four to 36 carbon chains and a variable degree of unsaturation, ending in a carboxyl group (Berg et al., 2003; Nelson & Cox, 2005). The moiety of carbon chains can be short (2-4 carbons), medium (6-12 carbons), long (14-18 carbons), and very long (derived from 18 carbon molecules; Agostoni & Bruzzese, 1992). The hydrocarbon chain can be saturated or may have one or more double unsaturated bonds (Bézard et al., 1994). Based on the number of unstaurations, the hydrocarbon chain may constitute monounsaturated fatty acids (MUFA) or polyunsaturated fatty acids (PUFA; Agostoni & Bruzzese, 1992; Bézard et al., 1994). The classification of PUFA is based on the location of the last double-bond near the methyl end, yielding the typical location n-3 or n-6. However, mammals cannot introduce double-bonds between C-9 and the methyl end of fatty acids; thus, mammals are not able to synthesize n-3 or n-6 PUFA or convert n-3 PUFAs into n-6 PUFAs or vice versa (Bézard et al., 1994; Colin et al., 2003; Dobryniewski et al., 2007). Instead, n-3 and n-6 PUFA are derived from other fatty acids that act as precursors (Stulnig, 2003). n-3 and n-6 PUFA can be synthesized from the precursors linoleic acid (18:2) and α -linolenic acid (18:3), which in turn may be synthesized from shorter-chain fatty acids, such as palmitic acid (C16:0; Cunnane et al., 1995). Similarly, saturated fatty acids (SFA) and MUFA can be synthesized from acetate precursors (e.g., carbohydrates, glycogenic amino acids) and PUFA (Brenna et al., 2009).

2.2 General properties

Fatty acids are esters in natural fats and oils but also exist in non-esterified forms, such as free fatty acids, that circulate in the blood of vertebrates via noncovalent bonds with the carrier protein serum albumin. Typically, the most abundant fatty acids have carbon chains from 14 to 24 atoms, although the most abundant fatty acids contain 16 to 18 atoms. In nature, the most abundant are unsaturated fatty acids, followed by saturated, with double-bonds and a *cis* configuration (Berg et al., 2003; Nelson & Cox, 2005). The *cis* configuration can be converted to the *trans* form by catalytic heating. Saturated fatty acids are very stable, whereas unsaturated acids are susceptible to oxidation (i.e., the more double-bonds, the higher susceptibility to oxidation; Gurr et al., 2002).

2.3 Physical and chemical properties

The physical properties of fatty acids are related to the length of their carbon chain and unsaturation. The nonpolar characteristics of the hydrocarbon chain explain the poor solubility of fatty acids in water. The polar carboxylic acid group (ionized at neutral pH) explains the poor solubility of short-chain fatty acids in water (Berg et al., 2003; Nelson & Cox, 2005). Likewise, longer chains have a higher melting point. Unsaturated fatty acids have a melting point that is lower than that of saturated fatty acids of the same length (Berg et al., 2003; Nelson & Cox, 2005).

2.4 Anabolic processes

The biotransformation process of fatty acids has been summarized by Nelson and Cox (2005). The synthesis of fatty acids may occur by *de novo* synthesis or modification of the carbon chain (Gurr et al., 2002). In *de novo* synthesis, fatty acids are synthesized from pyruvate, the final product of glycolysis, with the participation of a three-carbon intermediary and malonyl-CoA, an irreversible catalytic product of acetyl-CoA (Gurr et al., 2002).

The assembly of the carbon chains of fatty acids occurs through a four-step sequence. A saturated acyl group is the substrate for subsequent condensation with an activated malonyl group. With each step of the cycle, the acyl chain is extended by two carbons. The cycle is completed with the formation of a chain of 16 carbons (i.e., palmitic acid [C16:0], an SFA). Carbons C-16 and C-15 from palmitic acid are derived from the carboxyl and methyl carbons, respectively, of an acetyl-CoA. Other carbons are derived from acetyl-CoA via malonyl-CoA. NADPH acts as a reducing agent, and the two SH groups that are bound to the enzyme are the active group. All reactions in the synthesis are catalyzed by a multienzymatic complex, fatty acid synthase.

Palmitic acid is the terminal product in fatty acid synthesis in animal cells and is the precursor SFA and MUFA through elongation of the carbon chain. Palmitic acid (16:0) can be elongated to form stearate (18:0) or a longer carbon chain through the addition of acetyl groups with the participation of elongase enzymes. The process occurs via two elongation systems located in the mitochondria and smooth endoplasmic reticulum from the liver, brain, and some other tissues (Gurr et al., 2002).

One of the most important functions of elongation is the conversion of essential fatty acids into PUFA (Gurr et al., 2002). However, these fatty acids cannot be synthesized by mammalian cells and must be obtained from the diet as linoleic acid (18:2) and α -linolenic acid (18:3) to be transformed into PUFA, such as dihomo- γ -linolenic acid (18:3), arachidonic acid (20:4), eicosapentaenoic acid (20:5), and docosahexaenoic acid (DHA; 22:6; Haggarty, 2002).

A second mechanism for the synthesis of fatty acids is desaturation (Gurr et al., 2002). Palmitic acid and stearic acid serve as the precursors of two of the most common MUFA in animal tissues (i.e., palmitoleic acid [16:1] and oleic acid [18:1]), which have a *cis* double-bond between C-9 and C-10. The double-bond is introduced into the fatty acid chain by an oxidative reaction with the participation of O₂, NADH, and three proteins: cytochrome b5, a

flavoprotein (cytochrome b5 reductase), and the enzyme acyl-CoA desaturase, which catalyzes the reaction and acts at specific positions in the fatty acid carbon chain (Sprecher et al., 1995). Mammals have two types of desaturases: stearoyl-CoA desaturase (which catalyzes the synthesis of MUFA) and A5D/A6D desaturases (which participate in the biosynthesis of PUFA; Sampath & Ntambi, 2005).

2.5 Catabolic processes

β -oxidation is the conversion of fatty acids to acetyl-CoA and is the main source of energy for most organisms. Its name derives from the position of the carbon attacked in the acyl chain, and the process occurs in the mitochondria and peroxisomes (Gurr et al., 2002). β -oxidation occurs in three stages. In the first stage, the fatty acids lose two carbon units by oxidative removal, starting from the carboxyl group and ending in the acyl chain. For example, palmitic acid undergoes seven steps in the oxidative sequence and at each step loses two carbons as acetyl-CoA. At the end of seventh cycle, the C-15 and C-16 palmitic acid carbons still remain as acetyl-CoA. The final result is the conversion of the 16-carbon chain of palmitic acid into eight two-carbon acetyl groups in acetyl-CoA molecules. The formation of acetyl-CoA requires the removal of four hydrogen atoms (two pairs of electrons and four H⁺) in the middle of the acyl group by dehydrogenases.

In the second stage of oxidation, the acetyl groups of acetyl-CoA are oxidized in the mitochondrial matrix into CO₂ in the citric acid cycle. Thus acetyl-CoA derived from fatty acids enters the final stage of the oxidation of acetyl-CoA derived from glucose via glycolysis and pyruvate oxidation. The first two stages of oxidation produce NADH and FADH₂, which in the third stage donate electrons to the respiratory chain, and electrons pass to oxygen, resulting in the phosphorylation of ADP to ATP; thus, the result of the β -oxidation of fatty acids is ATP.

2.6 Physiological role

Fatty acids are involved in energetic, metabolic, and structural processes. Short-chain fatty acids act as growth factors. Long saturated chains are a source of energy, and long-chain unsaturated chains participate in fundamental metabolic processes (Agostoni & Bruzzese, 1992), such as the synthesis of eicosanoids, which are closely related to inflammatory processes (Mesa-García et al., 2006; Zamaria, 2004), the modulation of enzymatic activity, the activation of nuclear transcription factors, and the formation of free radicals in response to oxidative stress (Zamaria, 2004).

Very long-chain molecules constitute biological membranes and participate in development (Agostoni & Bruzzese, 1992). n-3 PUFA (linolenic acid) and n-6 PUFA (linoleic acid; Bézard et al., 1994; Colin et al., 2003; Sardesai, 1992; Sinclair, 1984) are structural components of all tissues and indispensable for the synthesis of the cell membrane (Uauy et al., 2000).

2.7 Mechanism of action on excitable tissues

Fatty acids accumulate in membrane phospholipids near the ion channel, which alters the tension of the membrane, causes conformational changes in the ion channel, and consequently alters its conductance (Leaf et al., 2002). Two forms of Na⁺/K⁺-ATPase

catalytic subunits are present in the nervous system. The α form is present in astrocytes, glial cells, and other tissues and is seemingly related to K^+ clearance. The $\alpha+$ subunit is present in neuronal tissue, possesses high affinity for cardiac glycosides, is stimulated by biogenic amines, and participates in Na^+ and K^+ transport. In addition to the well known role of the Na^+/K^+ pump in resting membrane potential, it also participates in the differentiation of nerve cells during neurulation (Stahl, 1986). The modulation of membrane protein function by molecules that possess both hydrophilic and hydrophobic ends has been ascribed to changes in bilayer fluidity and alterations in bilayer stiffness. For example, *N*-type calcium channels may be modulated by a decrease in bilayer stiffness (Lundbaek et al., 1996).

Because of the reputation of PUFA as cardiac protectors, many studies have explored the action of fatty acids on cardiac myocytes. In these cells, n-3 and n-6 PUFA (DHA, α -linolenic acid, arachidonic acid, and linoleic acid) but not *trans* MUFA or SFA reduce Na^+ currents (Xiao et al., 1995). Free PUFA modulate voltage-sensitive Na^+ channels through the inhibition of agonist binding to the Na^+ channel protein in a dose-dependent, saturable, reversible, and allosteric manner (Kang & Leaf, 1996) but do not upregulate cardiac Na^+ channel expression in the long-term (Kang et al., 1997). Although PUFA may produce supraventricular and ventricular arrhythmias, its anti-arrhythmic properties are attributable to inhibition of Na^+ voltage-dependent currents, leading to hyperpolarization and reducing the availability and release of Ca^{2+} and sharing some actions with lidocaine (Lombardi & Terranova, 2007; Xiao et al., 1997, 1998). In other tissues, such as human fetal tracheal cells, *cis* PUFA and MUFA (e.g., arachidonic acid, linoleic acid, and oleic acid) but not SFA (e.g., stearic acid, palmitic acid, and myristic acid) modulate Cl^- channel activity by interrupting the open channel current (Hwang et al., 1990). In smooth muscle cells, arachidonic acid, oleic acid, myristic acid, and linoleic acid but not myristoleic acid, caprylic acid, or palmitic acid activate K^+ currents (Ordway et al., 1989; Robertson & Steinberg, 1990), also producing hyperpolarization.

The motor cortex of the human brain contains primarily long-chain fatty acids, such as arachidonic acid (C20:4n-6) and DHA (C22:6n-3). Other shorter-chain fatty acids are more likely to be involved in vascular blood flow, and eicosanoid activity involved in responses to injury. In animals, through alternative processes of desaturation and elongation, arachidonic acid may be formed from linoleic acid (18:2n-6), and DHA may be formed from α -linolenic acid (18:3n-3) but in a relatively inefficient manner because of the characteristics of being rate limited and very slow. Therefore, its ingestion in the diet seems to be crucial. Double-blind, controlled studies are needed before reaching conclusions about the properties of PUFA as cardiac protectors.

Intriguing results have been found regarding the actions of fatty acids in nervous tissue. Fatty acids regulate ion channels (Ordway et al., 1991) and can be delivered to the cells from extracellular sources, such as albumin and lipoproteins (Ordway et al., 1991). Fatty acids can enter the brain and exert their effects on neurons when administered systemically (Lauritzen et al., 2000). PUFA easily cross the blood-brain barrier and accumulate in neuronal membranes (Robinson & Rapoport, 1986). Arachidonic acid and other fatty acids regulate ion channels themselves through direct action or indirectly through their metabolites (Ordway et al., 1991). Likewise, at least one *cis* MUFA (oleic acid), one n-6 PUFA

(arachidonic acid), and one n-3 PUFA (DHA) increase the binding of [³H]diazepam to the benzodiazepine/ γ -aminobutyric acid (GABA) receptor (Nielsen et al., 1988). Long-term ethanol or diazepam administration increases the proportions of plasma SFA and MUFA and decreases PUFA (Ristic et al., 1995). Therefore, some anxiolytic action may be expected.

The inhibition of GABA neurotransmission by arachidonic acid or its peroxidized metabolites contributes to the pathogenesis of ischemia-perfusion neuronal injury because the accumulation of these n-3 PUFA (but not SFA) inhibits GABA-mediated neuronal inhibition, leading to increased neuronal excitability (Schwartz & Yu, 1992). This may be related to the observation that barbiturates produce a Ca²⁺-dependent decrease in Cl⁻ flux through the GABA_A receptor, which is reduced by phospholipase A2 (Schwartz et al., 1988), leading to the increased formation of oxygen free radicals and consequently apoptosis. Interestingly, in the hippocampus, arachidonic acid helps maintain membrane fluidity (Fukaya et al., 2007) and enhances synaptic transmission (Williams et al., 1989). PUFA but not MUFA or SFA inactivate Na⁺ currents, reducing neuronal firing and increasing their refractory period in CA1 neurons (Vreugdenhil et al., 1996).

In neuroblastoma/glioma hybrid cell culture studies, PUFA (e.g., linoleic acid, linolenic acid, and arachidonic acid) decrease Na⁺ action potentials. One *trans* MUFA (i.e., oleic acid) does not produce such changes, and one SFA (i.e., palmitic acid) and one *trans* MUFA (i.e., elaidic acid) increase the frequency and amplitude of action potentials without influencing resting membrane potentials, Ca²⁺ action potentials, or membrane capacitance (Love et al., 1985).

Arachidonic acid also appears to modulate the activity of cytosolic protein kinase C by selective induction of phosphorylation, modulating transmembrane signaling (Khan et al., 1991). The fluidity of the acyl chains of fatty acids present in the bulk of membrane phospholipids modulates enzymatic activity (Harris, 1985).

In summary, n-3 PUFA modify some membrane functions, such as ion channel modulation, by increasing membrane fluidity (Simopoulos, 1999). The ion channel modulation exerted by fatty acids is very similar to that produced by local anesthetics, such as lidocaine (Bean et al., 1983), and some anticonvulsant drugs, such as phenytoin (Rogawski & Porter, 1990; Schwartz & Grigat, 1989). The activation of several neurotransmitter receptors, such as dopamine D₂, 5-hydroxytryptamine-3, and opioids, alters the membrane flux of K⁺ (Drukarch et al., 1989; Miyake et al., 1989). Some of the known effects of DHA include changes in membrane fluidity and stability (Litman et al., 2001), changes in dopaminergic and serotonergic transmission (Chalon et al., 2001; Zimmer et al., 2000, 2002), and the regulation of membrane-bound enzymes and cellular signal transduction (McNamara et al., 2006; Vaidyanathan et al., 1994).

2.8 Clinical aspects

The role of essential fatty acids in mammals was long been unknown, but more similarities than discrepancies appear to exist between the general actions of SFA, MUFA, and PUFA on diet pleasantness, visual appearance, smell, taste, aftertaste, and palatability, subjective hunger ratings, and energy intake in healthy males (Strik et al., 2010). Differences can be found with regard to undesirable effects. With regard to cholesterolemia, no differences

were found between diets rich in MUFA and PUFA, but a SFA-rich diet produced the highest cholesterol concentrations (Trautwein et al., 1999). Decades ago, fatty acids were perceived as precursors for the biosynthesis of other substances (e.g., those related to inflammatory processes) and other fatty acids (Friesen & Innis, 2006) that are components of the cell membrane (Carrié et al., 2000) may participate in many functional processes (Kidd, 2007).

2.9 Development

Docosahexaenoic acid is the main n-3 PUFA found in the phospholipid fraction of the brain and has been implicated in the prenatal and postnatal development of the retina and brain (Hamazaki et al., 1996; McCann & Ames, 2005; SanGiovanni et al., 2000). Deficiencies in DHA during development are related to deficits in the structure of the retina, impairing visual acuity and cognitive function (Crawford, 1993; Neuringer et al., 1986; Reissbick et al., 1997).

During pregnancy, dietary *trans* fatty acids (e.g., elaidic acid) produce deleterious effects on health. The most abundant long-chain fatty acids in breast milk are DHA and arachidonic acid. Supplementation with marine oil products does not produce adverse effects and improves sensorial function and other cognitive functions after birth (Brenna & Lapillonne, 2009). Supplementation with DHA in infants that are less than 1 year old improves seeking behavior that later it is related to increased exploratory activity and less distractibility (Colombo et al., 2004). A DNA microarray study of the brain in rats subjected to different diets that contained different amounts of n-3 PUFA found some deficiencies in the expression of several genes, which became up- or downregulated and were related to the expression of cytochrome c and tumor necrosis factor (Kitajka et al., 2004). Maternal dietary SFA may produce persistent alterations in Na⁺,K⁺-ATPase function in the offspring, which could increase the risk of adulthood disease (Armitage et al., 2008).

2.10 Cognitive impairment

Decreased plasma levels of n-6 PUFA have been associated with physical rather than cognitive or behavioral ailments (Richardson, 2006). Deficiencies in DHA and eicosapentaenoic acid are involved in behavioral problems, such as attention deficit hyperactivity disorder, autism, dyspraxia, dyslexia, and aggression (Richardson, 2006; Stevens et al., 1996), and affective disorders, such as major depressive disorder, bipolar disorder, schizophrenia, and personality disorder. Evidence of altered PUFA status in mental illness, however, is weak. Reports of symptom improvement after PUFA consumption included patients with previous generalized dietary deficiencies of fatty acids (Liperoti et al., 2009; Milte et al., 2009) or other deleterious lifestyle habits (Suominen-Taipale et al., 2010), thus contaminating the interpretation of the data. n-3 PUFA supplementation appears to be effective only in depressive or Alzheimer's carriers of non-apolipoprotein E epsilon4 (Solfrizzi et al., 2010). In animal models of Alzheimer's disease, SFA and n-3 PUFA, including arachidonic acid, produced higher secretion of both A β -40 and -42 peptides compared with long-chain downstream omega-3 and MUFA. Lower levels of A β and amyloid plaques in the brain were observed when the subjects were fed a low-fat diet enriched with DHA (Amtul et al., 2011).

Some promising reports of the beneficial effects of n-3 PUFA on Alzheimer's disease and Huntington's disease showed that fatty acids appear to be devoid of any effect on cognition, aggression, hostility, and social behavior (Crawford et al., 2009).

2.11 Depression

Reports of the effects of fatty acids on depression have been controversial. For example, in an open-label study, juvenile bipolar disorder patients received supplementary eicosapentaenoic acid and DHA in their diet and exhibited a reduction in their clinical symptoms (Clayton et al., 2009). However, diets enriched with DHA failed to prevent postpartum depression in a randomized controlled trial (Makrides et al., 2010).

However, some intriguing results have been found. Membrane viscosity plays a role in the molecular bases of depression and other disorders and mediates the pharmacology of serotonin. Depression has been associated with low lipid raft viscosity (Cocchi et al., 2010a). The hydroxytryptophan transporter responsible for serotonin reuptake may be the functional locus for depression (Rosen, 2009), and an inverse relationship has been found between arachidonic acid content in neural tissue and the accessibility of serotonin to its receptors. However, an increase in arachidonic acid in brain tissue reduced membrane viscosity (i.e., increased fluidity; Cocchi et al., 2010b), reducing the accessibility of serotonin to its receptors (Heron et al., 1980). The brains of Flinders Sensitive rats, an animal model of depression, contain high concentrations of arachidonic acid (Green et al., 2005).

2.12 Calming effects of maternal biological fluids

Some odors can elicit a sense of family and home safety in adult mammals. Schapiro and Salas (1970) demonstrated that exposure to maternal odors in rat pups before weaning reduced the movements of pups. Oswalt and Meier (1975) found that infant rats reduce their emission of ultrasonic vocalizations when exposed to maternal odors. Therefore, maternal litter or home odors produce signs of calm. In contrast, kittens, pups, and human babies exhibit increased agitation and vocalizations when placed in an unfamiliar environment, but when they return to their nest or close proximity to their mother, both familiar odors, they calm down (Christensson et al., 1995; Michelsson et al., 1996; Schaal, 1988). The application of amniotic fluid odor to the nose significantly reduced crying in human babies when they were separated from their mothers (Varendi et al., 1998). Sullivan and Toubas (1998) suggested that maternal odors could be used to calm and reduce crying in babies. These fluids may be used to promote the acceptance of nipple feeding (Sullivan & Toubas, 1998) because breast milk odors (Rattaz et al., 2005) and milk odor (Nishitani et al., 2009) produce signs of calm. Olfactory exposure to maternal biological fluids (i.e., amniotic fluid, colostrum, and breast milk) appears to promote breastfeeding (Winberg & Porter, 1998).

Any odorant molecule requires a binding carrier protein with high affinity for membrane olfactory receptor neurons (Pelosi, 2001). Guiraudie-Capraz et al. (2005) used gas chromatography-mass spectrometry (GC-MS) to identify seven fatty acids (i.e., linoleic acid, palmitic acid, lauric acid, capric acid, myristic acid, palmitoleic acid, and oleic acids) in breast milk, colostrum, and amniotic fluid in pigs. Three carrier proteins were found not only in amniotic fluid, colostrum, and milk, but also in nasal mucosa and the vomeronasal organ, which seemingly mediate the fatty acid-induced initiation of perception (Guiraudie-

Capraz et al., 2003; Tegoni et al., 2000) with different affinities (Guiraudie-Capraz et al., 2003). Therefore, these proteins participate in the detection of chemical and biochemical signals, at least in pigs (Guiraudie-Capraz et al., 2005). Notably, these proteins have also been found in human amniotic fluid (Liberatori et al., 1997) and colostrum (Murakami et al., 1998), suggesting the stimulation of olfactory receptors very early in life, even during intrauterine life.

2.13 Fatty acids and anxiety

Few studies have compared the effects of n-3 and n-6 fatty acids on behavior. Although better results have been found in animals that received n-3 fatty acids than n-6 fatty acids (Wainwright, 1992), the absence of control groups prevents the acceptance of the results. Another study sought to find a relationship between essential fatty acids and behavior. Nakashima et al. (1993) used the elevated plus maze to assess anxiolytic-like behavior in rodents. In this study, linoleic acid produced a trend toward anxiolysis compared with α -linolenic acid, but this study also lacked a control group.

In humans, Mamalakis et al. (1998) did not find any relationship between linoleic acid and myristic acid and anxiety measured with the Spielberg scale or trait anxiety measured and Zung scales. However, they detected a positive relationship between trait anxiety scores and the linoleic acid + α -linolenic acid / DHA + arachidonic acid ratio (Mills et al., 1994). However, a mixture of PUFA may reduce anxiety scores, reflected by increased appetite, increased sense of humor, increased strength, decreased fatigue, increased academic performance, decreased lack of sleep, and decreased plasma cortisol (Yehuda et al., 2005).

Pageat (2001) patented a product whose active ingredient is a mixture of fatty acids that has been used to decrease stress, anxiety, and aggression in mammals, such as pigs, dogs, cats, and even children, and reduce anxiety signs when the animals are separated from their mother or in an unfamiliar place. The same formulation was tested by McGlone and Anderson (2002) on weight gain, feeding efficiency, and agonistic behavior in piglets.

We recently used GC-MS to demonstrate that human amniotic fluid, colostrum, and maternal milk consistently contain eight fatty acids (Mendoza-López et al., 2010). Both human amniotic fluid and an artificial mixture of the same proportion of fatty acids produced anxiolytic effects comparable to diazepam in Wistar rats subjected to validated tests that measure anxiety, including the defensive burying test and elevated plus maze. We concluded that amniotic fluid and its fatty acids have anxiolytic effects (Contreras et al., 2011).

2.14 Fatty acids as feeding cues

Newborns are attracted to odors that come from their mother's breast (Porter & Winberg, 1999), milk, colostrum (Nowak et al., 2000), and amniotic fluid (Porter & Winberg, 1999; Schaal et al., 1998). This behavior could be related to the fact that during the last trimester, the odorants in amniotic fluid are in close contact with nasal chemoreceptors. Newborn infants may retain an olfactory memory of these odors and later respond to these signals during the early postnatal period (Hepper, 1995).

Amniotic fluid is a complex mixture of fetal and maternal fluid (Lev & Orlic, 1972). Its composition varies according to gestational age and the evolution of maternal-fetal

exchange. During early pregnancy, amniotic fluid is predominantly an ultrafiltrate of maternal serum. During late pregnancy, fetal urine is the main constituent of amniotic fluid (Loughhead et al., 2006).

Newborns oriented longer time to the odor of their own amniotic fluid compared with an unscented control (Schaal et al., 1995; Varendi et al., 1996). Recently, Contreras et al. (2011) analyzed the amniotic fluid, colostrum, and breast milk of 15 volunteer women. Eight fatty acids were consistently found in measurable amounts in the three biological fluids, including lauric acid, myristic acid, palmitic acid, palmitoleic acid, stearic acid, oleic acid, elaidic acid, and linoleic acid. The total amounts of fatty acids were different in each fluid, with the lowest amount found in amniotic fluid, followed by colostrum and milk. These results suggest that similar to other mammalian species (Guiraudie-Capraz et al., 2005; Pageat, 2001), some fatty acids present in biological fluids could serve as sensory cues of maternal and child identification. Additionally, newborns younger than 24 h preferentially orientated toward their own amniotic fluid and an artificial mixture of similar fatty acids (Díaz-Martel et al., 2010). This suggests that the first recognition of odors occurs during intrauterine life. Some of the fatty acids present in amniotic fluid could be a source of prenatal sensory stimulation, and colostrum odor is a bridge between amniotic fluid and milk (Contreras et al., 2011), thus leading to feeding behavior. Therefore, fatty acids could act as feeding cues, leading to appetitive behavior.

3. Conclusions

1. The functions of fatty acids as energy sources and their structural role in cellular membranes and as precursors of inflammatory processes are well known.
2. Fatty acids may modify the fluidity of the lipid membrane of cardiac and neuronal cells, impinging on ion channel permeability and decreasing cellular excitability. These conformational changes in the membrane may also modulate some neurotransmitter functions.
3. Decreased excitability produced by long-chain PUFA is related to some beneficial effects on cardiac function.
4. Similar actions on cardiac cell membranes appear to occur in neurons, in addition to neurotransmitter modulation. Some clinical studies of the therapeutic effects of fatty acids on neurological and psychiatric diseases have been conducted, but most of these studies need to be replicated using double-blind controlled designs before definitive conclusions can be made.
5. Fatty acids are components of amniotic fluid, colostrum, and milk and produce some anxiolytic effects.
6. The sensorial process of odor recognition related to fatty acids has been identified.
7. Fatty acids in maternal-fetal fluids appear to act as feeding cues that guide newborns to the maternal breast.

4. Acknowledgments

The authors thank Michael Arends for revising and editing the English of this manuscript. This study was partially supported by a grant from the Consejo Nacional de Ciencia y Tecnología, México (CONACyT: CB-2006-1, 61741) and Proyecto PAPITT-UNAM IN211111.

5. References

- Agostoni, C. & Bruzzese, M.G. (1992). Fatty acids: their biochemical and functional classification. *La Pediatria Medica e Chirurgica: medical and surgical pediatrics*, Vol.14, No.5, (September-October 1992), pp. 473-479, ISSN 0391-5387
- Amtul, Z.; Uhring, M.; Rozmahel, R.F. & Bevreuther, K. (2011). Structural insight into the differential effects of omega-3 and omega-6 fatty acids on the production of A β peptides and amyloid plaques. *Journal of Biological Chemistry*, Vol. 286, No.8, (February 2011), pp. 6100-6107, ISSN 1083-351X
- Armitage, J.A.; Gupta, S.; Wood, C.; Jensen, R.I; Samuelsson, A.M; Fuller, W.; Shattock, M.J.; Poston, L. & Taylor, P.D. (2008). Maternal dietary supplementation with saturated, but not monounsaturated or polyunsaturated fatty acids, leads to tissue-specific inhibition of offspring Na⁺,K⁺-ATPase. *Journal of Physiology*, Vol. 586, No.Pt 20, (October 2008), pp. 5013-5022, ISSN 1469-7793
- Bean, B.P.; Cohen, C.J. & Tsien, R.W. (1983). Lidocaine block of cardiac sodium channels. *Journal of General Physiology*, Vol. 81, No. 5, (May 1983), pp. 613-642, ISSN 1540-7748
- Berg, J.M.; Tymoczko, J.L. & Stryer, L. (2003). *Bioquímica*, 5th ed, Reverté, ISBN 0-06-097550-4, Barcelona, España
- Bézar, J.; Blond, J.P.; Bernard, A. & Clouet, P. (1994). The metabolism and availability of essential fatty acids in animal and human tissues. *Reproduction Nutrition Development*, Vol.34, No.6, pp. 539-568, ISSN 1297-9708
- Brenna, J.T. & Lapillonne, A. (2009). Background paper on fat and fatty acid requirements during pregnancy and lactation. *Annals of Nutrition & Metabolism*, Vol.55, No.1-3, (September 2009), pp. 97-122, ISSN 1421-9697
- Brenna, J.T.; Salem, N. Jr.; Sinclair, A.J. & Cunnane, S.C. (2009). α -Linolenic acid supplementation and conversion to n-3 long-chain polyunsaturated fatty acids in humans. *Prostaglandins Leukotrienes & Essential Fatty Acids (PLEFA)*, Vol.80, No.2-3, (February & March 2009), pp. 85-91, ISSN 0952-3278
- Carrié, I.; Clément, M.; de Javel, D.; Francès, H. & Bourre, J.M. (2000). Phospholipid supplementation reverses behavioral and biochemical alterations induced by n-3 polyunsaturated fatty acid deficiency in mice. *Journal of Lipid Research*, Vol.41, No.3, (March 2000), pp. 473-480, ISSN 1539-7262
- Chalon, S.; Vancassel, S. ; Zimmer, L. ; Guilloteau, D. & Durand, G. (2001). Polyunsaturated fatty acids and cerebral function: focus on monoaminergic neurotransmission. *Lipids*, Vol.36, No.9, (September 2001), pp. 937-944, ISSN 1558-9307
- Christensson, K.; Cabrera, T.; Christensson, E.; Uvnäs-Moberg, K. & Winberg, J. (1995). Separation distress call in the human neonate in the absence of maternal body contact. *Acta Paediatrica*, Vol.84, No.5, (May 1992), pp. 468-473, ISSN 1651-2227
- Clayton, E.H.; Hanstock, T.L.; Hirneth, S.J.; Kable, C.J.; Garg, M.L. & Hazell, P.L. (2009). Reduced mania and depression in juvenile bipolar disorder associated with long-chain omega-3 polyunsaturated fatty acid supplementation. *European Journal of Clinical Nutrition*, Vol.63, No.8, (August 2009), pp. 1037-1040, ISSN 0954-3007
- Cocchi, M.; Gabrielli, F.; Tonello, L. & Pregnolato, M. (2010a). The interactome hypothesis of depression. *NeuroQuantology*, Vol.8, No.4, (December 2010), pp. 603-613, ISSN 1303-5150

- Cocchi, M.; Tonello, L. & Lercker, G. (2010b). Fatty acids, membrane viscosity, serotonin and ischemic heart disease. *Lipids in Health & Disease*, Vol.8, No.9, (September 2010), pp. 97, ISSN 1476-511X
- Colin, A.; Reggers, J.; Castronovo, V. & Anseau, M. (2003). Lipids, depression and suicide. *L'Encéphale*, Vol.29, No.1, (January & February 2003), pp. 49-58, ISSN 0013-7006.
- Colombo, J.; Kannass, K.N.; Shaddy, D.J.; Kundurthi, S.; Maikranz, J.M.; Anderson, C.J.; Blaga, O.M. & Carlson, S.E. (2004). Maternal DHA and the development of attention in infancy and toddlerhood. *Child Development*, Vol.75, No.4, (July & August 2004), pp. 1254-1267, ISSN 1467-8624
- Contreras, C.M.; Rodríguez-Landa, J.F.; Gutiérrez-García, A.G.; Mendoza-López, R.; García-Ríos, R.I. & Cueto-Escobedo, J. (2011). Anxiolytic-like effects of human amniotic fluid and its fatty acids in Wistar rats. *Behavioural Pharmacology*, Vol.22, No.7, (October 2011), pp. 655-662, ISSN 1473-5849
- Crawford, M.A.; Bazinet, R.P. & Sinclair, A.J. (2009). Fat intake and CNS functioning: ageing and disease. *Annals of Nutrition & Metabolism*, Vol.55, No.1-3, (September 2009), pp. 202-228, ISSN 1421-9697
- Crawford, M.A. (1993). The role of essential fatty acids in neural development: implications for perinatal nutrition. *The American Journal of Clinical Nutrition*, Vol.57, No.5 Suppl, (May 1993), pp. 703S-709S, ISSN 1938-3207
- Cunnane, S.C.; Ryan, M.A.; Craig, K.S.; Brookes, S.; Koletzko, B.; Demmelmair, H.; Singer, J. & Kyle, D.J. (1995). Synthesis of Inoleate and α -linoleated by chain elongation in the rat. *Lipids*, Vol.30, No.8, (August 1995), pp. 781-783, ISSN 1558-9307
- Díaz-Marte, C.; Gutiérrez-García, A.G.; Mendoza-López, M.R. & Contreras, C.M. (2010). Recién nacidos despliegan movimientos de orientación hacia su líquido amniótico y algunos ácidos grasos. *Rev Med UVV*, Vol.10, No.2, (July-December 2010), pp. 6-10, ISSN 1870-3267
- Dobryniewski, J.; Szajda, S.D.; Waszkiewicz, N. & Zwierz, K. (2007). Biology of essential fatty acids (EFA). *Przegląd Lekarski*, Vol.64, No.2, pp. 91-99, ISSN 0033-2240
- Drukarch, B.; Schepens, E.; Schoffemeer, A.N. & Stoof, J.C. (1989). Stimulation of D-2 dopamine receptors decreases the evoked in vitro release of [3 H]acetylcholine from rat neostriatum: role of K^+ and Ca^{2+} . *Journal of Neurochemistry*, Vol.52, No.6, (June 1989), pp. 1680-1685, ISSN 1471-4159
- Friesen, R. & Innis S.M. (2006). Maternal dietary fat alters amniotic fluid and fetal intestinal membrane essential n-6 and n-3 fatty acids in the rat. *American Journal of Physiology Gastrointestinal & Liver Physiology*, Vol.290, No.3, (March 2006), pp. G505-G510, ISSN 1522-1547
- Fukaya, T.; Gondaira, T.; Kashiya, Y.; Kotani, S.; Ishikura, Y.; Fujikawa, S.; Kiso, Y. & Sakakibara, M. (2007). Arachidonic acid preserves hippocampal neuron membrane fluidity in senescent rats. *Neurobiology of Aging*, Vol.28, No.8, (August 2007), pp. 1179-1186, ISSN 0197-4580
- Green, P.; Gispan-Herman, I. & Yadid, G. (2005). Increased arachidonic acid concentration in the brain of Flinders Sensitive Line rats, an animal model of depression. *Journal of Lipid Research*, Vol.46, No.6, (June 2005), pp. 1093-1096, ISSN 1539-7262

- Guiraudie-Capraz, G. ; Pageat, P. ; Cain, A.H. ; Madec, I. & Nagnan-Le Meillour, P. (2003). Functional characterization of olfactory binding proteins for appeasing compounds and molecular cloning in the vomeronasal organ of pre-pubertal pigs. *Chemical Senses*, Vol.28, No.7, (September 2003), pp. 609-619, ISSN 1464-3553
- Guiraudie-Capraz, G. ; Slomianny, M.C. ; Pageat, P. ; Malosse, C. ; Cain, A.H. ; Orgeur, P. & Nagnan-Le Meillour, P. (2005). Biochemical and chemical supports for a transnatal olfactory continuity through sow maternal fluids. *Chemical Senses*, Vol.30, No.3, (March 2005), pp. 241-251, ISSN 1464-3553
- Gurr, M.I.; Harwood, J.L. & Frayn, K.N. (2002). *Lipid biochemistry: an introduction*, 5th ed, Blackwell Science, ISBN 0632054093, Oxford, United Kingdom
- Haggarty, P. (2002). Placental regulation of fatty acid delivery and its effect on fetal growth: a review. *Placenta*, Vol.23, No.Suppl A, (April 2002), pp. S28-S38, ISSN 0143-4004
- Hamazaki, T.; Sawazaki, S.; Itomura, M.; Asaoka, E.; Nagao, Y.; Nishimura, N.; Yazawa, K., Kuwamori, T. & Kobayashi, M. (1996). The effect of docosahexaenoic acid on aggression in young adults: a placebo-controlled double-blind study. *Journal of Clinical Investigation*, Vol.97, No.4, (February 1996), pp. 1129-1133, ISSN 00219738
- Harris, W.E. (1985). Modulation of (Na⁺,K⁺)-ATPase activity by the lipid bilayer examined with dansylated phosphatidylserine. *Biochemistry*, Vol.24, No.12, (June 1985), pp. 2873-2883, ISSN 0264-6021
- Hepper P.G. (1995). Human fetal olfactory learning. *International Journal of Prenatal & Perinatal Psychology and Medicine*, Vol.7, No.2, (June 1993-2002), pp. 147-151, ISSN 0943-5417
- Heron, D.S.; Shinitzky, M.; Hershkowitz, M. & Samuel, D. (1980). Lipid fluidity markedly modulates the binding of serotonin to mouse brain membranes. *Proceeding of the National Academic of Sciences of the United States of the American*, Vol.77, No.12, (December 1980), pp. 7463-7467, ISSN 1091-6490
- Hwang, T.C.; Guggino, S.E. & Guggino, W.B. (1990). Direct modulation of secretory chloride channels by arachidonic and other cis unsaturated fatty acids. *Proceeding of the National Academic of Sciences of the United States of the American*, Vol.87, No.15, (August 1990), pp. 5706-5709, ISSN 1091-6490
- Kang, J.X. & Leaf, A. (1996). Evidence that free polyunsaturated fatty acids modify Na⁺ channels by directly binding to the channel proteins. *Proceeding of the National Academic of Sciences of the United States of the American*, Vol.93, No.8, (April 1996), pp. 3542-3546, ISSN 1091-6490
- Kang, J.X.; Li, Y. & Leaf, A. (1997). Regulation of sodium channel gene expression by class I antiarrhythmic drugs and n - 3 polyunsaturated fatty acids in cultured neonatal rat cardiac myocytes. *Proceeding of the National Academic of Sciences of the United States of the American*, Vol.94, No.6, (March 1997), pp. 2724-2728, ISSN 1091-6490
- Khan, W.; el Touny, S. & Hannun, Y.A. (1991). Arachidonic and cis-unsaturated fatty acids induce selective platelet substrate phosphorylation through activation of cytosolic protein kinase C. *FEBS Letters*, Vol.292, No.1-2, (November 1991), pp. 98-102, ISSN 0014-5793
- Kidd, P.M. (2007). Omega-3 DHA and EPA for cognition, behavior, and mood: clinical findings and structural-functional synergies with cell membrane phospholipids.

- Alternative Medicine Review*, Vol.12, No.3, (September 2007), pp. 207-227, ISSN 1089-5159
- Kitajka, K.; Sinclair, A.J.; Weisinger, R.S.; Weisinger, H.S.; Mathai, M.; Jayasooriya, A.P.; Halver, J.E. & Puskás, L.G. (2004). Effects of dietary omega-3 polyunsaturated fatty acids on brain gene expression. *Proceeding of the National Academic of Sciences of the United States of the American*, Vol.101, No.30, (July 2004), pp. 10931-10936, ISSN 1091-6490
- Lauritzen, I.; Blondeau, N.; Heurteaux, C.; Widmann, C.; Romey, G. & Lazdunski, M. (2000). Polyunsaturated fatty acids are potent neuroprotectors. *The EMBO Journal*, Vol.19, No.8, (April 2000), pp. 1784-1793, ISSN 0261-4189
- Leaf, A.; Xiao, Y.F. & Kang, J.X. (2002). Interactions of n-3 fatty acids with ion channels in excitable tissues. *Prostaglandins Leukotrienes & Essential Fatty Acids (PLEFA)*, Vol.67, No.2-3, (August-September 2002), pp. 113-120, ISSN 0952-3278
- Lev, R. & Orlic, D. (1972). Protein absorption by the intestine of the fetal rat in utero. *Science*, Vol.177, No.48, (August 1972), pp. 522-524, ISSN 1095-9203
- Liberatori, S.; Bini, L.; De Felice, C.; Magi, B.; Marzocchi, B.; Raggiaschi, R.; Frutiger, S.; Sanchez, J.C.; Wilkins, M.R.; Hughes, G.; Hochstrasser, D.F.; Bracci, R. & Pallini, V. (1997). A two-dimensional protein map of human amniotic fluid at 17 weeks' gestation. *Electrophoresis*, Vol.18, No.15, (December 1997), pp. 2816-2822, ISSN 1522-2683
- Liperoti, R.; Landi, F.; Fusco, O.; Bernabei, R. & Onder, G. (2009). Omega-3 polyunsaturated fatty acids and depression: a review of the evidence. *Current Pharmaceutical Desing*, Vol.15, No.36, (December 2009), pp. 4165-4172, ISSN 1381-6128
- Litman, B.J.; Niu, S.L.; Polozova, A. & Mitchell, D.C. (2001). The role of docosahexaenoic acid containing phospholipids in modulating G protein-coupled signaling pathways: visual transduction. *Journal of Molecular Neuroscience*, Vol.16, No.2-3, (April-June 2001), pp. 237-242, ISSN 0895-8696
- Lombardi, F. & Terranova, P. (2007). Anti-arrhythmic properties of N-3 poly-unsaturated fatty acids (n-3 PUFA). *Current Medicine Chemistry*, Vol.14, No.19, (December 1994), pp. 2070-2080, ISSN 0929-8673
- Loughhead, A.M.; Fisher, A.D.; Newport, D.J.; Ritchie, J.C.; Owens, M.J.; DeVane, C.L. & Stowe, Z.N. (2006). Antidepressants in amniotic fluid: another route of fetal exposure. *American Journal of Psychiatry*, Vol.163, No.1, (January 2006), pp. 145-147, ISSN 1535-7228
- Love, J.A.; Saum, W.R. & McGee, R.Jr. (1985). The effects of exposure to exogenous fatty acids and membrane fatty acid modification on the electrical properties of NG108-15 cells. *Cellular and Molecular Neurobiology*, Vol.5, No.4, (December 1985), pp. 333-352, ISSN 1573-6830
- Lundbaek, J.A.; Birn, P.; Girshman, J.; Hansen, A.J. & Andersen, O.S. (1996). Membrane stiffness and channel function. *Biochemistry*, Vol.35, No.12, (March 1996), pp. 3825-3830, ISSN 0264-6021
- Makrides, M.; Gibson, R.A.; McPhee, A.J.; Yelland, L.; Quinlivan, J. & Ryan P. (2010). Effect of DHA supplementation during pregnancy on maternal depression and neurodevelopment of young children: a randomized controlled trial. *The Journal of*

- American Medical Association*, Vol.304, No.15, (October 2010), pp. 1675-1683, ISSN 0098-7484
- Mamalakis, G.; Kafatos, A.; Tornaritis, M. & Alevizos, B. (1998). Anxiety and adipose essential fatty acid precursors for prostaglandin E1 and E2. *Journal of the American College of Nutrition*, Vol.17, No. 3, (June, 1998), pp. 239-243, ISSN 0731-5724
- McCann, J.C. & Ames, B.N. (2005). Is docosahexaenoic acid, an n-3 long-chain polyunsaturated fatty acid, required for development of normal brain function? An overview of evidence from cognitive and behavioral tests in humans and animals. *American Journal of Clinical Nutrition*, Vol.82, No.2, (August 2005), pp. 281-295, ISSN 0002-9165
- McGlone, J.J. & Anderson, D.L. (2002). Synthetic maternal pheromone stimulates feeding behavior and weight gain in weaned pigs. *Journal of Animal Science*, vol.80, No.12, (December 2002), pp.3179-3183, ISSN 0021-8812
- McNamara, R.K.; Ostrander, M.; Abplanalp, W.; Richtand, N.M.; Benoit, S.C. & Clegg, D.J. (2006). Modulation of phosphoinositide-protein kinase C signal transduction by omega-3 fatty acids: implications for the pathophysiology and treatment of recurrent neuropsychiatric illness. *Prostaglandins, Leukotrienes, and Essential Fatty Acids*, vol.75, No.4-5, (October-November 2006), pp.237-257, ISSN 0952-3278
- Mendoza-López, M.R.; Contreras, C.M.; Gutiérrez-García, A.G. & Díaz-Martel, C. (2010). ¿Los ácidos grasos presentes en líquidos maternos participan en la comunicación materno-infantil? *Procesos Psicológicos y Sociales*, Vol.6, No.1-2, (July-December 2010), pp.1-25, ISSN 1870-5618
- Mesa-García, M.D.; Aguilera-García, C.M. & Gil-Hernández, A. (2006). Importance of lipids in the nutritional treatment of inflammatory diseases. *Nutrición Hospitalaria*, Vol.21, (May 2006), pp.28-41, ISSN 0212-1611
- Michelsson, K.; Christensson, K.; Rothgänger, H. & Winberg, J. (1996). Crying in separated and non-separated newborns: sound spectrographic analysis. *Acta Paediatrica*, Vol.85, No.4, (April 1996), pp. 471-475, ISSN 0803-5253
- Mills, D.E.; Huang, Y.S.; Narce, M. & Poisson, J.P. (1994). Psychosocial stress, catecholamines and essential fatty acid metabolism in rats. *Proceedings of the Society for Experimental Biology and Medicine*, Vol.205, No.1, (January 1994), pp.56-61, ISSN 0037-9727
- Milte, C.M.; Sinn, N. & Howe, P.R. (2009). Polyunsaturated fatty acid status in attention deficit hyperactivity disorder, depression, and Alzheimer's disease: towards an omega-3 index for mental health? *Nutrition Reviews*, Vol.67, No.10, (October 2009), pp. 573-590, ISSN 1753-4887
- Miyake, M.; Christie, M.J. & North, R.A. (1989). Single potassium channels opened by opioids in rat locus ceruleus neurons. *Proceedings of the National Academy of Sciences of the United States of America*, Vol.86, No.9, (May 1989), pp.3419-3422, ISSN 0027-8424
- Murakami, K.; Lagarde, M. & Yuki, Y. (1998). Identification of minor proteins of human colostrum and mature milk by two-dimensional electrophoresis. *Electrophoresis*, Vol.19, No.14, (October 1998), pp. 2521-2527, ISSN 0173-0835

- Nakashima, Y.; Yuasa, S.; Hukamizu, Y.; Okuyama, H.; Ohhara, T.; Kameyama, T. & Nabeshima, T. (1993). Effect of a high linoleate and a high α -linolenate diet on general behavior and drug sensitivity in mice. *Journal of Lipid Research*, Vol.34, No.2, (February 1993), pp.239-247, ISSN 0022-2275
- Nelson, D.L. & Cox, M.M. (2005). *Lehninger Principles of Biochemistry*, Omega, ISBN 0-7167-4339-6, Barcelona, España
- Neuringer, M.; Connor, W.E.; Lin, D.S.; Barstad L. & Luck, S. (1986). Biochemical and functional effects of prenatal and postnatal omega 3 fatty acid deficiency on retina and brain in rhesus monkeys. *Proceedings of the National Academy of Sciences of the United States of America*, Vol.83, No.11, (June 1986), pp.4021-4025, ISSN 0027-8424
- Nielsen, M.; Witt, M.R. & Thøgersen, H. (1988). [3 H]diazepam specific binding to rat cortex in vitro is enhanced by oleic, arachidonic and docosahexenoic acid isolated from pig brain. *European Journal of Pharmacology*, Vol.146, No.2-3 (February 1988), pp.349-353, ISSN 0014-2999
- Nishitani, S.; Miyamura, T.; Tagawa, M.; Sumi, M.; Takase, R.; Doi, H.; Moriuchi, H. & Shinohara K. (2009). The calming effect of a maternal breast milk odor on the human newborn infant. *Neuroscience Research*, Vol.63, No.1, (January 2009), pp.66-71, ISSN 0168-0102
- Nowak, R.; Porter, R.H.; Lévy, F.; Orgeur, P. & Schaal, B. (2000). Role of mother-young interactions in the survival of offspring in domestic mammals. *Reviews Reproduction*, Vol.5, No.3, (September 2000), pp.153-163, ISSN 1359-6004
- Ordway, R.W.; Singer, J.J. & Walsh, J.V. Jr. (1991). Direct regulation of ion channels by fatty acids. *Trends in Neurosciences*, Vol.14, No.3, (March 1991), pp.96-100, ISSN 0166-2236
- Ordway, R.W.; Walsh, J.V.Jr. & Singer, J.J. (1989). Arachidonic acid and other fatty acids directly activate potassium channels in smooth muscle cells. *Science*, Vol.244, No.4909, (June 1989), pp.1176-1179, ISSN 0036-8075
- Oswalt, G.L. & Meier, G.W. (1975). Olfactory, thermal, and tactual influences on infantile ultrasonic vocalization in rats. *Developmental Psychobiology*, Vol.8, No.2, (May 1975), pp.129-135, ISSN 0012-1630
- Pageat, P. (2001). Pig appeasing pheromones to decrease stress, anxiety and aggressiveness. *US Patent No. 6,169,113*.
- Pelosi, P. (2001). The role of the perireceptor events in vertebrates olfaction. *Cell and Molecular Life Sciences*, Vol.58, No.4, (April 2001), pp.503-509, ISSN 1420-682X
- Porter, R.H. & Winberg, J. (1999). Unique salience of maternal breast odors for newborn infants. *Neuroscience and Biobehavioral Reviews*, Vol.23, No.3, (January 1999), pp.439-449, ISSN 0149-7634
- Rattaz, C.; Goubet, N. & Bullinger, A. (2005). The calming effect of a familiar odor on full-term newborns. *Journal of Developmental and Behavioral Pediatrics*, Vol.26, No.2, (April 2005), pp.86-92, ISSN 0196-206X
- Reisbick, S.; Neuringer, M.; Gohl, E.; Wald, R. & Anderson, G.J. (1997). Visual attention in infant monkeys: effects of dietary fatty acids and age. *Developmental Psychology*, Vol.33, No.3, (May 1997), pp.387-395, ISSN 0012-1649

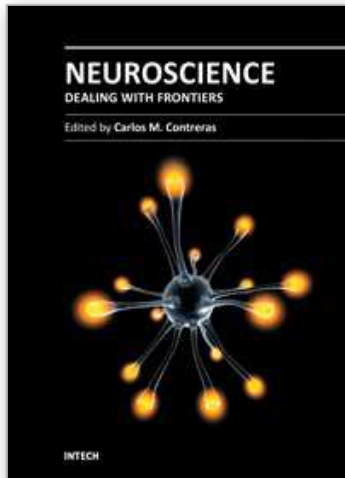
- Richardson, A.J. (2006). Omega-3 fatty acids in ADHD and related neurodevelopmental disorders. *International Review of Psychiatry*, Vol.18, No.2, (April 2006), pp.155-172, ISSN 0954-0261
- Ristic, V.; Vrbaski, S.; Lalic, Z. & Miric, M. (1995). The effect of ethanol and diazepam on the fatty acid composition of plasma and liver phospholipids in the rat. *Biological & Pharmaceutical Bulletin*, Vol.18, No.6, (June 1995), pp.842-845, ISSN 0918-6158
- Robertson, D.W. & Steinberg, M.I. (1990). Potassium channel modulators: scientific applications and therapeutic promise. *Journal of Medicine Chemistry*, Vol.33, No.6, (June 1990), pp.1529-1541, ISSN 0022-2623
- Robinson, P.J. & Rapoport, S.I. (1986). Kinetics of protein binding determine rates of uptake of drugs by brain. *The American Journal of Physiology*, Vol.251, No.6, (December 1986), pp.R1212-R1220, ISSN 0002-9513
- Rogawski, M.A. & Porter, R.J. (1990). Antiepileptic drugs: pharmacological mechanisms and clinical efficacy with consideration of promising developmental stage compounds. *Pharmacology Reviews*, Vol.42, No.3, (September 1990), pp.223-286, ISSN 0031-6997
- Rosen, C.J. (2009). Breaking into bone biology: serotonin's secrets. *Nature Medicine*, Vol.15, No.2, (February 2009), pp.145-146, ISSN 0031-6997
- Sampath, H. & Ntambi, J.M. (2005). Polyunsaturated fatty acid regulation of genes of lipid metabolism. *Annual Review of Nutrition*, Vol.25, (2005), pp.317-340, ISSN 0199-9885
- SanGiovanni, J.P.; Parra-Cabrera, S.; Colditz, G.A.; Berkey, C.S. & Dwyer, J.T. (2000). Meta-analysis of dietary essential fatty acids and long-chain polyunsaturated fatty acids as they relate to visual resolution acuity in healthy preterm infants. *Pediatrics*, Vol.105, No.6, (June 2000), pp.1292-1298, ISSN 1098-4275
- Sardesai, V.M. (1992). The essential fatty acids. *Nutrition in Clinical Practice*, Vol.7, No.4, (August 1992), pp.179-186, ISSN 0884-5336
- Schaal, B.; Marlier, L. & Soussignan, R. (1995). Responsiveness to the odour of the amniotic fluid in the human neonate. *Biology of the Neonate*, Vol.67, No.6, (September 2009), pp.397-406, ISSN 0006-3126
- Schaal, B.; Marlier, L. & Soussignan, R. (1998). Olfactory function in the human fetus: evidence from selective neonatal responsiveness to the odor of amniotic fluid. *Behavioral Neuroscience*, Vol.112, No.6, (December 1998), pp.1438-1449, ISSN 0735-7044
- Schaal, B. (1988). Olfaction in infants and children: developmental and functional perspectives. *Chemical Senses*, Vol.13, No.2, (June 1988), pp.145-190, ISSN 0379-864X
- Schapiro, S. & Salas, M. (1970). Behavioral response of infant rats to maternal odor. *Physiology and Behavior*, Vol.5, No.7, (July 1970), pp.815-817, ISSN 0031-9384
- Schwartz, R.D.; Skolnick, P. & Paul, S.M. (1988). Regulation of γ -aminobutyric acid/barbiturate receptor-gated chloride ion flux in brain vesicles by phospholipase A₂: possible role of oxygen radicals. *Journal of Neurochemistry*, Vol.50, No.2, (February 1988), pp.65-71, ISSN 0022-3042
- Schwartz, R.D. & Yu, X. (1992). Inhibition of GABA-gated chloride channel function by arachidonic acid. *Brain Research*, Vol.585, No.1-2, (July 1992), pp.405-410, ISSN 0006-8993

- Schwarz, J.R. & Grigat, G. (1989). Phenytoin and carbamazepine: potential- and frequency-dependent block of Na currents in mammalian myelinated nerve fibers. *Epilepsia*, Vol.30, No.3, (May-June 1989), pp.286-294, ISSN 0013-9580
- Simopoulos, A.P. (1999). Essential fatty acids in health and chronic disease. *The American Journal of Clinical Nutrition*, Vol.70 No.3, (September 1999), pp.560S-569S, ISSN 0002-9165
- Sinclair, H.M. (1984). Essential fatty acids in perspective. *Human Nutrition. Clinical Nutrition*, Vol.38, No.4, (July 1984), pp.245-260, ISSN 0263-8290
- Solfrizzi, V.; Frisardi, V.; Capurso, C.; D'Introno, A.; Colacicco, A.M.; Vendemiale, G.; Capurso, A. & Panza, F. (2010). Dietary fatty acids in dementia and predementia syndromes: epidemiological evidence and possible underlying mechanisms. *Ageing Research Reviews*, Vol.9, No.2, (April 2010), pp.184-189, ISSN 1568-1637
- Sprecher, H.; Luthria, D.L.; Mohammed, B.S. & Baykousheva, S.P. (1995). Reevaluation of the pathways for the biosynthesis of polyunsaturated fatty acids. *Journal of Lipid Research*, Vol.36, No.12, (December 1995), pp.2471-2477, ISSN 0022-2275
- Stahl, W.L. (1986). The Na,K-ATPase of nervous tissue. *Neurochemistry International*, Vol.8, No.4, (March 1986), pp.449-476, ISSN 0197-0186
- Stevens, L.J.; Zentall, S.S.; Abate, M.L.; Kuczek, T. & Burgess, J.R. (1996). Omega-3 fatty acids in boys with behavior, learning, and health problems. *Physiology and Behavior*, Vol.59, No.4-5, (April-May 1996), pp.915-920, ISSN 0031-9384
- Strik, C.M.; Lithander, F.E.; McGill, A.T.; MacGibbon, A.K.; McArdle, B.H. & Poppitt, S.D. (2010). No evidence of differential effects of SFA, MUFA or PUFA on post-ingestive satiety and energy intake: a randomised trial of fatty acid saturation. *Nutrition Journal*, Vol.9, (May 2010), pp.24, ISSN 1475-2891
- Stulnig, T.M. (2003). Immunomodulation by polyunsaturated fatty acids: mechanisms and effects. *International Archives of Allergy and Immunology*, Vol.132, No.4, (December 2003), pp.310-321, ISSN 1018-2438.
- Sullivan, R.M. & Toubas, P. (1998). Clinical usefulness of maternal odor in newborns: soothing and feeding preparatory responses. *Biology of the Neonate*, Vol.74, No.6, (December 1998), pp.402-408, ISSN 0006-3126
- Suominen-Taipale, A.L.; Partonen, T.; Turunen, A.W.; Männistö, S.; Jula, A. & Verkasalo, P.K. (2010). Fish consumption and omega-3 polyunsaturated fatty acids in relation to depressive episodes: a cross-sectional analysis. *Pediatrics*, Vol.5, No.5, (August 2010), pp.e10530, ISSN 0031-4005
- Tegoni, M.; Pelosi, P. ; Vincent, F. ; Spinelli, S. ; Campanacci, V. ; Grolli, S. ; Ramoni, R. & Cambillau, C. (2000). Mammalian odorant binding proteins. *Biochimica Biophysica Acta*, vol.1482, No.1-2, (October 2000), pp.229-240, ISSN 0006-3002
- Trautwein, E.A.; Rieckhoff, D.; Kunath-Rau, A. & Erbersdobler, H.F. (1999). Replacing saturated fat with PUFA-rich (sunflower oil) or MUFA-rich (rapeseed, olive and high-oleic sunflower oil) fats resulted in comparable hypocholesterolemic effects in cholesterol-fed hamsters. *Annals of Nutrition & Metabolism*, Vol.43, No.3, (May-June 1999), pp.159-172, ISSN 0250-6807

- Uauy, R.; Mena, P. & Rojas, C. (2000). Essential fatty acids in early life: structural and functional role. *The Proceedings of the Nutrition Society*, Vol.59, No.1, (February 2000), pp.3-15, ISSN 0029-6651
- Vaidyanathan, V.V.; Rao, K.V. & Sastry, P.S. (1994). Regulation of diacylglycerol kinase in rat brain membranes by docosahexaenoic acid. *Neuroscience Letters*, Vol.179, No.1-2, (September 1994), pp.171-174, ISSN 0304-3940
- Varendi, H. ; Christensson, K. ; Porter, R.H. & Winberg, J. (1998). Soothing effect of amniotic fluid smell in newborn infants. *Early Human Development*, Vol.51, No.1, (April 1998), pp.47-55, ISSN 0378-3782
- Varendi, H.; Porter, R.H. & Winberg, J. (1996). Attractiveness of amniotic fluid odor: evidence of prenatal learning? *Acta Paediatrica*, Vol.85, No.10, (October 1996), pp.1223-1227, ISSN 0803-5253
- Vreugdenhil, M.; Bruehl, C.; Voskuyl, R.A.; Kang, J.X.; Leaf, A. & Wadman, W.J. (1996). Polyunsaturated fatty acids modulate sodium and calcium currents in CA1 neurons. *Proceedings of the National Academy of Sciences of the United States of America*, Vol.93, No.22, (October 1996), pp.12559-12563, ISSN 0027-8424
- Wainwright, P.E. (1992). Do essential fatty acids play a role in brain and behavioral development? *Proceedings of the Nutrition Society*, Vol.61, No.2, (November 2005), pp.61-69, ISSN 2001130
- Williams, J.H.; Errington, M.L.; Lynch, M.A. & Bliss, T.V. (1989). Arachidonic acid induces a long-term activity-dependent enhancement of synaptic transmission in the hippocampus. *Nature*, Vol.341, No.6244, (October 1989), pp.739-742, ISSN 0028-0836.
- Winberg, J. & Porter, R.H. (1998). Olfaction and human neonatal behaviour: clinical implications. *Acta Paediatrica*, Vol.87, No.1, (January 1998), pp.6-10, ISSN 0803-5253
- Xiao, Y.F.; Gomez, A.M.; Morgan, J.P.; Lederer, W.J. & Leaf, A. (1997). Suppression of voltage-gated L-type Ca²⁺ currents by polyunsaturated fatty acids in adult and neonatal rat ventricular myocytes. *Proceedings of the National Academy of Sciences of the United States of America*, Vol.94, No.8, (April 1997), pp.4182-4187, ISSN 0027-8224
- Xiao, Y.F.; Kang, J.X.; Morgan, J.P. & Leaf, A. (1995). Blocking effects of polyunsaturated fatty acids on Na⁺ channels of neonatal rat ventricular myocytes. *Proceedings of the National Academy of Sciences of the United States of America*, Vol.92, No.24, (November 1995), pp.11000-11004, ISSN 0027-8224
- Xiao, Y.F.; Wright, S.N.; Wang, G.K.; Morgan, J.P. & Leaf, A. (1998). Fatty acids suppress voltage-gated Na⁺ currents in HEK293t cells transfected with the α -subunit of the human cardiac Na⁺ channel. *Proceedings of the National Academy of Sciences of the United States of America*, Vol.95, No.5, (March 1998), pp.2680-2685, ISSN 0027-8424
- Yehuda, S.; Rabinovitz, S. & Mostofsky, D.I. (2005). Mixture of essential fatty acids lowers test anxiety. *Nutritional Neuroscience*, Vol.8, No.4, (August 2005), pp.265-267, ISSN 1028-415X
- Zamaria, N. (2004). Alteration of polyunsaturated fatty acid status and metabolism in health and disease. *Reproduction, Nutrition, Development*, Vol.44, No.3, (May-June 2004), pp.273-282, ISSN 0926-5287

- Zimmer, L.; Delion-Vancassel, S.; Durand, G.; Guilloteau, D.; Bodard, S.; Besnard, J.C. & Chalon, S. (2000). Modification of dopamine neurotransmission in the nucleus accumbens of rats deficient in n-3 polyunsaturated fatty acids. *Journal of Lipid Research*, Vol.41, No.1, (January 2000), pp.32-40, ISSN 0022-2275
- Zimmer, L.; Vancassel, S.; Cantagrel, S.; Breton, P.; Delamanche, S.; Guilloteau, D.; Durand, G. & Chalon, S. (2002). The dopamine mesocorticolimbic pathway is affected by deficiency in n-3 polyunsaturated fatty acids. *The American Journal of Clinical Nutrition*, Vol.75, No.4, (April 2002), pp.662-667, ISSN 0002-9165

IntechOpen



Neuroscience - Dealing With Frontiers

Edited by Dr. Carlos M. Contreras

ISBN 978-953-51-0207-6

Hard cover, 440 pages

Publisher InTech

Published online 16, March, 2012

Published in print edition March, 2012

The Neuronal Doctrine recently reached its 100th year and together with the development of psychopharmacology by the middle of 20th century promoted spectacular developments in the knowledge of the biological bases of behavior. The overwhelming amount of data accumulated, forced the division of neuroscience into several subdisciplines, but this division needs to dissolve in the 21st century and focus on specific processes that involve diverse methodological and theoretical approaches. The chapters contained in this book illustrate that neuroscience converges in the search for sound answers to several questions, including the pathways followed by cells, how individuals communicate with each other, inflammation, learning and memory, the development of drug dependence, and approaches to explaining the processes that underlie two highly incapacitating chronic degenerative illnesses.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Carlos M. Contreras, Ana G. Gutiérrez-García and Diana Idania Vásquez-Hernández (2012). Fatty Acids and Emotional Behavior, *Neuroscience - Dealing With Frontiers*, Dr. Carlos M. Contreras (Ed.), ISBN: 978-953-51-0207-6, InTech, Available from: <http://www.intechopen.com/books/neuroscience-dealing-with-frontiers/fatty-acids-and-emotional-behavior>

INTECH
open science | open minds

InTech Europe

University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

© 2012 The Author(s). Licensee IntechOpen. This is an open access article distributed under the terms of the [Creative Commons Attribution 3.0 License](#), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

IntechOpen

IntechOpen