Docosapentaenoic acid (22:5n-3): a review of its biological effects

Gunveen Kaur[1,2], David Cameron-Smith[2], Manohar Garg[3] and Andrew J Sinclair[1,2]

[1] Metabolic Research Unit, School of Medicine, Deakin University,
Waurn Ponds, 3217, Victoria, Australia

[2] School of Exercise and Nutrition Sciences, Deakin University,
Burwood, 3126, Victoria, Australia

[3] School of Biomedical Sciences & Pharmacy, University of Newcastle,
Callaghan NSW 2308, Australia

Key Words:
n-3 polyunsaturated fatty acids (VLCPUFA), eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA), docosahexaenoic acid (DHA).

To whom correspondence should be addressed
Andrew J. Sinclair,
Metabolic Research Unit
School of Medicine, Pigdons Road,
Deakin University, Waurn Ponds, 3217, Victoria, Australia.
Fax: +61-3-52272170
Phone +61-3-52272703
email andrew.sinclair@deakin.edu.au

Abstract

This article summarises the current knowledge available on metabolism and the biological effects of n-3 docosapentaenoic acid (DPA). n-3 DPA has not been extensively studied because of the limited availability of the pure compound. n-3 DPA is an elongated metabolite of EPA and is an intermediary product between EPA and DHA. The literature on n-3 DPA is limited, however the available data suggests it has beneficial health effects. *In vitro* n-3 DPA is retro-converted back to EPA, however it does not appear to be readily metabolised to DHA. *In vivo* studies have shown limited conversion of n-3 DPA to DHA, mainly in liver, but in addition retro-conversion to EPA is evident in a number of tissues. n-3 DPA can be metabolised by lipoxygenase, in platelets, to form ll-hydroxy-7,9,13,16,19- and 14-hydroxy-7,10,12,16,19-DPA. It has also been reported that n-3 DPA is effective (more so than EPA and DHA) in inhibition of aggregation in platelets obtained from rabbit blood. In addition, there is evidence that n-3 DPA possesses 10-fold greater endothelial cell migration ability than EPA, which is important in wound healing processes. An *in vivo* study has reported that n-3 DPA reduces the fatty acid synthase and malonyl activity levels in n-3 DPA-supplemented mice and these effects were stronger than the EPA-supplemented mice. Another recent *in vivo* study has reported that n-3 DPA may have a role in attenuating age related decrease in spatial learning and long term potentiation. However, more research remains to be done to further investigate the biological effects of this n-3 VLCPUFA.

Abbreviations

AA, arachidonic acid; ACC, acetyl coenzyme A; ALA, alpha linolenic acid; BAE, Bovine aortic endothelial cells; ChREBP, carbohydrate response element binding protein; COX, cyclooxygenase; CPT-1, carnitine palmitoyl transferase-1; DHA, docosahexaenoic acid; 17S-H(p) DPA, 17S-hydro(peroxy) docosapentaenoic acid; DPA, docosapentaenoic acid; EC, endothelial cells; EFA, essential fatty acid; EPA, eicosapentaenoic acid; FASn, fatty acid synthase; HETE, 12-hydroxy- 5,8,10,14-eicosatetraenoic acid; HNF-α, hepatic nuclear factor-α; HTT, 5,8,10-heptadecatrienoic acid; LA, linoleic acid; LOX, lipoxygenase; L-PK, liver pyruvate kinase; LT, leukotriene; LXR, liver X receptor; OHDPA, hydroxydocosapentaenoic acid; PC, phosphatidylcholine; PE, phosphatidylethanolamine; PG, prostaglandin; PPAR, peroxisome proliferator-activated receptor; SREBP sterol regulatory element binding protein; TAG, triacylglycerol; TNF- α, tumor necrosis factor- α; TX, thromboxane; VEGF, vascular endothelial growth factor; VLCPUFA, very long chain polyunsaturated fatty acids.

1. Introduction

The realisation that brain grey matter from many different mammals was rich in n-3 long chain polyunsaturated fatty acids (n-3 VLCPUFA), especially DHA was a stimulus for much research on the biological role(s) of n-3 VLCPUFA (1, 2). Since then many studies have been conducted to investigate the beneficial effects of n-3 VLCPUFA in neural function, reducing risk the of cardiovascular events, diabetes mellitus, inhibiting growth of tumour cells, modulating gene expression, anti-inflammatory activity and lipid lowering potential (3-8). Most of these studies have been conducted on fish oils which typically contain all the three n-3 VLCPUFA, namely eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA) and docosahexaenoic acid, (DHA) (Fig 1). Many studies have addressed the unique actions of EPA and DHA individually, because these two fatty acids have been available in purified form. What has emerged from this research is that there are both unique as well as overlapping actions. For example DHA has unique actions in promoting normal functioning of brain, while both EPA and DHA have overlapping actions in lowering blood lipid levels. Because pure n-3 DPA has not been readily available in quantity or at an affordable price, the role(s) of n-3 DPA have not been systematically examined. To date few studies have been conducted using pure or enriched n-3 DPA, yet the data available points to beneficial effects of n-3 DPA. The aim of this review is to summarize this current knowledge on the biological effects of n-3 DPA.

2. Synthesis and metabolism of n-3 DPA

Alpha-linolenic acid (ALA) (n-3), one of the two essential fatty acids (EFA), can be metabolized *in vivo* by desaturation and elongation enzymes to form a series of highly unsaturated n-3 VLCPUFA. The major products of this pathway are EPA, DPA and DHA (9). n-3 DPA is formed by chain elongation of EPA which is believed to be mediated by the enzymes fatty acid elongase – 2 (FAE - 2) and FAE - 5 (10, 11). The conversion of n-3 DPA

to DHA was initially believed to be the result of the activity of Δ4 desaturase, converting 7,10,13,16,19-22:5 (DPA) to 4,7,10,13,16,19-22:6 (DHA). But later studies reported that DPA was first elongated to 24:5n-3 which was then desaturated, by the activity of Δ6 desaturase, to form 24:6n-3 (12). 24:6n-3 is translocated from the endoplasmic reticulum to the peroxisome where this 24 carbon fatty acid is then chain-shortened to 22:6n-3 (DHA) by β-oxidation. However, in some marine algae like *Pavlova lutheri* and *Thraustochytrium* sp., the Δ4 desaturase cDNA has been sequenced and isolated (13, 14). It has been shown that introduction of this Δ4 desaturase into *Saccharomyces cerevisiae* and *Brassica juncea* results in production of DHA in vegetative tissues (13).

ALA supplementation studies conducted in 1960s, in rats, showed the increase in the tissue proportions (liver and heart) of ALA, EPA, DPA and DHA. These were long-term studies, conducted for a duration of 80-100 days, and involved refeeding rats which had initially been made EFA deficient. The results showed that supplementation with ALA there were increases in ALA, EPA, n-3 DPA and DHA as the dietary ALA level was increased (15-17). However, most human supplementation studies have led to the belief that the major products of ALA metabolism are EPA and n-3 DPA and that the capacity of humans to convert ALA to DHA is limited (18-20); tracer studies report that females have greater capacity for synthesis of DHA than males (19, 20). A recent review has summarised the data from various ALA supplementation studies conducted in human adults and concluded that ALA supplementation generally leads to an increase in plasma EPA and n-3 DPA levels but has little or no effect on DHA levels (21). In animals, ALA has been shown to be more prone to deposition in adipose tissue, β–oxidation or excretion via skin rather than metabolism to DHA (22) . An alternative reason for limited synthesis of DHA from ALA is the competition between 24:5n-3 and ALA for the Δ6 desaturase enzyme (Fig 1) (23). In other words, when there is a high ALA level,

the ALA itself (or indeed LA) could inhibit metabolism of 24:5n-3 to 24:6n-3, thus limiting the availability of the precursor to form DHA.

In case of n-3 DPA, endothelial cells supplemented with DPA show a substantial increase in EPA in the cells, but there is little evidence of DHA formation. Similarly when these cells were supplemented with EPA, there was a significant increase in n-3 DPA, but not DHA (24, 25). However, media from n-3 DPA-incubated cells contained small amounts of DHA suggesting that n-3 DPA was converted to DHA and then released into the media (24). In primary rat hepatocytes, it was observed that ^{14}C-EPA was elongated to n-3 DPA linearly over a 24 hour period; in turn, the n-3 DPA was elongated to 24:5n-3, however no DHA was detected in these primary hepatocytes. The conversion of n-3 DPA to EPA is referred to as retro-conversion. The process of retroconversion was first described in 1970 (26) for DHA, and subsequent work in human fibroblasts indicated the retroconversion of both DHA and n-3 DPA was likely to involve the peroxisomal acyl-CoA oxidase (Fig 1) (27, 28). It has been demonstrated using fibroblasts, that cells deficient in this enzyme cannot perform the chain shortening of n-3 DPA to EPA (27).

Two recent *in vivo* studies also provide evidence for retroconversion of n-3 DPA into EPA. A study conducted in *Sprague Dawley* rats reported that n-3 DPA supplementation for 7 days (oral gavage of 50 mg/day of DPA as a free fatty acid) increased n-3 DPA concentrations in all tissues examined and EPA concentrations in liver, heart and skeletal muscle. However, the DHA concentration was increased only in liver (29). Similarly a study conducted in C57BL/KsJ db/db mice reported that after 4 weeks of supplementation with a synthetic triacylglycerol containing three n-3 DPA residues (tri-DPA), the proportion of EPA was increased in liver and kidney but there was no evidence of an increase in DHA in any of the tissues examined (30). There is evidence of formation of DHA from n-3 DPA in the retina of miniature poodle dogs which received an intravitreal injection of ^{14}C-DPA (31).

3. Isomers of DPA

There is another isomer of DPA which is an n-6 fatty acid. The n-6 DPA content is low in most mammalian tissues, except testes tissue (32, 33). In fish & fish oils, the n-3 isomer of DPA is substantially higher than the n-6 isomer (34). An algal oil from *Schizochytrium sp*. which is rich in DHA, also contains about 15 % n-6 DPA (35). The physiological behaviour of n-3 and n-6 DPA differs profoundly despite only differing in the position of two double bonds in the acyl chain (36). Deficiency of n-3 fatty acids in animals leads to a depletion of DHA and a compensatory rise in n-6 DPA level in most tissues, especially brain and retina (37, 38). Supplementation with n-6 DPA did not produce the benefits afforded by DHA for spatial task performance or in other words for brain function (39). In retina, DHA is the major VLCPUFA in the rod outer segment (ROS) membrane phospholipids. In n-3 PUFA deficiency studies, the n-6 DPA does not completely replace DHA in phosphatidylethanolamine (PE) and phosphatidylcholine (PC) species in the retina and the loss of this one double bond is enough to induce functional deficits in retinal signalling pathways (40). Similarly, n-6 DPA could not fully support the protective role of DHA in cell survival and apoptosis in mouse neurobalstoma cells (41).

4. Biological effects of n-3 DPA

The n-3 VLCPUFA have been shown to have many beneficial biological effects. These include their role in cell membrane functions, eicosanoid production and regulation of gene expression. However, most of these studies have been conducted using either fish oil (mixture of n-3 VLCPUFA) or pure EPA and DHA. Although there are studies which suggest a positive association between dietary n-3 DPA and heart health (42, 43), there are only a limited number of studies which have investigated the biological effects of pure n-3 DPA and most of these studies have been conducted using either endothelial cells or platelets (Table 1).

A recent study reported that aged rats fed either EPA or n-3 DPA for 56 days showed neuroprotective effects (44). Both EPA and n-3 DPA attenuated the age-related increases in caspase 3 activity and microglial activation and the changes observed were associated with restoration of long term potentiation and improved performance in spatial learning task. The authors reported that both n-3 DPA and EPA reduce the age-related oxidative changes *in vivo*.

4.1 Effect of n-3 DPA on eicosanoid production

Eicosanoids are the signalling molecules in the body that control many physiological systems. Eicosanoids include prostaglandins (PG), prostacyclins, thromboxanes (TX) leukotrienes (LT), lipoxins, hydroxyeicosatetraenoic acid and epoxyeicosatetraenoic acid (45). Eicosanoid synthesis is induced in the body in different physiological and/or pathological conditions including inflammation and cancer. They are involved in modulating the intensity and duration of inflammation and immune response (46). Arachidonic acid (AA), is the substrate for the production of eicosanoids, under the action of cyclooxygenase (COX) and lipoxygenase (LOX) enzymes. In platelets, AA is metabolised by COX to form TXA_2, 5,8,10 heptadecatrienoic acid (HHT) and by LOX to 12-hydroxy-5,8,10,14-eicosatetraenoic acid (12-HETE) (47). In platelets, n-3 DPA is metabolized into 11- and l4-hydroxy docosapentaenoic acids via the LOX pathway (47). When platelets were incubated with n-3 DPA, along with AA, this inhibited the COX enzyme thereby reducing the TXA_2 and HHT production from AA. In turn, more AA was available for shunting to the LOX pathway resulting in increased production of 12-HETE.

Platelet aggregation is an early event in the development of thrombosis and is initiated by TXA_2. The results from an *ex vivo* study conducted in rabbit platelets showed that EPA, n-3 DPA and DHA inhibited collagen- or AA-stimulated platelet aggregation dose-dependently,

and that n-3 DPA was the most potent inhibitor (48). These fatty acids also suppressed TXA_2 formation by platelets which were exposed to collagen, thrombin or AA. In these experiments, n-3 DPA was the most potent inhibitor of COX-1 activity. n-3 DPA enhanced formation of 12-HETE in response to collagen or AA by intact platelets, while EPA and DHA had less of an effect. These results suggest that n-3 DPA possesses potent activity for interfering with the COX pathway and accelerating the LOX pathway, thus inhibiting platelet aggregation most effectively. In a human whole blood *ex vivo* study, n-3 DPA was equally effective as EPA and DHA in inhibiting platelet aggregation, in female subjects however, in male subjects only EPA inhibited platelet aggregation. (49).

n-3 DPA has also been shown to reduce the prostacyclin production (by two fold) in endothelial cells (EC) compared with control cells when stimulated with endogenous AA-mobilizing agents such as bradykinin and calcium ionophore A23187. It was also reported that prostacyclin production in cells incubated with EPA was less inhibited than in cells incubated with n-3 DPA. Since the inhibition was approximately proportional to the amount of EPA in cells, regardless of n-3 DPA content in the cells, this study suggested that inhibition of prostacyclin by n-3 DPA was due to its retro-conversion into EPA (50).

EPA and DHA also act as precursors of novel pro-resolving and anti-inflammatory mediators. These mediators include resolvins of the E series from EPA, resolvins of the D-series or their aspirin triggered forms from DHA and LOX initiated neuroprotectins from DHA (51). These n-3 VLCPUFA-derived resolvins and protectins have unique structures, are biosynthesized by independent pathways in leukocytes, brain, microglial and retinal cells and share anti-inflammatory actions *in vivo*. Since n-3 DPA is known to be metabolised by LOX enzymes, it is speculated that n-3 DPA might also act as a precursor for production of DPA-related D-series of resolvins or neuroprotectins.

4.2 Effect of n-3 DPA on endothelial cell (EC) migration

EC migration and proliferation are important processes in the control of wound-healing response of blood vessels. Direct pretreatment of ECs with n-3 DPA (0.01-1.0 microgram/ml) resulted in a dose-dependent increase in migration in response to fetal bovine serum. Moreover, maximum stimulation of EC migration by n-3 DPA pretreatment (0.5 microgram/ml) was achieved at a concentration one-tenth of that required for maximal stimulation by EPA pretreatment (5.0 micrograms/ml), indicating that n-3 DPA is a potent stimulator of EC migration. In EC, EPA was elongated to n-3 DPA, with little DHA being formed (25). These data suggest that the stimulatory effect of EPA on EC migration occurs via n-3 DPA, and that n-3 DPA may act as a powerful anti-atherogenic factor (25). Another study conducted in bovine aortic endothelial (BAE) cells reported that the migrating activity of these cells stimulated with vascular endothelial growth factor (VEGF) was suppressed by DPA pretreatment. The pretreatment of BAE cells with n-3 DPA also suppressed tube-forming activity induced by VEGF, which suggests its positive role in preventing angiogenesis. The effect of n-3 DPA was stronger than those of EPA and DHA. n-3 DPA treatment of BAE cells also caused the suppression of VEGF receptor-2 (VEGFR-2, the kinase insert domain-containing receptor) expression. These data indicate that n-3 DPA has a potent inhibitory effect on angiogenesis possibly through the suppression of VEGFR-2 expression (5).

4.3 n-3 VLCPUFA regulate expression of several genes and enzymes

One of the roles of n-3 VLCPUFA in the body is in the regulation of gene expression. Although many genes and pathways have been reported to be regulated by n-3 VLCPUFA, it is the ability of these n-3 VLCPUFA to regulate genes involved in lipid oxidation and cellular inflammation that highlights a unique molecular activity (Fig 2). A variety of mechanisms

have been proposed to account for the impact on gene expression, demonstrated both acutely and chronically, following n-3 VLCPUFA exposure, including: alterations in membrane composition and associated lipid signalling, eicosanoid production, oxidant stress, nuclear receptor activation or covalent modification of specific transcription factors (52). The discovery of Gottlicher et al (1992) of nuclear receptors capable of binding fatty acids to modulate gene expression established a direct role for fatty acids at nuclear level (53). The main receptors that interact with n-3 VLCPUFA to regulate gene expression are peroxisome proliferator receptors (PPAR), liver X receptor (LXR) and hepatic nuclear factor - 4α (HNF-4α) (52). In addition, n-3 VLCPUFA also regulate gene expression by interacting with the transcription factors including; sterol regulatory element binding protein (SREBP) and carbohydrate response element binding protein (ChREBP) (54). The important lipogenic genes down-regulated by n-3 VLCPUFA are SREBP-1c, acetyl CoA carboxylase (ACC-2), fatty acid synthase (FASn) and ChREBP. SREBP-1c is a hepatic gene transcription factor that plays an important role in controlling transcription of genes involved in fatty acid synthesis, especially in liver (55).

Few studies have looked at the effect of pure n-3 DPA on genes involved in fat oxidation and fat synthesis. However, in hepatocytes, n-3 DPA has been shown to induce PPARα, but EPA and DHA had a stronger and more consistent effects (56). A recent study reported that n-3 DPA reduced the expression of lipogenic genes *in vivo*. Supplementation of mice with pure n-3 DPA (in TAG form) for 4 weeks significantly reduced the hepatic enzyme activity of FAS and malic enzyme (ME) in the cytosolic fraction. In this study, the mice fed with n-3 DPA also showed a reduction in hepatic TG levels (30). The n-3 DPA fed to these animals was a synthetic tri-DPA which is not present naturally in the diet.

n-3 DPA has also been reported to have a positive role in reducing the expression of inflammatory genes. Inflammation is an immune response to injury. However, inflammation

in walls of blood vessels is thought to play a role in the development of atherosclerotic plaques and thus lead to cardio-vascular disease. Tumor necrosis factor (TNF-α) is a prototypic pro-inflammatory cytokine and a mediator of systemic inflammation and immune responses. Supplementation of L929 murine fibrosarcoma cells with EPA, n-3 DPA and DHA was shown to reduce TNF-induced necrotic cell death; in contrast, preincubation with oleic acid, linoleic acid or 20:3n-3 did not affect TNF-induced necrosis. The order of effectiveness was DHA > n-3 DPA > / =EPA (57).

4.4 Conclusions and future perspective

These data suggest that n-3 DPA may possess some beneficial and perhaps unique properties, however, more extensive research is required to investigate the biological effects of pure n-3 DPA *in vitro* and *in vivo* as there are still questions that remain unanswered. For example is n-3 DPA an effective precursor of DHA in brain?; is it a significant a reservoir of EPA in the body?; is n-3 DPA conserved from β-oxidation relative to other n-3 polyunsaturated fatty acids?; does n-3 DPA have any unique/specific biological properties?

Acknowledgments

The authors would like to acknowledge the funds provided by Meat and Livestock Australia (Project code: D.MHN.0022) and the Molecular and Medical Research Strategic Research Centre, School of Medicine, Deakin University.

REFERENCES

1. Crawford MA, Casperd NM, Sinclair AJ. The long chain metabolites of linoleic avid linolenic acids in liver and brain in herbivores and carnivores. Comp Biochem Physiol B. 1976;54(3):395-401.
2. Crawford MA, Sinclair AJ. Nutritional influences in the evolution of mammalian brain. In: lipids, malnutrition & the developing brain. Ciba Found Symp. 1971:267-92.
3. Arita M, Yoshida M, Hong S, Tjonahen E, Glickman JN, Petasis NA, et al. Resolvin E1, an endogenous lipid mediator derived from omega-3 eicosapentaenoic acid, protects against 2,4,6-trinitrobenzene sulfonic acid-induced colitis. Proc Natl Acad Sci U S A. 2005 May 24;102(21):7671-6.
4. Aktas H, Halperin JA. Translational regulation of gene expression by omega-3 fatty acids. J Nutr. 2004 Sep;134(9):2487S-91S.
5. Tsuji M, Murota SI, Morita I. Docosapentaenoic acid (22:5, n-3) suppressed tube-forming activity in endothelial cells induced by vascular endothelial growth factor. Prostaglandins Leukot Essent Fatty Acids. 2003 May;68(5):337-42.
6. Kitajka K, Puskas LG, Zvara A, Hackler L, Jr., Barcelo-Coblijn G, Yeo YK, et al. The role of n-3 polyunsaturated fatty acids in brain: modulation of rat brain gene expression by dietary n-3 fatty acids. Proc Natl Acad Sci U S A. 2002 Mar 5;99(5):2619-24.
7. Fujikawa M, Yamazaki K, Hamazaki T, Wakaki K, Koizumi F, Yano S, et al. Effect of eicosapentaenoic acid ethyl ester on albuminuria in streptozotocin-induced diabetic rats. J Nutr Sci Vitaminol (Tokyo). 1994 Feb;40(1):49-61.
8. Shimizu H, Ohtani K, Tanaka Y, Sato N, Mori M, Shimomura Y. Long-term effect of eicosapentaenoic acid ethyl (EPA-E) on albuminuria of non-insulin dependent diabetic patients. Diabetes Res Clin Pract. 1995 Apr;28(1):35-40.
9. Mohrhauer H, Holman RT. Tracer Experiments to Assess Metabolic Conversions of Polyunsaturated Fatty Acids. J Am Oil Chem Soc. 1965 Jul;42:639-43.
10. Horton JD, Shah NA, Warrington JA, Anderson NN, Park SW, Brown MS, et al. Combined analysis of oligonucleotide microarray data from transgenic and knockout mice identifies direct SREBP target genes. Proc Natl Acad Sci U S A. 2003 Oct 14;100(21):12027-32.
11. Wang Y, Botolin D, Christian B, Busik J, Xu J, Jump DB. Tissue-specific, nutritional, and developmental regulation of rat fatty acid elongases. J Lipid Res. 2005 Apr;46(4):706-15.
12. Voss A, Reinhart M, Sankarappa S, Sprecher H. The metabolism of 7,10,13,16,19-docosapentaenoic acid to 4,7,10,13,16,19-docosahexaenoic acid in rat liver is independent of a 4-desaturase. J Biol Chem. 1991 Oct 25;266(30):19995-20000.
13. Qiu X, Hong H, MacKenzie SL. Identification of a Delta 4 fatty acid desaturase from Thraustochytrium sp. involved in the biosynthesis of docosahexanoic acid by heterologous expression in Saccharomyces cerevisiae and Brassica juncea. J Biol Chem. 2001 Aug 24;276(34):31561-6.
14. Tonon T, Harvey D, Larson TR, Graham IA. Identification of a very long chain polyunsaturated fatty acid Delta4-desaturase from the microalga Pavlova lutheri. FEBS Lett. 2003 Oct 23;553(3):440-4.
15. Mohrhauer H, Holman RT. Effect of Linolenic Acid Upon the Metabolism of Linoleic Acid. J Nutr. 1963 Sep;81:67-74.
16. Mohrhauer H, Holman RT. The Effect of Dietary Essential Fatty Acids Upon Composition of Polyunsaturated Fatty Acids in Depot Fat and Erythrocytes of the Rat. J Lipid Res. 1963 Jul;4:346-50.

17. Mohrhauer H, Holman RT. The Effect of Dose Level of Essential Fatty Acids Upon Fatty Acid Composition of the Rat Liver. J Lipid Res. 1963 Apr;4:151-9.
18. Burdge GC, Calder PC. Conversion of alpha-linolenic acid to longer-chain polyunsaturated fatty acids in human adults. Reprod Nutr Dev. 2005 Sep-Oct;45(5):581-97.
19. Burdge GC, Jones AE, Wootton SA. Eicosapentaenoic and docosapentaenoic acids are the principal products of alpha-linolenic acid metabolism in young men. Br J Nutr. 2002 Oct;88(4):355-63.
20. Burdge GC, Wootton SA. Conversion of alpha-linolenic acid to eicosapentaenoic, docosapentaenoic and docosahexaenoic acids in young women. Br J Nutr. 2002 Oct;88(4):411-20.
21. Brenna JT, Salem N, Jr., Sinclair AJ, Cunnane SC. alpha-Linolenic acid supplementation and conversion to n-3 long-chain polyunsaturated fatty acids in humans. Prostaglandins Leukot Essent Fatty Acids. 2009 Feb-Mar;80(2-3):85-91.
22. Fu Z, Sinclair AJ. Novel pathway of metabolism of alpha-linolenic acid in the guinea pig. Pediatr Res. 2000 Mar;47(3):414-7.
23. Portolesi R, Powell BC, Gibson RA. Competition between 24:5n-3 and ALA for {Delta}6 desaturase may limit the accumulation of DHA in HepG2 cell membranes. J Lipid Res. 2007 Jul;48(7):1592-8.
24. Achard F, Benistant C, Lagarde M. Interconversions and distinct metabolic fate of eicosapentaenoic, docosapentaenoic and docosahexaenoic acids in bovine aortic endothelial cells. Biochim Biophys Acta. 1995 Apr 6;1255(3):260-6.
25. Kanayasu-Toyoda T, Morita I, Murota S. Docosapentaenoic acid (22:5, n-3), an elongation metabolite of eicosapentaenoic acid (20:5, n-3), is a potent stimulator of endothelial cell migration on pretreatment in vitro. Prostaglandins Leukot Essent Fatty Acids. 1996 May;54(5):319-25.
26. Stoffel W, Eker, Assad H, Sprecher H. Enzymatic studies on the mechanism of the retroconversion of C22-polyenoic fatty acids to their C20-homologues. Hoppe Seylers Z Physiol Chem. 1970 Dec;351(12):1545-54.
27. Christensen E, Woldseth B, Hagve TA, Poll-The BT, Wanders RJ, Sprecher H, et al. Peroxisomal beta-oxidation of polyunsaturated long chain fatty acids in human fibroblasts. The polyunsaturated and the saturated long chain fatty acids are retroconverted by the same acyl-CoA oxidase. Scand J Clin Lab Invest Suppl. 1993;215:61-74.
28. Reddy JK, Hashimoto T. Peroxisomal beta-oxidation and peroxisome proliferator-activated receptor alpha: an adaptive metabolic system. Annu Rev Nutr. 2001;21:193-230.
29. Kaur G, Begg DP, Barr D, Garg M, Cameron-Smith D, Sinclair AJ. Short-term docosapentaenoic acid (22:5 n-3) supplementation increases tissue docosapentaenoic acid, DHA and EPA concentrations in rats. Br J Nutr. Jan;103(1):32-7.
30. Gotoh N, Nagao K, Onoda S, Shirouchi B, Furuya K, Nagai T, et al. Effects of three different highly purified n-3 series highly unsaturated fatty acids on lipid metabolism in C57BL/KsJ-db/db mice. J Agric Food Chem. 2009 Nov 25;57(22):11047-54.
31. Alvarez RA, Aguirre GD, Acland GM, Anderson RE. Docosapentaenoic acid is converted to docosahexaenoic acid in the retinas of normal and prcd-affected miniature poodle dogs. Invest Ophthalmol Vis Sci. 1994 Feb;35(2):402-8.
32. Tam PS, Sawada R, Cui Y, Matsumoto A, Fujiwara Y. The metabolism and distribution of docosapentaenoic acid (n-6) in the liver and testis of growing rats. Biosci Biotechnol Biochem. 2008 Oct;72(10):2548-54.
33. Tam PS, Umeda-Sawada R, Yaguchi T, Akimoto K, Kiso Y, Igarashi O. The metabolism and distribution of docosapentaenoic acid (n-6) in rats and rat hepatocytes. Lipids. 2000 Jan;35(1):71-5.

34. Gundstone FD, Harwood JL, Padley FB. The Lipid Handbook. London: Chapman & Hall,; 1994.
35. Sanders TA, Gleason K, Griffin B, Miller GJ. Influence of an algal triacylglycerol containing docosahexaenoic acid (22 : 6n-3) and docosapentaenoic acid (22 : 5n-6) on cardiovascular risk factors in healthy men and women. Br J Nutr. 2006 Mar;95(3):525-31.
36. Deng Y, Almsherqi ZA, Shui G, Wenk MR, Kohlwein SD. Docosapentaenoic acid (DPA) is a critical determinant of cubic membrane formation in amoeba Chaos mitochondria. Faseb J. 2009 Sep;23(9):2866-71.
37. Guesnet P, Pascal G, Durand G. Effects of dietary alpha-linolenic acid deficiency during pregnancy and lactation on lipid fatty acid composition of liver and serum in the rat. Reprod Nutr Dev. 1988;28(2A):275-92.
38. Homayoun P, Durand G, Pascal G, Bourre JM. Alteration in fatty acid composition of adult rat brain capillaries and choroid plexus induced by a diet deficient in n-3 fatty acids: slow recovery after substitution with a nondeficient diet. J Neurochem. 1988 Jul;51(1):45-8.
39. Lim SY, Hoshiba J, Salem N, Jr. An extraordinary degree of structural specificity is required in neural phospholipids for optimal brain function: n-6 docosapentaenoic acid substitution for docosahexaenoic acid leads to a loss in spatial task performance. J Neurochem. 2005 Nov;95(3):848-57.
40. Niu SL, Mitchell DC, Lim SY, Wen ZM, Kim HY, Salem N, Jr., et al. Reduced G protein-coupled signaling efficiency in retinal rod outer segments in response to n-3 fatty acid deficiency. J Biol Chem. 2004 Jul 23;279(30):31098-104.
41. Kim HY, Akbar M, Lau A. Effects of docosapentaenoic acid on neuronal apoptosis. Lipids. 2003 Apr;38(4):453-7.
42. Oda E, Hatada K, Katoh K, Kodama M, Nakamura Y, Aizawa Y. A case-control pilot study on n-3 polyunsaturated fatty acid as a negative risk factor for myocardial infarction. Int Heart J. 2005 Jul;46(4):583-91.
43. Rissanen T, Voutilainen S, Nyyssonen K, Lakka TA, Salonen JT. Fish oil-derived fatty acids, docosahexaenoic acid and docosapentaenoic acid, and the risk of acute coronary events: the Kuopio ischaemic heart disease risk factor study. Circulation. 2000 Nov 28;102(22):2677-9.
44. Kelly L, Grehan B, Chiesa A, O'Mara S, Downer E, Sahyoun G, et al. The polyunsaturated fatty acids, EPA and DPA exert a protective effect in the hippocampus of the aged rat. Neurobiology of Aging. 2010;Article in press.
45. Tassoni D, Kaur G, Weisinger R, Sinclair A. The role of eicosanoids in the brain. Asia Pac J Clin Nutr. 2008;17(S1):220-8.
46. Calder PC, Grimble RF. Polyunsaturated fatty acids, inflammation and immunity. Eur J Clin Nutr. 2002 Aug;56 Suppl 3:S14-9.
47. Careaga MM, Sprecher H. Synthesis of two hydroxy fatty acids from 7,10,13,16,19-docosapentaenoic acid by human platelets. J Biol Chem. 1984 Dec 10;259(23):14413-7.
48. Akiba S, Murata T, Kitatani K, Sato T. Involvement of lipoxygenase pathway in docosapentaenoic acid-induced inhibition of platelet aggregation. Biol Pharm Bull. 2000 Nov;23(11):1293-7.
49. Phang M, Garg ML, Sinclair AJ. Inhibition of platelet aggregation by omega-3 polyunsaturated fatty acids is gender specific-Redefining platelet response to fish oils. Prostaglandins Leukot Essent Fatty Acids. 2009 Jul;81(1):35-40.
50. Benistant C, Achard F, Ben Slama S, Lagarde M. Docosapentaenoic acid (22:5,n-3): metabolism and effect on prostacyclin production in endothelial cells. Prostaglandins Leukot Essent Fatty Acids. 1996 Oct;55(4):287-92.
51. Serhan CN, Chiang N. Endogenous pro-resolving and anti-inflammatory lipid mediators: a new pharmacologic genus. Br J Pharmacol. 2007 Oct 29;153(1:S):200-15.

52. Chow CK, editor. Fatty acids in foods and their health implications. Third ed. Boca Raton: CRC Press; 2008.
53. Gottlicher M, Widmark E, Li Q, Gustafsson JA. Fatty acids activate a chimera of the clofibric acid-activated receptor and the glucocorticoid receptor. Proc Natl Acad Sci U S A. 1992 May 15;89(10):4653-7.
54. Chow CK. Fatty Acids in Foods andTheir Health Implications. Third, illustrated, revised ed. Chow CK, editor. Boca Raton: CRC Press; 2007.
55. Horton JD, Goldstein JL, Brown MS. SREBPs: transcriptional mediators of lipid homeostasis. Cold Spring Harb Symp Quant Biol. 2002;67:491-8.
56. Pawar A, Jump DB. Unsaturated fatty acid regulation of peroxisome proliferator-activated receptor alpha activity in rat primary hepatocytes. J Biol Chem. 2003 Sep 19;278(38):35931-9.
57. Kishida E, Tajiri M, Masuzawa Y. Docosahexaenoic acid enrichment can reduce L929 cell necrosis induced by tumor necrosis factor. Biochim Biophys Acta. 2006 Apr;1761(4):454-62.
58. Williard DE, Harmon SD, Kaduce TL, Preuss M, Moore SA, Robbins ME, et al. Docosahexaenoic acid synthesis from n-3 polyunsaturated fatty acids in differentiated rat brain astrocytes. J Lipid Res. 2001 Sep;42(9):1368-76.
59. Langelier B, Alessandri JM, Perruchot MH, Guesnet P, Lavialle M. Changes of the transcriptional and fatty acid profiles in response to n-3 fatty acids in SH-SY5Y neuroblastoma cells. Lipids. 2005 Jul;40(7):719-28.

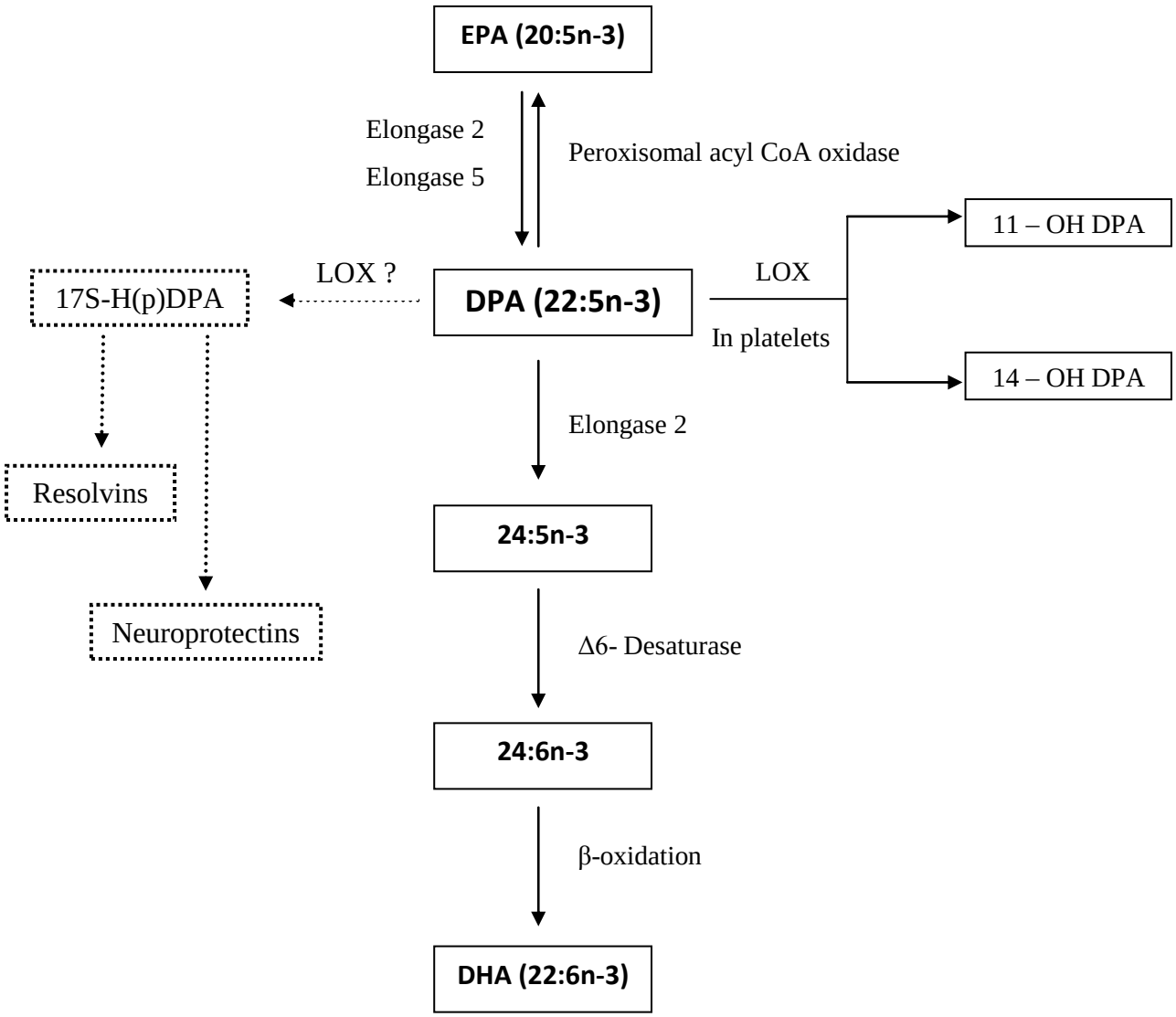

Fig 1: *Metabolites of n-3 DPA. DPA forms two hydroxy acids (11- and 14-OH DPA) via an indomethacin-insensitive pathway. DPA can be retro-converted into EPA in cells and animals and is likely to involve the peroxisomal acyl coA oxidase. Since n-3 DPA is known to be metabolized by LOX enzymes, it is speculated that n-3 DPA might also act as a precursor for production of DPA-related D-series of resolvins or neuroprotectins.*

(Abbreviations: EPA – Eicosapentaenoic acid; DPA – Docosapentaenoic acid; DHA – Docosahexenoic acid; LOX – Lipooxygenase; OH DPA – Hydroxy docosapentaenoic acid; 17S-H(p)DPA – 17S hydro (peroxy) docosapentaenoic acid.)

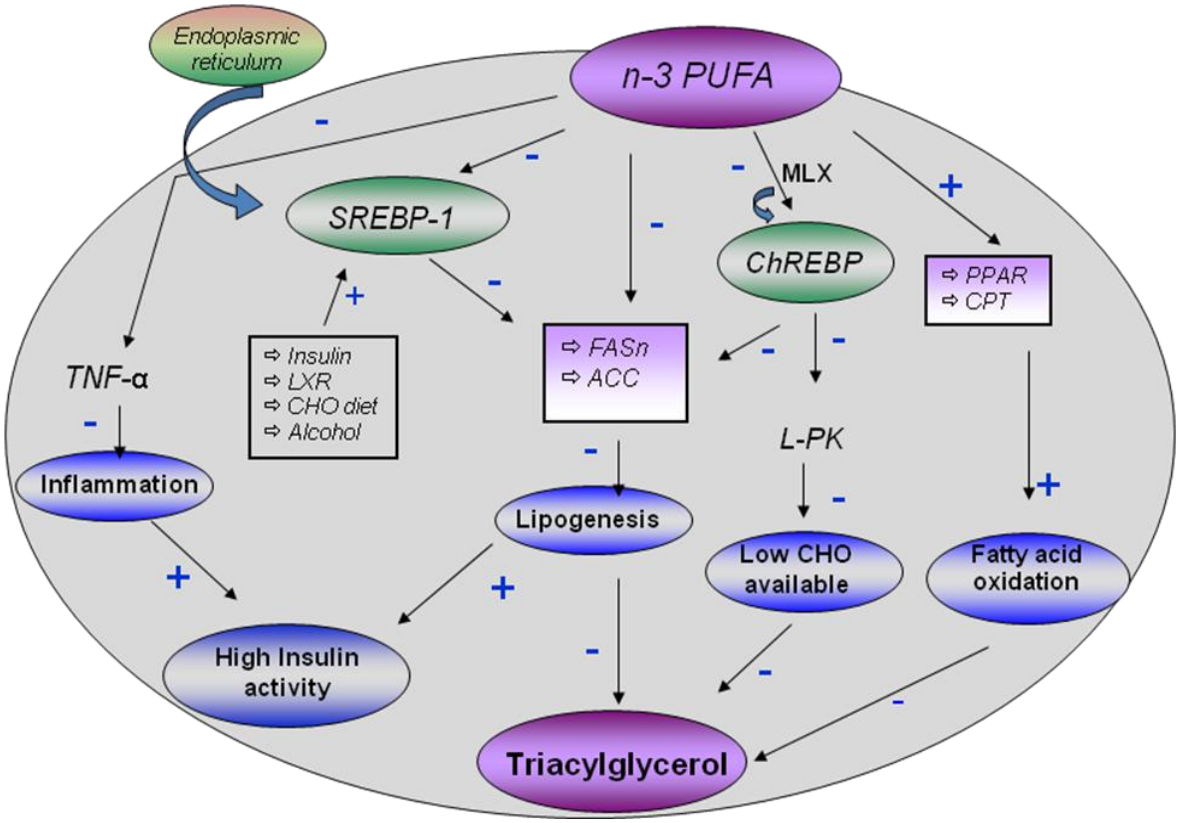

Fig 2 *Mechanisms involved in triacylglycerol lowering effect of n-3 VLCPUFA. n-3 VLCPUFA mediate the triacylglycerol lowering effect by upregulating fat oxidation genes like PPAR and CPT-1. They also downregulate the genes involved in fat synthesis like SREBP-1c, ACC and FASn, thereby decreasing the fat synthesis n-3 VLCPUFA also decrease expression of ChREBP which inturn lowers the expression of L-PK and lower the amount of carbohydrates available for triacylglycerol synthesis. (PUFA polyunsaturated fatty acids; PPAR peroxisome proliferator receptor ; CPT-1 carnitine palmitoyl transferase 1; SREBP-1c sterol regulatory element binding protein, L-PK liver pyruvate kinase, ACC acetyl CoA carboxylase; FASn fatty acid synthase; ChREBP carbohydrate response element binding protein.)*

582 **Table 1: List of literature available on n-3 DPA**

Year	Author	Model	Findings
***In vitro* and *ex vivo* Studies**			
1984	Careaga and Sprecher	Human platelets	Platelets metabolize 7,10,13,16,19-DPA (22:5(n-3)) into ll-hydroxy-7,9,13,16,19- and 14-hydroxy-7,10,12,16,19-DPA via an indomethacin-insensitive pathway. n-3 DPA inhibits the synthesis of both 5,8,10-heptadecatrienoic acid and thromboxine B_2 from arachidonic acid.
1991	Rosenthal et al	Fibroblasts and retinoblasts	Although fibroblasts desaturate [14C]22:5(n-3), the process appears to be qualitatively different from that of retinoblastoma cells.
1993	Christensen et al	Fibroblasts	Peroxisomal acyl CoA oxidase is responsible for the chain-shortening of DHA and n-3 DPA.
1995	Achard et al	Endothelial cells	EPA, n-3 DPA and DHA are actively interconverted to each other in endothelial cells.
1996	Benistant et al	Endothelial cells	n-3 DPA bound to albumin produced two-fold less prostacyclin compared to control cells when stimulated with endogenous arachidonic acid-mobilizing agents
1996	Kanayasu-Toyoda et al	Endothelial cells	The stimulative effect of EPA on EC migration occurs via n-3 DPA, and that n-3 DPA may act as a powerful anti-atherogenic factor.
2000	Akiba et al	Rabbit platelets(*ex vivo*)	EPA, n-3 DPA and DHA inhibit collagen- or arachidonic acid-stimulated platelet aggregation dose-dependently among which n-3 DPA was the most potent inhibitor.
2001	Arita et al	Human promyelocytic leukemia cells	n-3 VLCPUFA including n-3 DPA-induce apoptosis of leukemia cells (HL-60), in part by direct action on the cells and by activation of the caspase cascade through cytochrome *c* release coupled with mitochondrial membrane depolarization.
2001	Williard et al	Rat brain astrocytes	Astrocytes can synthesise and incorporate [3-^{14}C]DHA into the cell PL from [3-^{14}C]ALA and [3-^{14}C]DPA and also release it into the media as free fatty acid (58).

2003	Tsuji et al	Endothelial cells	n-3 DPA suppressed tube-forming activity induced by vascular endothelial growth factor (VEGF) and n-3 DPA has a potent inhibitory effect on angiogenesis through the suppression of VEGFR-2 expression
2003	Pawar and Jump	Hepatocytes	Metabolic labelling indicated that a significant fraction of 14C-EPA was elongated to n-3 DPA in hepatocytes. Cells treated with DPA or DHA led to a significant accumulation of EPA in the NEFA pool. EPA and DHA, but not n-3 DPA, are active ligands for PPARα.
2005	Langelier et al	Neuroblastoma cells	The incorporation of EPA, DPA, and preformed DHA followed a dose–response saturating curve, whereas that of DHA synthesized either from α-LNA, EPA, or DPA peaked at concentrations of precursors below 15–30 μM and sharply decreased with higher doses. DPA was readily formed from EPA and DHA was formed from both EPA and n-3 DPA (59).
2006	Kishida et al	Fibrosarcoma cells	Attenuation of TNF-induced necrosis by the supplementation of various C20 or C22 polyunsaturated fatty acids is mainly attributable to the enrichment of three kinds of polyunsaturated fatty acids, i.e., DHA, n-3 DPA or AA, in cell phospholipids.
2009	Phang et al	Human platelets (*ex vivo*)	EPA was significantly more effective in reducing platelet aggregation compared with n-3 DPA and DHA. However, when grouped by gender, in females all three n-3VLCPUFA were effective. But in men EPA was more effective than n-3 DPA and DHA.
***In vivo* Studies**			
1993	Alvarez et al	Miniature poodle dogs	Intravitreal injection of dogs with ^{14}C-DPA (n-3) led to formation of ^{14}C-DHA in the rod outer segment lipids. There was no difference in % dpm of DHA generated in normal dogs and dogs affected with progressive rod-cone degeneration. There was also evidence of label in 24:5 n-3 and 24:6 n-3.
2009	Kaur et al	Sprague Dawley rats	n-3 DPA can be converted to DHA in the liver, in a short-term study, and that in addition it is partly retroconverted to EPA in liver, adipose, heart and skeletal muscle.
2009	Gotoh et al	C57BL/KsJ-db/db mice	n-3 DPA and DHA treatment decreased the hepatic TG levels compared to the control while EPA was most effective in reducing serum TG levels.

2010	Kelly et al	Young and aged rats	Oral doses of n-3 DPA downregulated microglial activation and decreased the activation of sphingomyelinase and caspase 3 and consequently attenuated the age-related decrease in spatial learning and long-term potentiation.
Association Studies			
2000	Rissanen et al	-	Men in the highest fifth of the proportion of serum DHA + n-3 DPA in all fatty acids had a 44% reduced risk of acute coronary events compared with men in the lowest fifth in a prospective population study.
2005	Oda et al	-	Serum levels (%weight) of linolenic acid, EPA, n-3 DPA, and total n-3 VLCPUFA were significantly lower in patients with acute myocardial infarction than the control group in a case control study.

583

584 (Abbreviations: EPA – Eicosapentaenoic acid; n-3 DPA – Docosapentaenoic acid; DHA – Docosahexaenoic acid; LOX – Lipooxygenase)

585