Effects of dietary fatty acids on reproduction in ruminants

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Fats in the diet can influence reproduction positively by altering both ovarian follicle and corpus luteum function via improved energy status and by increasing precursors for the synthesis of reproductive hormones such as steroids and prostaglandins. Dietary fatty acids of the n-3 family reduce ovarian and endometrial synthesis of prostaglandin F2α, decrease ovulation rate in rats and delay parturition in sheep and humans. Polyunsaturated fatty acids such as linoleic, linolenic, eicosapentaenoic and docosahexaenoic acids may inhibit prostaglandin F2α synthesis through mechanisms such as decreased availability of its precursor arachidonic acid, an increased competition by these fatty acids with arachidonic acid for binding to prostaglandin H synthase, and inhibition of prostaglandin H synthase synthesis and activity. It is not known whether polyunsaturated fatty acids regulate expression of candidate genes such as phospholipase A2 and prostaglandin H synthase via activation of nuclear transcription factors such as peroxisome proliferator-activated receptors. Manipulation of the fatty acid profile of the diet can be used potentially to amplify suppression of uterine synthesis of prostaglandin F2α during early pregnancy in cattle, which may contribute to a reduction in embryonic mortality. Feeding fats and targeting of fatty acids to reproductive tissues may be a potential strategy to integrate nutrition and reproductive management to improve animal productivity.

Several studies report improved reproductive performance in lactating dairy cows fed supplemental fat. A recent review on the effects of dietary fat on fertility of dairy cows showed that 11 of 20 articles reported improvement (Staples et al., 1998). Authors suggest that this effect was probably not a result of improvement of the energy status of the cow but that increased fertility could be due to effects of dietary fatty acids on the pituitary, ovaries and uterus.

Fats are classified as lipids, which are biological compounds that are soluble in organic solvents. Lipids include cholesterol and fats such as triacylglycerols and phospholipids. Phospholipids are major components of cellular membranes, and are a source of fatty acids for the synthesis of a variety of effector molecules such as the eicosanoids, a group of compounds that includes prostaglandins, thromboxanes and leukotrienes. Cholesterol is another component of the cellular membrane and is the precursor for the synthesis of steroid hormones.

The structure of fatty acids, that is, the length of the acyl chain, the number of double bonds in the chain, and the types of isomer formed by each double bond largely determines their function. Saturated fatty acids do not have double bonds in the acyl chain. Unsaturated fatty acids are classified into different families according to the position of the first double bond relative to the methyl end. For example, linoleic acid has 18 carbon atoms and two double bonds (C18:2), with its first double bond at the sixth position from the methyl end, and is therefore a member of the n-6 family. In contrast, linolenic acid (C18:3) belongs to the n-3 family because the first of its double bonds is at the third carbon position. Processing of fatty acids in one family can only generate fatty acids of the same family, i.e. a fatty acid of the n-3 family cannot be converted into a member of n-6 family and vice versa (Fig. 1).

Fatty acids present in vertebrates are either generated by de novo synthesis or are absorbed from the diet. Fatty acids from any source may undergo elongation and desaturation to generate fatty acids with different biochemical properties. Elongation involves the addition of two-carbon units to a carbon chain through the action of elongase. Desaturation is a process catalysed by desaturase enzymes that insert a double bond in the acyl chain (Fig. 1). Desaturase enzymes are classified according to the position of insertion of the double bond. For example, Δ6 desaturase inserts a double bond between the sixth and seventh carbon from the carboxyl end. The range of possible positions for insertion of double bonds varies according to the organism. In animals, desaturation of fatty acids does not occur at positions greater than Δ9 (Cook, 1996). This prevents animals from synthesizing fatty acids of the n-3 and n-6 families. Since animals have absolute requirements for some fatty acids of the n-3 and n-6 families, these fatty acids are considered to be essential and must be provided by the diet. For example, linoleic acid (C18:2, n-6) is an essential fatty acid required for the synthesis of arachidonic acid (C20:4, n-6), and of eicosanoids (Fig. 2) (Cook, 1996).

Reproduction in ruminants is associated closely with the availability of energy. Fats are glyceride esters of fatty acids and are important sources of energy. Dietary fats favour reproductive function by supplying energy and by actions on reproductive processes that are not related to energy. For example, increased availability of fatty acid precursors allows increased steroid and eicosanoid secretion, which can alter ovarian and uterine function and affect pregnancy rates. At the cell, fatty acids may have a direct effect on the transcription of genes that encode proteins that are essential to reproductive events. The focus of this review is to examine the reproductive
digestion and absorption of fats

Dietary fats can undergo modification in the rumen. Bacteria of the ruminal flora digest dietary triacylglycerols, phospholipids and galactolipids releasing fatty acids from their glycerol backbone. Released unsaturated fatty acids have some of their double bonds reduced, and the isomer orientation changed in a process called fatty acid biohydrogenation. Some PUFAs of the n-3 family, eicosapentaenoic acid (C20:5, n-3) and docosahexaenoic acid (C22:6, n-3) have been shown to undergo negligible biohydrogenation (Ashes et al., 1992). Eicosapentaenoic acid and docosahexaenoic acid are typically derived from fish oil and meal. Fat supplements partially resistant to biohydrogenation, such as calcium salts of long-chain fatty acids (CaLCFA), have been developed to increase the amount of unsaturated fatty acids reaching the duodenum and being incorporated into adipose tissue and milk.

Effect of dietary fats on LH secretion, ovarian follicular dynamics, function of corpus luteum and steroidogenesis

Secretion of LH from the pituitary and follicular growth in cattle are regulated partially by the energy status of the animal. The energy status in lactating animals has been defined as the net energy intake of the animal minus the net energy required for maintenance and that required for milk production. Negative energy states prolong post-partum anoestrus (Randel, 1990) and reduce the frequency of pulses of LH that are necessary for growth of ovarian follicles to the preovulatory stage in cattle and sheep (Schillo, 1992). Supplemental fat is included frequently in rations to increase energy concentration in the diet, which could result in an increase in energy intake and improve the energy status of the cow (Blum et al., 1995; Harrison et al., 1995; Palmquist and Weiss, 1994). Energy provided by fat supplementation increases LH secretion in animals that consume less energy than required (Hightshoe et al., 1991; Sklan et al., 1994). However, a mechanism independent from energy by which dietary fatty acids affect LH secretion has not yet been established in ruminants.

Several studies have shown that feeding supplemental fat alters the growth dynamics of the ovarian follicle and that this effect is somewhat independent from energy. Supplemental fat feeding in a manner that was isocaloric with the control diet without fat supplement stimulated programmed growth of a preovulatory follicle (Lucy et al., 1993). Effects of supplemental fat also include increased total number of follicles (Lucy et al., 1991a, b; Wehrman et al., 1991; Thomas and Williams, 1996; Beam and Butler, 1997; Lammoglia, 1997) and increased size of preovulatory follicles (Lucy et al., 1990, 1991a, 1993; Beam and Butler, 1997; Oldick et al., 1997). Increased size of preovulatory follicles may be due to increased concentrations of plasma LH, which stimulates the latter stage of follicular growth. Further research is required to determine whether dietary fatty acids affect the secretion of LH and whether increased size and numbers of follicles are associated with increased pregnancy rates.

In one study, fat supplementation increased the concentration of total cholesterol in follicular fluid. This finding might be related to the fact that granulosa cells collected from follicles of supplemented cows showed increased progesterone and androstenedione secretion in vitro (Wehrman et al., 1991). The ovulation of larger follicles, as observed in the supplemented
Dietary fat supplementation in cows consistently increases plasma concentrations of cholesterol (Grummer and Carroll, 1991), the precursor for the synthesis of progesterone. The fact that ruminants treated with supplemental fat often have small increases in plasma concentrations of progesterone (Staples et al., 1998) indicates that greater availability of cholesterol results in increased secretion of progesterone. However, incubation of dispersed bovine luteal cells with PUFAs such as eicosapentaenoic and docosahexaenoic acid decreases the secretion of progesterone (Hinckley et al., 1996). Further research is required to determine whether dietary fats affect progesterone secretion in vivo.

There is also evidence for a reduced rate of clearance of progesterone when animals are supplemented with fats. When the corpora lutea of cows were removed by ovariectomy, the rate of decrease of plasma concentrations of progesterone observed was smaller in cows fed a fat supplement of CaLCFA than in cows not fed supplemental fat (Hawkins et al., 1995). Increased concentrations of plasma progesterone in the luteal phase before and after insemination have been associated with higher pregnancy rates (Butler et al., 1996; Maurer and Etchernkamp, 1982). Since progesterone prepares the uterus for implantation of the embryo and helps maintain pregnancy by stimulating histotroph for nourishment of the conceptus, increased plasma progesterone may improve pregnancy rates in animals fed supplemental dietary fat.

**Dietary fatty acids and synthesis of prostaglandins**

Prostaglandins are one type of bioactive compound derived from 20 carbon fatty acids (Box 1). Prostaglandins of the 2 series (for example PGF$_{2\alpha}$) are important regulators of parturition, and, in some species, cause regression of the corpus luteum that leads to the initiation of a new oestrous cycle. Arachidonic acid (AA; C20:4 n-6) can be processed by PGHS, eicosanoid and lipoxygenase to generate prostaglandins of the 2 series, eicosanoid and di-HETEs, respectively. DAG, diacylglycerol.
Box 1. Eicosanoids

The bioactive compounds derived from 20 carbon fatty acids include prostaglandins, thromboxanes and leukotrienes, which are grouped under the general term eicosanoids. Prostaglandins and thromboxanes are products of the prostaglandin H synthase (PGHS) pathway and are called prostanoids. The fatty acids dihomom-γ-linolenic, arachidonic acid and eicosapentaenoic acid are precursors for the synthesis of prostanoids of the 1, 2 and 3 series, respectively (Bergstrom et al., 1984). The number of the series corresponds to the number of double bonds in the prostanoid, that is, prostaglandin F$_{2a}$ (PGF$_{2a}$) contains 2 double bonds.

of phospholipase A$_2$ (PLA$_2$). Released arachidonic acid can be processed by the PGHS enzyme complex to produce prostanoids and thromboxanes (PGD$_2$, PGE$_2$, PGF$_{2a}$, TXA$_2$, PGI$_2$), by lipoxigenases to produce leukotrienes (LT$A_4$, LTB$_4$, LTC$_4$, LTD$_4$) and hydroxyeicosatetraenoic acids (HETEs), and by cytochrome P$_{450}$ epoxygenases to produce epoxyeicosatrienoic acids (EETs) (Fig. 2). Arachidonic acid is stored in the phospholipids of the cellular plasma membrane and its concentrations are relatively high in rat uterine tissues (5–10% of total uterine lipid (Howie et al., 1992)). The PGHS contains both cyclooxygenase (COX) and peroxidase activity, and converts arachidonic acid into PGH$_2$. This compound is processed further by the different prostaglandin synthases to generate PGD$_2$, PGE$_2$, PGF$_{2a}$, TXA$_2$ and prostacyclin (PGI$_2$).

Essential fatty acids of the n-3 and n-6 families have been shown to inhibit the secretion of eicosanoids in several cell types cultured in vitro (Levine and Worth 1994; Achard et al., 1997). Other studies have demonstrated reduced eicosanoid synthesis when fatty acids of the n-3 and n-6 families are fed in the diet. Supplementation of dairy cows with fish meal (5.4% of the diet) resulted in an attenuation of the induced PGFM response in peripheral plasma, in response to an injection of oxytocin on day 15 of a synchronized oestrous cycle (Oldick et al., 1997). Collectively, these results indicate that high concentrations of PUFAs in the diet can decrease the endometrial secretion of prostaglandins.

The dynamics of bovine corpus luteum regression in response to exogenous PGF$_{2a}$ also can be altered by dietary fish meal. Cows ($n = 56$) were fed fish meal at either 0 or 2.8% of diet dry matter from about 24–109 days post-partum. On day 58 post-partum all cows were injected with a luteolytic dose of PGF$_{2a}$. Two days after injection of PGF$_{2a}$, the proportion of cows with plasma concentrations of progesterone that were >1 ng ml$^{-1}$ was greater when fish meal was included in the diet than when the control diet was fed (29 versus 4%) (Burke et al., 1997). Thus, it is possible that fatty acids present in the fish oil reduce the sensitivity of the corpus luteum to PGF$_{2a}$. Since eicosapentaenoic acid present in fish meal is the precursor for the formation of the vasodilatory PGI$_3$ (Needelman et al., 1979), it is possible that the delay in corpus luteum regression is mediated by a partial neutralization of the vasconstrictive action of PGF$_{2a}$ that normally occurs during luteolysis. Alternatively fish meal feeding may reduce the uterine secretion of PGF$_{2a}$ that delayed the completion of functional luteolysis.

Involvement of PUFAs in the suppression of PGF$_{2a}$ secretion during early pregnancy in cows also has been demonstrated. When monitoring the metabolism of radiolabelled arachidonic acid by bovine microsomes, addition of endometrial cytosol from pregnant cows had a greater inhibitory action than that from non-pregnant cows at day 17 of the oestrous cycle (Thatcher et al., 1994). Purification indicated that the inhibitor was enriched in linoleic acid. The ability of linoleic acid to inhibit PGHS activity has been reported by Pace-Asciak and Wolfe (1968) and Thatcher et al. (1994).

Increased pregnancy rates observed when fat supplements are fed may be mediated by reduced PGF$_{2a}$ secretion from the uterus and decreased sensitivity of the corpus luteum to PGF$_{2a}$. Suppression of PGF$_{2a}$ secretion and maintenance of the corpus luteum are obligatory steps for establishment of pregnancy in cows, and failures in this process can cause the loss of up to 40% of the pregnancies (Ayalon, 1978; Maurer and Chenault, 1983; Thatcher et al., 1994). Reducing PGF$_{2a}$ secretion through the feeding of PUFAs could improve fertility by reducing embryonic losses caused by defective suppression of PGF$_{2a}$ secretion during early pregnancy.

Effects of prostaglandins on ovulation

Prostaglandins E$_2$ and F$_{2a}$ are important mediators of the ovulatory process. Their concentration in follicular fluid increases sharply before ovulation. The administration of inhibitors of prostaglandin synthesis such as indomethacin blocks ovulation in rats, rabbits, pigs, sheep, monkeys and humans through the reductions of both PGE$_2$ and PGF$_{2a}$ (Sogn et al., 1987). When rats were fed diets containing high concentrations of eicosapentaenoic acid and docosahexaenoic acid, the number of corpora lutea found after the first oestrus was reduced. Since the release of GnRH in the rat has been associated with activation of PGE$_2$-dependent pathways (Ojeda et al., 1979; DePaolo et al., 1982; Kim and Ramirez, 1986; Zhang et al., 1992), eicosapentaenoic and docosahexaenoic acids may have caused a decrease in
hypothalamic synthesis of PGE₂, which prevented GnRH re-
lease and decreased the frequency of ovulations. Experiments
have not been designed to examine specifically whether feeding
of supplemental fats, such as fish meal or fish oil, interferes
with ovulation of the preovulatory follicle in cattle. However,
after injection of GnRH and PGE₂ given 7 days apart, oestrous
detection and conception rates to the synchronized service
were normal in cows that were fed fish meal (Burke et al.,
1997).

Effects of prostaglandins on labour
Parturition is a process that is accompanied by the massive
release of prostaglandins. Alterations of fatty acids in the
endometrium have been described in normal parturition, and
manipulations of fatty acid content used experimentally to
delay onset of parturition. Fatty acids of the n-3 family
have been shown to affect uterine activity during parturition
in rats and sheep, and to delay the onset of parturition in
humans (Olsen et al., 1992). Supplementing linoleic acid to
a diet deficient in essential fatty acids resulted in an impair-
ment of parturition in rats (Leat and Northrop, 1979). This
also occurred when fish oil was given to rats as the major
dietary essential fatty acid source, and an inhibition of uterine
synthesis of PGE₂ was detected (Leaver et al., 1986). In pre-term
pregnant sheep, intravenous infusion of a 20% n-3 fatty acid
emulsion resulted in a delay in the onset of induced labour
and delivery compared with a control group infused with
an emulsion of soybean oil containing 7% n-3 fatty acids. In
animals treated with the 20% n-3 fatty acid infusion, maternal
and fetal plasma concentrations of PGE₂ were lower than in
control animals, suggesting a possible effect on PGHS. Infusion
of betamethasone resulted in a decrease of plasma pro-
gesterone concentrations in both groups and in an increase in
oestriadiol concentration only in animals of the control group
(Baguma-Nibashaka et al., 1999). These workers suggested that
n-3 fatty acids may have affected the conversion of pro-
gesterone to oestriadiol by downregulating placental 17β-
hydroxylase (P₂⁰⁵ 17β-OH). Since oestriadiol upregulates PGHS,
it is possible that PGE₂ did not increase in the n-3 treated group
because of insufficient oestriadiol support. An alternative expla-
nation is that labelling the phospholipid pools with n-3 fatty
acids altered the dynamics of prostaglandin secretion. Indeed,
concentrations of eicosapentaenoic acid esterified to membrane
phospholipids of the ovine endometrium normally drop sig-
nificantly during the last third of gestation (Zhang et al.,
1995). This finding suggests that factors inhibitory to prostaglandin
synthesis are decreased before parturition. Concentrations of
arachidonic acid in endometrial phospholipids of sheep de-
clined during labour, suggesting utilisation for synthesis of prosta-
glandins of the 2 series can occur through a reduction in the
synthesis of arachidonic acid or through displacement of exist-ent arachidonic acid from the phospholipid pool by other fatty
acids (Fig. 3).

Reduced synthesis of arachidonic acid
One possible step contributing to the reduction of uterine
content of arachidonic acid involves decreased synthesis of
arachidonic acid in uterine tissue or in tissues that are exporters
of fatty acids. Since there are no reports of arachidonic acid
synthesis in the ruminant endometrium, supply from the circu-
lation is likely the most important source. Desaturation in
ruminants occurs primarily in adipose tissue as the ruminant
liver has a limited capacity for exporting triacylglycerols and
lipoproteins (Emery et al., 1992). Synthesis of arachidonic acid
in the liver can be decreased by high concentrations of PUFAs
in the diet, as dietary PUFAs, particularly eicosapentaenoic
acid and docosahexaenoic acid, are major inhibitors of desatu-
rature and elongation in liver cells (Fig. 3; Bezard et al.,
1994).

Dietary supplementation of rats with fish oil (eicosapenta-
enoic acid and docosahexaenoic acid) or linseed oil (high in
linolenic acid) reduced the Δ6, Δ5 and Δ9 desaturation of linoleic
acid and linolenic acid by liver microsomes, and the concen-
tration of arachidonic acid in liver phospholipids (Christiansen
et al., 1991; Garg et al., 1988). In addition, when fish oil rich in
n-3 fatty acids was fed to rats, there was an increase in the incor-
poration of n-3 fatty acids into liver microsomal lipid rela-
tive to the n-6 fatty acid family. Incubation of tissues containing
desaturase activity with PGFAs also decreases desaturation.
The Δ5 and Δ6 desaturase activity of rat hepatoma cells was re-
duced when they were incubated with eicosapentaenoic acid
and docosahexaenoic acid (Larsen et al., 1997). In one study,
elongation activity was increased and desaturation decreased
when rat hepatoma cells were incubated with fatty acids of
the n-3 and n-6 families (De Alaniz and De Gomez Dumm,
1990).

Competition of n-3 fatty acids for desaturase activity
Another step to account for reduced arachidonic acid syn-
thesis involves preferential processing of n-3 fatty acids by
Δ6 desaturase at the expense of desaturation of n-6 fatty acids
(Sprecher, 1981). When deuterated linoleic acid and linolenic
acid were fed simultaneously to humans, the conversion of
linolenic acid to eicosapentaenoic acid and docosahexaenoic
acid was greater than the conversion of linoleic acid to arachid-
onic acid (Emken et al., 1990). In this case, the presence of high
concentrations of linoleic acid in the diet would compete with
linoleic acid for binding with Δ6 desaturase and reduce the con-
version of linoleic acid to arachidonic acid. In human intestinal
epithelial cells, the desaturation–elongation pathway was re-
ported to have a preference for linolenic acid and to be subject
to an efficient feedback regulation by eicosapentaenoic acid
(Chen and Nilsson, 1993).

Altered fatty acid profile in the plasma membrane
Reduced availability of arachidonic acid for incorporation
into phospholipids of the plasma membrane will result in
greater incorporation of other fatty acids, which may or may
not be precursors of other eicosanoids (Fig. 3). Indeed, displacement of arachidonic acid from cell membrane phospholipids has been demonstrated in animals fed diets rich in n-3 fatty acids. Trujillo and Broughton (1995) reported a significant reduction in the proportion of arachidonic acid present in phospholipids extracted from liver cells from rats fed for 4 weeks with diets rich in n-3 fatty acids. The fatty acid composition of the diet was related to the content of C20 and C22 fatty acids in the rat uterus (Howie et al., 1992). Feeding a diet rich in n-3 fatty acids for 3 weeks resulted in a 50% replacement of the rat uterine phospholipid pool of n-6 fatty acids with n-3 fatty acids. Another interesting finding of this study was the ability of the uterus to conserve a relatively stable concentration of arachidonic acid in its lipid pools in spite of a prolonged period of dietary deprivation of its precursors. This conservation of arachidonic acid was further supported by the fact that rats fed diets with a n-3:n-6 ratio that was 700–800 times greater than that of rats fed the control diet. On the basis of this observation, it was proposed that the process of incorporation of fatty acids into uterine lipid pools is selective and favours the incorporation of arachidonic acid. Other studies also support this concept (Leaver and Ning, 1981; Ning et al., 1983). Nevertheless, arachidonic acid pools can be replaced substantially by feeding n-3 fatty acids. Changes in uterine fatty acid composition were detected 3 weeks after the introduction of treatment diets, indicating that the metabolic turnover of the uterine phospholipid pool is high.

**Competition of PUFAs for PGHS**

Another possible mechanism for dietary reduction in prostaglandin synthesis is the competition of PUFAs such as dihomom-g-linolenic (C20:3, n-6) and eicosapentaenoic with arachidonic acid for PGHS (Fig. 3). Increased amounts of eicosapentaenoic acid could result in increased synthesis...
of prostaglandins of the 3 series, and reduced synthesis of PGF\textsubscript{2\alpha}. Consequently, reproductive responses regulated by PGF\textsubscript{2\alpha} would be reduced. Concentrations of arachidonic acid in the rat uterus are consistently greater than those of dihomo-\gamma-linoleic and eicosapentaenoic acid, even when high eicosapentaenoic acid diets are fed. However, the ratio of eicosapentaenoic acid:arachidonic acid can be altered considerably through manipulation of the diet (Howie \textit{et al.}, 1992). Indeed, feeding rats with diets rich in n-3 fatty acids resulted in increased secretion of prostaglandins of the 3 series from uterine explants cultured \textit{in vitro} (Leaver \textit{et al.}, 1991).

**Inhibition of PGHS synthesis and activity**

The PUFAs can also inhibit PGHS synthesis \textit{in vitro} (Achard \textit{et al.}, 1997), and competitively inhibit the conversion of arachidonic acid to prostaglandins of the 2 series (Corey \textit{et al.}, 1983; Fig. 3). When bovine aortic endothelial cells where incubated with eicosapentaenoic acid or docosahexaenoic acid, PGHS-1 mRNA was reduced. Since the reduction in PG\textsubscript{I}\textsubscript{2} synthesis was greater than the reduction in PGHS-1 message, these authors suggested that the activity of PG\textsubscript{I} was affected (Achard \textit{et al.}, 1997). Incubation of rat hepatoma cells with arachidonic acid, eicosapentaenoic acid, docosahexaenoic acid, or with heineicosapentaenoic acid (C\textsubscript{21}:5, n-3), a synthetic fatty acid, caused reductions in activity of the COX enzyme, a component of PGHS. Eicosapentaenoic acid inactivated the enzyme almost completely when added 30 s before addition of arachidonic acid as substrate (Larsen \textit{et al.}, 1997). Although there are no data indicating that PGHS synthesis is inhibited \textit{in vivo} by dietary PUFAs, findings from studies \textit{in vitro} support this concept and may partially explain reduced secretion of eicosanoids when high concentrations of PUFAs are fed.

**Effects on gene expression**

Dietary fatty acids inhibit the expression of genes involved in hepatic lipogenesis (Jump \textit{et al.}, 1996) and may repress genes involved in the synthesis of prostaglandins, such as those encoding PLA\textsubscript{2} and PGHS-2. The proposed mechanisms for regulation of gene expression by PUFAs involve activation of nuclear transcription factors such as peroxisome proliferator-activated receptors (PPARs). The PPARs interact with peroxisome proliferator response elements (PPRESP) in the regulatory region of target genes to activate or repress transcription (Jump \textit{et al.}, 1996; Fig. 3). A mechanism for repression of gene expression independent of PPARs has been proposed in which PUFAs bind to PUFAbinding proteins. The PUFA–PUFA binding protein complex then binds to response elements to repress gene transcription (Sessler and Ntambi, 1998). To date, it is not known whether PPARs regulate PLA\textsubscript{2} and PGHS-2 genes in the uterus.

Collectively, these findings suggest that increasing dietary PUFA can alter the synthesis of prostaglandins of the 2 series by: (i) partial replacement of arachidonic acid in phospholipid pools, which limits the amount of arachidonic acid precursor available for prostaglandin synthesis; (ii) decreasing arachidonic acid biosynthesis by inhibition of \Delta\textsubscript{6} and \Delta\textsubscript{5} desaturase enzymes that are necessary for conversion of linoleic acid to arachidonic acid; (iii) acting as a direct competitive inhibitor with arachidonic acid for PGHS; and (iv) directly decreasing gene expression of PGHS.

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