

Documentation of Fatty Acid Profiles in Lamb Meat and Lamb-Based Infant Foods

Anna Nudda, Michelle K. McGuire, Gianni Battacone, Maria G. Manca, Roberta Boe, and Giuseppe Pulina

Abstract: Lamb meat, when used in the weaning diet of children, is presumed to have a lower allergenicity than other forms of red meat. In children with atopic dermatitis and multiple food hypersensitivities, consumption of lamb meat has also resulted in significant clinical improvements in the severity of the eczematous lesions. Lamb meat is also of special interest in infant nutrition because it provides a somewhat unique fatty acid (FA) profile that mirrors what is thought to be optimal for neonatal growth and development. However, very little is known about how the processing of fresh meat (FM) into prepared infant foods influences its FA composition. In this study, we compared the FA profile of FM from suckling lambs with those of homogenized (HO) and lyophilized (LIO) baby foods prepared primarily with lamb meat. The results show that the content of total omega-3 polyunsaturated FAs was the highest in FM (more than 3-fold) compared to commercial baby food, due to largely higher contents of α -linolenic acid (1.5-fold higher), eicosapentaenoic acid (6-fold higher), and docosahexaenoic acid (10-fold higher). Furthermore, arachidonic acid was more than 6-fold higher in FM compared to LIO and HO. Results from this study suggest the possibility of enhancing the FA profile of commercial baby food based on meat by using lamb meat, but care should be taken during processing so that important FAs are not lost.

Keywords: fatty acids, infant food, meat quality, nutrition, omega-3

Practical Application: In this article, we have documented that meat from the suckling lamb is an interesting and potentially important source of omega-3-FAs, especially some of the long-chain polyunsaturated FAs (LC-PUFAs) that are essential for optimal neonatal growth and development. These results may have special implications to the infant food industry, in that products made using meat from suckling lambs may provide not only exceptional amounts of these FAs, but also other limiting essential nutrients such as iron. This may be especially important in regions of the world, such as Italy, where use of lamb meat as a weaning food is common during infancy.

Introduction

The importance of fatty acids (FAs), especially long-chain polyunsaturated FAs (LC-PUFAs) for optimal fetal and neonatal growth and development, is well documented (Koletzko and others 2008). Of particular interest in this regard are arachidonic acid (ARA; C20:4 n6) and docosahexaenoic acid (DHA; C22:6 n3) that are essential to development and function of the brain and retina (Lauritzen and others 2001). DHA and ARA are derived directly from the diet or from conversion of their respective dietary precursors α -linolenic acid (ALA, C18:3 n3) and linoleic acid (LA, C18:2 n6), respectively, in the liver (Rapoport and others 2007). Inadequate supplies of n6 and n3 FA can negatively impact the development of the central nervous system with long-term changes in learning ability and reduced visual function (Koletzko and others 2008). Experimental evidence suggests that newborns are able to synthesize some ARA and DHA from LA and ALA, respectively, via the desaturation-elongation pathways (Carnielli and

others 1996; Koletzko and others 1998), but that this is limited in early life. Due to the importance of LC-PUFA during infancy, experts in the area of infant nutrition recommend substantial dietary intake, with suggested ratios of LA to ALA of 8:1 (IOM 2002; ESPGHAN 2005).

Human milk is considered the “gold standard” for infant nutrition and the best source of all FA during early life (Fidler and others 2000; Brenna and others 2007), but by 4 to 6 mo of life addition of complementary foods (for example, fish, meat) is recommended to provide adequate amounts of certain essential nutrients such as iron. In many developed countries, commercial baby foods based on meat and fish are commonly added to the infant's diet at this time. In fact, at weaning meat is often included in a baby's meals in the form of commercially lyophilized (LIO) and homogenized (HO) products because they are considered practical to use, have high digestibility, and are presumed to be safer and more balanced from a nutritional point of view than foods prepared at home.

In Italy, the first meat frequently recommended by many pediatricians is lamb. This is related to the presumed lower allergenicity of this meat compared with other types of meat. Beef allergy is not an infrequent occurrence, with an incidence between 3.28% and 6.52% among children with atopic dermatitis (Fiocchi and others 2000). However, although lamb has been proposed as a beef “substitute” in this regard, insufficient information is available

MS 20100773 Submitted 7/9/2010, Accepted 12/5/2010. Authors Nudda, Battacone, Manca, Boe, and Pulina are with Dipt. di Scienze Zootechniche, Univ. degli Studi di Sassari, Sassari 07100, Italy. Author McGuire is with the School of Biological Sciences, Washington State Univ., Pullman, WA, U.S.A. Direct inquiries to author Nudda (E-mail: anudda@uniss.it).

on the cross-reactivity between beef and lamb protein sources in the atopic population. Nonetheless, there is some evidence that the introduction of lamb in the diet of children might have positive effects in the treatment of Short Bowel Syndrome (Cardi and others 1998a) and Sandifer Syndrome (Cardi and others 1998b). The use of lamb meat in the diet of children with atopic dermatitis and multiple food hypersensitivities has also been associated with significant clinical improvement in the severity of the eczematous lesions (Martino and others 1998). The mechanisms by which lamb might be more easily tolerated in some infants and children, however, is not known and may be due to differences in protein and lipid profiles.

Although the relative importance of FA in growing infants and young children has been documented, there is very little information published concerning FA content of meat-based baby foods. The FA composition of lamb meat is related largely to breed, feeding regimen, age at slaughter, and animal weight (Diaz and others 2005; Valvo and others 2005; Lanza and others 2006; Serra and others 2009). In addition, the origin of lamb meat may influence the final nutritional characteristics of lamb-based baby foods. The aim of this study was to compare the FA profiles of fresh lamb meat with those of commercially available, lamb-based infant foods.

Materials and Methods

Materials

Sampling was carried out between 2008 and 2009. The 2 commercial lamb-based infant foods considered were HO and LIO (freeze-dried; LIO) baby foods from different infant food companies. In particular, 5 lots of HO (with 2 samples from each lot) were collected from 3 companies (A, B, and C), for a total of 30 samples. For the LIO food, 3 lots (with 3 samples from each lot) were collected from 2 of the previous companies (one company does not produce LIO) for a total of 18 samples. The number of lots sampled depended on availability over a 6-mo period. Moreover, 32 samples of fresh meat (FM) from suckling lambs (Sarda breed) were also purchased from 4 local grocery stores ($n = 7, 5, 8$, and 12 for grocery 1, 2, 3, and 4, respectively). Specifically, samples of *longissimus dorsi* and of the leg (*semitendinosus*, *semimembranosus*, and *femoral biceps*) were selected for the analysis. After removal of the intermuscular residual adipose tissue from these muscles, the FM samples were freeze-dried and finely ground in a food processor.

Analytical procedure

The protein contents of FM and baby foods (on a wet-weight basis) were determined using a 2200 KjeltecTM automatic distillation unit (Foss Tecator, Höganäs, Sweden). Dry matter content was determined by oven drying at 105 °C for 24 h. The FA profiles were determined by gas chromatography using a gas chromatograph Varian 3400 (Varian Instrument, Palo Alto, Calif., U.S.A.). Fat was extracted from samples using the method described previously (Nudda and others 2008). The FM samples were LIO and finely ground in a food processor before analysis. Lipids were extracted with a chloroform:methanol (2:1 v/v) solution using the modified Folch method described by Clark and others (1982). Briefly, 1 g LIO sample was placed in a 50-mL tube; 30-mL chloroform:methanol (2:1) were added, the tube capped, shaken by hand for 30 s, sonicated for 5 min, and then centrifuged at 600 × g for 10 min at room temperature. The supernatant was then filtered under vacuum and 6 mL 1% NaCl (wt/vol) were added. The tube was centrifuged at approximately 600 × g for 10 min. The upper methanol:water layer was then removed using a water aspirator

and discarded. The chloroform extract layer was evaporated under nitrogen, and the residual fat (~25 mg) was transesterified. FA methyl esters (FAMES) were prepared using the standard FIL-IDF base-catalyzed methylation procedure (FIL-IDF 1999). FAMES were separated in a capillary column (CP-select CB for Fame; 100 m × 0.32 mm i.d., 0.25-μm film thickness, Varian Inc.); injector and flame ionization detector temperatures were both set at 255 °C. For all samples, the following temperature program was implemented: 75 °C for 1 min, increased at 8 °C/min to 165 °C, held for 35 min, increased at 5.5 °C/min to 210 °C, held for 1 min, and finally increased at 15 °C/min to 240 °C and held for 15 min. The split ratio was 1:40, and helium was used as the carrier gas with a pressure of 37 psi.

FAs were identified by comparing retention times of peaks with those of external methyl ester standards (Component FAME Mix; Supelco, Bellefonte, Pa., U.S.A.). In addition, PUFA-2, a nonconjugated 18:2 isomer mixture of individual PUFA, all cis-5,8,11,14,17 C20:5 (eicosapentaenoic acid, EPA), all cis-4,7,10,13,16,19 C22:6 (DHA), all cis-5,8,11,14 C20:4 (ARA), all cis-6,9,12 C18:3, and all cis-9,12,15 C18:3 (Matreya Inc., Pleasant Gap, Pa., U.S.A.) were used to identify PUFA. High purity individual isomers of conjugated LA (CLA; cis-9, trans-11 and trans-10, cis-12; Matreya Inc., Pleasant Gap) were used to identify most CLA isomers of interest. Additional standard CLA isomers cis-9, cis-11 C18:2, trans-9, trans-11 C18:2, trans-11, trans-13 C18:2 (77% cis,trans; 2% cis,cis; 6% trans,trans) (Matreya Inc., Pleasant Gap), a CLA mixture standard (Nu-Check-Prep. Inc., Elysian, Minn., U.S.A.), and published isomeric profiles (Kramer and others 2004) were used to identify the CLA isomers.

Calculation and statistical analysis

The content of each FAME was expressed as weight proportion of total FAME. The sum of n3 PUFA (C18:3, C20:5, and C22:6 n3), the sum of n6 PUFA (C18:2 n6, C20:3 n6, C20:4 n6, and C22:4 n6), and the ratio n6:n3 were calculated.

The differences between FA composition of the different foods were analyzed according to a completely randomized design with a one-way analysis of variance that included the fixed effect of type of products (HO, LIO, and FM). Differences among companies were tested separately for each baby food using linear model that included the fixed effect of brand and the random effect of lot (SAS Inst., 2003). Multiple comparisons among different levels of fixed factors in both models were performed using a Tukey test.

Results and Discussion

According to label information, the HO of all companies contained 40% of lamb meat (cooking water, corn starch, sunflower oil, citric acid) in a 80 g jar, whereas that of the LIO samples contained 85% of lamb meat in corn starch and rice flour in a 30 g jar, which correspond to 220 to 230 g of meat in 100 g of LIO product. Average protein content of LIO and HO products determined in our laboratory were in accordance with the medium protein content reported on their nutritional labels (data not shown). However, the lipid contents determined in our laboratory were lower than those reported on the nutritional labels likely due to differences in the methods of lipid extraction used. In addition, the fat contents of LIO products were highly variable among brands. Values of fat content ranged from 15.0% to 23.0% in LIO (11.7 and 18.7 ± 0.73 in brands A and B, respectively; $P < 0.01$) and from 4.0% to 5.4% in HO (3.7, 4.0 and 4.7 in brands A, B, and C, respectively; $P = 0.10$).

The FA profiles of each of the FM and the 2 commercial baby products are reported in Table 1. The statistical analysis showed differences among the 3 products tested for all FAs. For instance, the FM samples showed the highest content of PUFA n3 (more than 300% greater than the commercial products) mainly due to higher contents of C18:3 n3 and especially EPA (6-fold higher) and DHA (10-fold higher). The contents of PUFA n3 in HO and LIO were higher than values observed in baby food based on beef meat (Nudda and others 2009). The DHA content of FM from Sarda lambs was found to be comparable to those reported previously for other breeds (Serra and others 2009) but higher than that found in lamb meat from heavier animals fed a grass-based diet (Demirel and others 2006; Bessa and others 2008). DHA has not been detected in commercial baby food products containing beef, veal, chicken, and turkey (Elmadfa and Majchrzak 2000). Because LC-PUFAs are incorporated preferentially into membrane phospholipids rather than the neutral lipid fraction (Jerónimo and others 2009), the high content of LC-PUFA in the FM compared to commercial baby food suggests the use of meat obtained from fatter or heavier animals in the latter. It is noteworthy that suckling lambs from Sarda dairy ewes are generally slaughtered at a live weight of about 10 kg, and in adult animals the content of LC-PUFA n3 is very low (Nudda and others 2007). However, technological factors, such as cooking methods and heating, could also influence the FA composition of meat (Alfaia and others 2010).

The proportion of LC (C18:2 n6) in HO products was almost 3-fold higher than that of LIO and 5-fold higher than FM samples. This finding is probably related to the presence of vegetable oil in HO, usually sunflower oil that is particularly rich in C18:2 n6 (Shingfield and others 2006). In contrast, the content of c9,t11-CLA was higher in FM and LIO than in HO. The content of

vaccenic acid (VA; C18:1 t11), which represents more than 75% of the total C18:1 *trans* FA in most meat products, was lower in FM compared to LIO and HO samples and ranged from 1.1% to 3.1% in FM, 1.9% to 5.5% in LIO, and 0.2% to 5.3% in HO.

Interestingly, findings on the effects of consuming CLA have shown that this fat has potentially beneficial effects on human health (McGuire and McGuire 2000), and CLA (specifically the c9,t11-CLA isomer) consumption during “adolescence” in rats has lasting impact on reduction of the risk of mammary cancer (Ip and Thompson 1995; Thompson and others 1997). In addition, high CLA content in meat may improve meat processing characteristics in different species (Wiegand and others 2002).

It is assumed that the c9,t11-CLA isomer in body fat of ruminants originates mainly from endogenous synthesis from VA (Madron and others 2002), the major biohydrogenation intermediate of LA, and ALA produced in the rumen. However, suckling lamb is functional nonruminants, so there is little ruminal biohydrogenation of dietary FAs before they are absorbed from the intestine. Therefore, the content of VA is related to the VA content in the milk produced by the lactating ewe. As such, the content of CLA in lamb meat is partly related to the content of CLA in the ewe's milk and partly to the endogenous synthesis by VA through delta-9 desaturase activity. Due to the product:precursor relation between these 2 FAs, foods rich in CLA are generally also rich in VA. This is important because, in addition to ruminants, the conversion of VA to c9,t11-CLA has been reported in humans (Turpeinen and others 2002). The high content of VA and c9,t11-CLA in baby food samples suggest the inclusion of pasture in the diet of the animals from which the meat was obtained.

The proportion of ARA was more than 6-fold higher in FM compared to LIO and HO samples. ARA is one of the main

Table 1—Fat and protein contents and fatty acid profiles (mean $\pm$ SEM) of fresh lamb meat (FM) and homogenized (HO) and lyophilized (LIO) baby foods based on lamb meat.

	FM	LIO	HO	P-value
Protein, %	18.7 ^b $\pm$ 0.25	43.13 ^a $\pm$ 0.26	8.05 ^c $\pm$ 0.20	**
Fat, %	3.4 ^b $\pm$ 0.38	15.1 ^a $\pm$ 0.51	4.0 ^b $\pm$ 0.39	**
Moisture, %	74.8 ^a $\pm$ 0.72	1.9 ^a $\pm$ 0.93	81.6 ^a $\pm$ 0.72	**
Fatty acid (g/100 g)				
<C14	0.83 ^a $\pm$ 0.07	0.48 ^b $\pm$ 0.09	0.36 ^b $\pm$ 0.07	**
C14:0	5.46 ^a $\pm$ 0.32	3.78 ^b $\pm$ 0.42	2.37 ^b $\pm$ 0.32	**
C14:1	0.16 ^a $\pm$ 0.01	0.11 ^b $\pm$ 0.02	0.10 ^b $\pm$ 0.01	*
C16:0	20.71 ^a $\pm$ 0.51	22.62 ^a $\pm$ 0.68	17.42 ^b $\pm$ 0.53	**
C16:1	1.11 ^a $\pm$ 0.06	1.45 ^a $\pm$ 0.08	0.92 ^b $\pm$ 0.07	**
C18:0	14.18 ^b $\pm$ 0.44	20.69 ^a $\pm$ 0.59	15.72 ^b $\pm$ 0.45	**
C18:1 t11	2.18 ^b $\pm$ 0.24	3.70 ^a $\pm$ 0.33	2.96 ^{ab} $\pm$ 0.25	*
C18:1 c9	34.76 ^a $\pm$ 0.52	33.95 ^{ab} $\pm$ 0.69	32.47 ^b $\pm$ 0.54	**
C18:2 c9,c12 (LN)	6.26 ^b $\pm$ 1.21	3.11 ^b $\pm$ 1.62	19.51 ^a $\pm$ 1.25	**
C18:3 n3 (ALA)	1.30 ^a $\pm$ 0.05	0.91 ^b $\pm$ 0.07	0.85 ^b $\pm$ 0.05	**
CLA c9,t11	1.37 ^a $\pm$ 0.09	1.30 ^a $\pm$ 0.23	0.97 ^b $\pm$ 0.10	**
C20:4 n6 (ARA)	2.03 ^a $\pm$ 0.16	0.29 ^b $\pm$ 0.21	0.36 ^b $\pm$ 0.16	**
C20:5 n3 (EPA) ¹	0.65 ^a $\pm$ 0.05	0.08 ^b $\pm$ 0.06	0.11 ^b $\pm$ 0.05	**
C22:5 n3 (DPA) ²	0.96 ^a $\pm$ 0.06	0.22 ^b $\pm$ 0.08	0.21 ^b $\pm$ 0.06	**
C22:6 n3 (DHA) ³	0.64 ^a $\pm$ 0.05	0.05 ^b $\pm$ 0.07	0.05 ^b $\pm$ 0.05	**
CLA total	1.80 ^a $\pm$ 0.10	1.81 ^a $\pm$ 0.14	1.49 ^b $\pm$ 0.10	*
PUFA n3	3.56 ^a $\pm$ 0.18	1.25 ^b $\pm$ 0.24	1.22 ^b $\pm$ 0.19	**
PUFA n6	8.76 ^b $\pm$ 1.26	3.42 ^b $\pm$ 1.68	19.91 ^a $\pm$ 1.30	**
n6:n3	2.57 ^b $\pm$ 1.72	2.82 ^b $\pm$ 2.29	19.13 ^a $\pm$ 1.78	**
SFA ⁴	42.78 ^b $\pm$ 1.04	50.42 ^a $\pm$ 1.39	38.24 ^c $\pm$ 1.08	**
MUFA ⁵	42.06 ^a $\pm$ 0.47	44.90 ^a $\pm$ 0.63	40.63 ^b $\pm$ 0.49	**
PUFA ⁶	12.31 ^b $\pm$ 1.30	4.68 ^c $\pm$ 1.73	21.13 ^a $\pm$ 1.34	**
SFA:UFA	0.76 ^b $\pm$ 0.03	1.02 ^a $\pm$ 0.04	0.65 ^c $\pm$ 0.03	**
LA:ALA	4.81 ^a $\pm$ 2.62	3.25 ^b $\pm$ 3.49	33.45 ^b $\pm$ 2.70	**
ARA:DHA	3.57 ^a $\pm$ 0.45	6.56 ^b $\pm$ 0.64	7.09 ^b $\pm$ 0.52	**

** $P \leq 0.01$, * $P \leq 0.05$.

^{a,b,c} values within the same row with different superscript differ significantly ($P < 0.05$).

¹Eicosapentaenoic acid; ²docosapentaenoic acid; ³docosahexaenoic acid; ⁴saturated fatty acid; ⁵monounsaturated fatty acid; ⁶polyunsaturated fatty acid.

FAs of the brain. ARA supplementation, together with DHA, is considered essential for normal neural development of the infant (Carlson 2001). Supplementation of ARA alone has been shown to improve neurodevelopment of offspring from healthy and diabetic rats (Zhao and others 2009). For this reason, ARA is now a component of many infant formulas available throughout the world. The amount of ARA supplementation needed for optimal development is still undefined, but some clinical evidence suggest that an ARA:DHA ratio $>1:1$ was associated with improved cognitive outcomes (Hoffman and others 2009). However, the ARA has not been detected in samples of baby food products containing beef, veal, chicken, or turkey (Elmadfa and Majchrzak 2000).

The ratio of $n6:n3$ was 19:1 in HO, which is much higher than that of 2 to 3:1 normally recommended in the diet (Simopoulos 2008). The high content of LA in HO baby food may be one reason for the high levels of PUFA $n6$ and ratio of $n6$ to $n3$ essential FAs ($n6:n3$) in HO samples compared to LIO and FM samples. A similar ratio of $n6:n3$ was previously observed in HO baby food based on beef (Nudda and others 2009). In contrast, the FM and LIO had a more appropriate balance between $n3$ and $n6$ FAs both having an $n6:n3$ ratio of 2.8:1. In infant nutrition, there is likely even greater significance of obtaining the most beneficial LA:ALA ratio in the diet, because this may be an important factor in allowing ARA and DHA biosynthesis. Because both ARA and DHA are essential for normal neural development of the infant, infant diets should likely have an LA:ALA ratio of approximately 8:1 (IOM 2002) with a minimum of 5:1 and maximum of 15:1 (ESPGHAN 2005).

The recommended intake of some FA in the infant diet has been reported by scientific experts in the area of infant nutrition (IOM 2002). The adequate intake of PUFA $n3$ has been estimated to be 0.5 g/d in children 6 to 12 mo of age. Considering lamb meat with a lipid content of 3.5 g/100 g and 3.56% of PUFA $n3$ of total FA (Table 1), and that the total FA in lamb meat is about 70% to 75% of total lipids (Alfaia and others 2007), it can be approximately estimated that 100 g of raw meat can satisfy 18% of recommended daily allowance for PUFA $n3$. The adequate intake of LC-PUFA such as DHA has not yet been defined, but the World Assn. of Perinatal Medicine, Early Nutrition Academy, and Child Health Foundation (Koletzko and others 2008) stated that that DHA consumption should reach at least 0.2% of FA and not exceed 0.5% of total FA. The mean value of 0.35% of DHA and $<0.1\%$ of EPA on total FA in infant formula/diet has been previously reported at the Workshop on the Essentiality of and Recommended Dietary Intakes for Omega-6 and Omega-3 FAs (Simopoulos and others 1999). On the basis of this recommendation, intake by babies of 1 y that need about 30 g/d of fat (IOM 2002), 100 g of lamb meat can satisfy almost 15% of the minimum recommended level of DHA intake.

Conclusions

In conclusion, the composition of LIO samples demonstrated high variability in terms of total fat content and FA composition among the brands. However, in general, FA composition was more similar between LIO and FM samples than between HO and FM samples, probably as a consequence of the high level of vegetable oil added to HO products. Conversely, meat used for LIO products probably originated from lambs that were older and/or heavier than suckling lambs, as reflected by lower levels of PUFA. In conclusion, the use of meat from suckling lambs for baby foods may provide a reliable way to improve essential and LC-PUFA content of LIO products. However, the seemingly common use of

vegetable oil as an ingredient of HO products may cause potentially important modifications of FA composition and, consequently, lead to a difference in FA profiles of FM- and HO-based infant food products.

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