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CANINE PLASMA AND TISSUE FATTY ACID PROFILES AND THEIR CORRELATION WITH HAIR COAT CONDITIONS

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SUMMARY

This study was initiated to study the probable relationships between the fatty acid profiles of the plasma, skin, liver and brain and to determine their correlations with hair coat conditions in owned and stray dogs. A total of 35 dogs were used in this study. Twenty-three owned dogs obtained from the University Veterinary Hospital (UVH dogs) were subjected to blood sampling and hair coat scoring only. Twelve euthanized dogs were sourced from a local animal shelter (LAS dogs) and blood, brain, liver and skin samples were obtained. Hair coat scores were performed under standardized conditions and was found that the UVH dogs (median score = 4.1) had significantly better scores compared to LAS dogs (median score = 3.1, $P<0.05$). The UVH dogs had significantly lower ($P<0.05$) n-6:n-3 ratios and lower plasma arachidonate content. The skin and plasma fatty acid profiles correlated well with each other but no correlation was evident between the brain and plasma fatty acid profiles. Increased amounts of plasma and skin n-3 and n-6 polyunsaturated fatty acids were associated with better hair coat conditions. However, plasma n-6 fatty acids seemed to have a stronger positive correlation to hair coat scores in dogs ($\rho = 0.683$, $P<0.05$) compared to plasma n-3 fatty acids ($\rho = 0.512$, $P<0.05$) and fatty acid profiles from other tissues. In summary, this report underscores the importance of n-3 and n-6 fatty acids to the hair coat condition of dogs kept under humid tropical conditions.

Keywords: Dogs, hair coat, polyunsaturated fatty acids

INTRODUCTION

Fatty acids are critical for the maintenance of the epidermal barrier function in animals, in particular the palmitic acid, stearic acid, and both the n-3 and n-6 fatty acids (Thompson, 1992). The stearic and palmitic acids are critical saturated fatty acids (SFA) in membrane phospholipids, whereas n-3 and n-6 fatty acids play important roles in regulating the membrane fluidity and integrity. The linolenic acid (18:2 n-6) and alpha-linolenic acid (18:3 n-3) are also known as the essential fatty acids (EFA) as mammalian tissues lacked the necessary enzymes to synthesize them. These fatty acids are also important for the regulation of the metabolic and immune functions of the mammalian body (Newton, 1997). The n-3 fatty acids comprise a group of metabolically active polyunsaturated fatty acids (PUFA) derived from the elongation and desaturation of alpha linolenic acid. The n-6 fatty acids and their metabolites originated from linoleic acid. Both n-3 and n-6 PUFA contribute significantly to the regulation of cell membrane fluidity and skin health, and thus affect the hair coat condition of animals directly (Gurr *et al.,* 2002). It is known that increased intakes of n-3 fatty acids had been associated with better skin and hair coat condition in small animals (Watson, 1998) and laboratory animals such as guinea pigs (Fu and Sinclair, 2000). Accumulating data also indicate that n-3 fatty acids are capable of attenuating inflammatory processes in the mammalian body, such as atopy in dogs (Abba *et al.,* 2005), chronic renal disease (Donadio *et al.,* 1994), inflammatory bowel disease (Haumann, 1997), limiting radiation-induced damage on pig skins (Hopewell *et al.,* 1992) and improving hair coat conditions in horses (Goh *et al.,* 2004). However, it is imperative that both n-3 and n-6 fatty acids co-exist in a balanced proportion in the animal body. This is due to the fact that they compete for the same enzyme system that would result in the activation of pro-inflamatory (via n-6 fatty acid metabolites) or anti-inflamatory responses (via n-3 fatty acid metabolites) within the host itself (Lands, 1992).

The majority of published reports do not describe the specific changes in the fatty acid profile of metabolically active organs such as the liver and brain in relation to hair coat conditions. This is probably because most published works have limited access to cadaveric animals for tissue samplings. Moreover, the resistance of brain tissues to diet-induced fatty acid profile changes seemed to have de-emphasized this need (Anding and Hwang, 1986). It is known that the liver is a very important organ for fatty acid synthesis, storage and mobilization in mammals (Gurr *et al.,* 2002), and skin tissues depend solely on fatty acids transported by the blood plasma (Lloyd, 1989), derived from fatty acid synthesis sites such as the liver (Li *et al.,* 1992). Therefore, it is probable that any changes in hair coat conditions linked to both skin and plasma fatty acid profile changes could be traced to the changes in liver fatty acid compositions. If given

enough time, the altered hepatic fatty acid profile might result in measurable changes to the brain fatty acid profiles. Thus, the aim of this study was to explore the probable correlations between the fatty acid profiles of the plasma, skin, liver and brain with hair coat scores of owned and stray dogs kept under Malaysian conditions.

MATERIALS AND METHODS

Animal subjects

A total of 35 dogs were used in this study. Twenty-three were owned dogs obtained with their owners' consent at the University Veterinary Hospital (UVH), Faculty of Veterinary Medicine, Universiti Putra Malaysia, and 12 euthanized dogs from a local animal shelter (LAS). All dogs were within the 2–10 year-old age range. The UVH dogs comprised 14 males and 9 females with an average bodyweight of 12.3 ± 5.2 kg (mean ± SD). These dogs were brought to the University Veterinary Hospital by their owners for routine check-ups or other minor procedures. Dogs from the animal shelter (LAS) comprised an equal number of males and females, with an average bodyweight of 10.2 ± 2.7 kg. Plasma fatty acid profiles and hair coat scores were determined from all 35 dogs, while the 12 LAS dogs were used exclusively to investigate the correlations between tissue and plasma fatty acids. The dietary information, clinical and hair coat management history were collected for all dogs whenever possible.

Plasma and tissue samplings

The UVH dogs were subjected to blood sampling only, whereas the euthanized LAS dogs contributed blood plasma, skin, brain and liver samples. Three mL of blood were collected from each animal into ethyldiaminetetraacetate (EDTA) Vacutainer™ tubes and centrifuged at 1000 G to obtain the plasma. Blood from the euthanized LAS dogs was obtained at the point of euthanasia at the animal shelter. Carcasses of the euthanized dogs were transported immediately within an hour to the Faculty of Veterinary Medicine, UPM for post mortem and body organ samplings. All tissue samples were wrapped with aluminium foil and stored at -20°C until total lipids determination.

Plasma and tissue fatty acid profile determination

The total fatty acids were extracted from the plasma and organ samples using the chloroform-methanol 2:1 (v/v) solvent system. Forty mL of chloroform-methanol (2:1, v/v) were added to three mL of plasma or 0.5 g of homogenised organ sample in a 50 mL stoppered tube. The mixture was shaken, flushed with nitrogen and sealed. The mixture was left to stand for at least 12 h and was then filtered through a No.1 Whatman filter paper into a separating flask. Five mL of chloroform-methanol (2:1, v/v) was used to wash the lipid residue on the tube and the filter paper. Ten mL of normal saline was then added into the separating flask to facilitate phase separation. The mixture was then left to stand for at least 4 h. After complete separation, the lower phase was collected into a round flask bottle and evaporated by rotary evaporation at 70-75°C. The extracted lipids were transferred into methylation tubes with stoppers and chloroform-methanol (2:1, v/v) was added to a final volume of five mL. The lipid extract was then dried and concentrated under nitrogen gas. The fatty acids were transmethylated to fatty acid methyl esters (FAME) using 14% methanolic boron trifluoride, and separated on a Supelco SP™-2330 fused silica capillary column (30m, 0.25mm ID, 0.20 µm film thickness, Supelco Inc., Bellefonte, PA, USA) in a 5890 Hewlett-Packard Gas-Liquid Chromatograph (Hewlett-Packard Co., Avondale, PA, USA) equipped with a Flame Ionization Detector (FID). Purified nitrogen gas flowing at 40 mL/min was used as the carrier gas. The injector temperature was programmed at 200°C and the detector at 250°C. The column temperature was set at a range of 100-190°C with temperature increment programmed at a rate of 7.2°C/min to facilitate separation. Identification of the fatty acid methyl esters was based on the comparison of the sample retention times to those of a known fatty acid methyl ester standard (Sigma Chemical Co., St Louis, MO, USA). An internal standardisation method was used to quantify the various fatty acids in the plasma, where a known concentration of heneicosanoic acid (21:0) (Sigma Chemical Co., St Louis, MO, USA) was added to each sample prior to transmethylation.

Hair coat scoring

None of the dogs had a history of grooming or usage of any hair coat-enhancing products within a month prior to this study. Apart from bathing frequencies, all dogs had similar hair coat management histories. Hair coat scores were performed on dogs that had not been bathed for two weeks. This corresponded to the minimum interval between baths for both UVH and LAS dogs. The hair coat condition for each dog was photographed and scored using a five-point scoring system adapted from Goh *et al.* (2004). Score of 1 described a dull hair coat with coarse and broken hair distributed over the entire body surface area. Score 2 pointed to a dull hair coat condition with coarse and broken hair distributed over half of the total body surface area. Score 3 described a dull hair coat with few patches of broken hair visible. Score 4 pertained to a reasonably smooth and shiny hair coat with occasional traces of broken or loose hairs. Score 5 was given to dogs with a very smooth, shiny and healthy looking hair coat with no trace of broken or loose hairs.

Table 1: Plasma fatty acid profile and hair coat score comparisons between UVH and LAS dogs

	UVH dogs (n=23)		LAS dogs (n=12)	
Plasma fatty acids	(mean ± SD mg/100g)	%	(mean ± SD mg/100g)	%
Lauric acid (12:0)	1.1 ± 0.3	0.2	0.7 ± 0.3	0.2
Myristic acid (14:0)*	3.7 ± 0.9	0.8	2.2 ± 1.0	0.5
Palmitic (16:0)*	81.9 ± 11.1	18.3	69.4 ± 7.2	16.5
Palmitoleic (16:1)*	3.1 ± 0.5	0.7	2.6 ± 0.4	0.6
Stearic (18:0)	79.5 ± 11.0	17.8	73.2 ± 8.0	17.4
Oleic (18:1)*	69.9 ± 9.3	15.6	55.2 ± 5.7	13.2
Linoleic (18:2 n-6)	113.5 ± 8.5	25.4	116.3 ± 10.1	27.7
Linolenic (18:3 n-3)*	11.6 ± 2.3	2.6	6.8 ± 2.1	1.6
Arachidic (20:0)*	0.4 ± 0.1	0.1	0.8 ± 0.3	0.2
Eicosaenoic (20:1)	nd		nd	
Arachidonic (20:4 n-6)*	82.2 ± 8.8	18.4	92.5 ± 9.6	22.0
Eicosapentaenoic (20:5 n-3)	nd		nd	
Docosapentaenoic (22:5 n-3)	nd		nd	
Docosahexaenoic (22:6 n-3)	nd		nd	
Total saturated fatty acids (SFA)	166.6 ± 20.5	37.3	146.3 ± 11.5	34.9
Total unsaturated fatty acids (UFA)	280.3 ± 18.8	62.7	273.4 ± 20.1	65.1
Total PUFA n-3 (or n-3 fatty acids)*	11.6 ± 2.3	2.6	6.8 ± 2.1	1.6
Total PUFA n-6 (or n-6 fatty acids)	195.7 ± 12.1	43.8	208.8 ± 16.6	49.7
n-6 : n-3 ratio*	16.9		30.7	
UFA : SFA ratio	1.7		1.9	
Median hair coat score*	4.1		3.1	

* absolute values were significantly different at P<0.05;
nd = not detected; PUFA = polyunsaturated fatty acids

Data analyses

The fatty acid values were expressed both as the absolute amount of each fatty acid in milligrams per 100g tissue (mg/100g) and as a percentage of total fatty acids (%). The absolute amount of each plasma fatty acid in the UVH dogs was compared to their equivalents from the LAS dogs using the independent T-test procedure. Hair coat score and ratiometric data differences between the UVH and LAS groups were analysed using the Mann-Whitney non-parametric test. The Pearson's correlation was performed to investigate the relationships between plasma and tissue n-3 and n-6 fatty acid profiles, and their correlations with hair coat scores were elucidated using the Spearman's rank correlation. All statistical analyses were performed using the SPSS software at 95% confidence level (SPSS, 2004).

RESULTS

The plasma fatty acid profile and hair coat scores of the UVH dogs were different from the LAS dogs (Table 1). Hair coat condition was significantly better (P<0.05) among the owned dogs in the UVH group. All dogs within the UVH group had different dietary histories and this explained the moderately high coefficient of variation (0.13 – 0.27) observed for each plasma fatty acid in Table 1. The linolenic acid and total n-3 fatty acids content were significantly higher (P<0.05) in the plasma of UVH dogs. Although both the plasma total n-6 fatty acids and linoleic acid content were similar in both groups, the UVH dogs had significantly lower plasma arachidonic acid (P<0.05). This had contributed to a lower n-6:n-3 ratio in the plasma of UVH dogs at 16.9 versus 30.7 for the LAS dogs.

Table 2 shows the tissue fatty acid profile in the brain, liver and skin of LAS dogs. It is clear that the fatty acid amount and composition are different between organs. The long chain n-3 fatty acids such as the eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA) and docosahexaenoic acid (DHA) were not detected in skin samples, whereas the brain lacked DPA. Brain samples had a total of 4237.2 mg/100g fatty acids, compared to the liver and skin at 2419 mg/100g and 1882 mg/100g, respectively. Proportionally, the unsaturated fatty acids (UFA) content of the skin approximated that of the plasma at about 68%. Both the brain and liver had between 52 – 58% of their total fatty acids as UFA. The n-6 fatty acids were the major PUFA in the liver at 33.6%, followed by the skin at 26.3%, while the brain had a more balanced proportion of n-3 and n-6 fatty acids. It was also interesting to note that the skin had the lowest proportion and absolute amount of arachidonic acid among the three organs, although it had a sizable amount of linoleic acid. The precursor fatty acid for the n-3 fatty acids - the linolenic acid - comprised about 1% of the total fatty acid content in each organ, although its

Table 2 : Brain, liver and skin fatty acid profiles from the LAS dogs (n=12)#

Fatty acids	Brain		Liver		Skin	
	(mg/100g)	%	(mg/100g)	%	(mg/100g)	%
Lauric acid (12:0)	nd		1.6 ± 0.2	0.1	nd	
Myristic acid (14:0)	23.1 ± 3.6	0.5	29.0 ± 3.1	1.2	nd	
Palmitic (16:0)	906.7 ± 99.8	21.4	409.3 ± 37.2	16.9	388.5 ± 26.8	20.6
Palmitoleic (16:1)	25.3 ± 2.1	0.6	21.9 ± 3.5	0.9	12.1 ± 1.8	0.6
Stearic (18:0)	1068.4 ± 123.2	25.2	589.1 ± 50.2	24.4	195.4 ± 18.1	10.4
Oleic (18:1)	1261.3 ± 101.7	29.8	335.7 ± 31.8	13.9	751.9 ± 57.5	40.0
Linoleic (18:2 n-6)	53.0 ± 9.6	1.3	402.4 ± 39.6	16.6	366.6 ± 23.8	19.5
Linolenic (18:3 n-3)	29.8 ± 6.6	0.7	19.7 ± 3.2	0.8	21.1 ± 2.5	1.1
Arachidic (20:0)	1.3 ± 0.3	0.0	5.4 ± 0.8	0.2	0.9 ± 0.1	0.0
Eicosaenoic (20:1)	1.1 ± 0.3	0.0	3.9 ± 0.9	0.2	16.2 ± 1.4	0.9
Arachidonic (20:4 n-6)	445.1 ± 52.1	10.5	411.2 ± 37.5	17.0	129.3 ± 11.3	6.9
Eicosapentaenoic (20:5 n-3)	118.5 ± 16.3	2.8	56.8 ± 14.4	2.3	nd	
Docosapentaenoic (22:5 n-3)	nd		18.0 ± 2.7	0.7	nd	
Docosahexaenoic (22:6 n-3)	303.6 ± 46.5	7.2	115.0 ± 16.7	4.8	nd	
Total saturated fatty acids (SFA)	1999.5 ± 198.2	47.2	1034.4 ± 93.4	42.8	584.8 ± 43.1	31.1
Total unsaturated fatty acids (UFA)	2237.7 ± 156.3	52.8	1384.6 ± 112.5	57.2	1297.2 ± 95.9	68.9
Total PUFA n-3 (n-3 fatty acids)	451.9 ± 50.0	10.7	209.5 ± 19.9	8.7	21.1 ± 2.5	1.1
Total PUFA n-6 (n-6 fatty acids)	498.1 ± 53.2	11.8	813.6 ± 38.1	33.6	495.9 ± 36.7	26.3
n-6 : n-3 ratio	1.1		3.9		23.5	
UFA : SFA ratio	1.1		1.3		2.2	

nd = not detected; PUFA = polyunsaturated fatty acids

no statistical analysis was performed as the values had very different variances

Table 3: Correlations between plasma and tissue n-3 fatty acid profiles in the LAS dogs (n=12)

	Correlation with plasma total n-3 fatty acid
Skin total n-3 fatty acid	r = 0.096, P<0.05
Liver total n-3 fatty acid	Not correlated
Brain total n-3 fatty acid	Not correlated

Table 4: Correlations between plasma and tissue n-6 fatty acid profiles in the LAS dogs (n=12)

	Correlation with plasma total n-6 fatty acid
Skin total n-6 fatty acid	r = 0.122, P<0.05
Liver total n-6 fatty acid	r = 0.105, P<0.05
Brain total n-6 fatty acid	Not correlated

concentration seemed to be higher in the brain tissues. However, the presence of huge amounts of long chain n-3 fatty acids such as EPA, DPA and DHA in the brain lowered the n-6 : n-3 ratio to around 1.1. This was in stark contrast to the skin at 23.5 where n-6 fatty acids dominated.

Results from Tables 3 and 4 demonstrate that the n-3 and n-6 fatty acid profiles of the skin and plasma were weakly correlated to each other. The liver total n-6 fatty acids were weakly correlated with the plasma n-6 fatty acids, although this was not the case for the total n-3 fatty acids in the liver. The brain n-3 and n-6 fatty acid profiles were not correlated to their equivalents in the plasma at all.

It was found that increased plasma n-3 and n-6 fatty acid levels were associated with a better hair coat scores (ρ = 0.401, P<0.05). The plasma n-6 fatty acids had a stronger correlation with the hair coat score (ρ=0.683, P<0.05) compared to the plasma n-3 fatty acids versus hair coat score (ρ=0.512, P<0.05). However, the plasma n-6 to n-3 ratios did not correlate significantly with the hair coat scores. In general, the skin fatty acid profiles had significant but moderate correlation with the hair coat score. The reduction of n-6 and n-3 ratios in the skin was found to be correlated with better hair coat conditions. Only the total n-6 fatty acids concentration in the liver was positively correlated to the hair coat score of the UVH and LAS dogs. The other liver fatty acid parameters along with those from the brain tissues did not correlate with the hair coat condition of the dogs at all.

DISCUSSION

In general, none of the experimental subjects in this study exhibited n-3 or n-6 fatty acid deficiencies. Essential fatty acid deficiency among cats and dogs is rather uncommon. It is usually characterized by the extreme depletion of n-3 or n-6 fatty acids along with the appearance of the eicosatrienoic acid (20:3 n-9), or commonly known as the "Mead acid" (Gurr *et al.,* 2002).

The UVH and LAS dogs had different plasma fatty acid profiles due to differences in their dietary regimes. In fact, dietary fat sources and the level of fatty acid intake are crucial determinants of the plasma and tissue fatty acid compositions (Campbell *et al.,* 1995). It was clear that the UVH dogs had a lower n-6:n-3 ratio as a result of a higher total n-3 fatty acids and lower plasma arachidonate. These may explain the better hair coat scores among the UVH dogs, as balanced n-3 and n-6 fatty acids metabolism are known to regulate skin health in dogs (Campbell, 1993). Abba *et al.* (2005) have also reported that decreased plasma arachidonic acid concentration is associated with less severe forms of skin atopy, and thus better skin health in dogs. The n-3 fatty acids exert their anti-inflammatory effects on the skin and local tissues via two mechanisms. Firstly, the presence of higher n-3 fatty acids in the skin and plasma promote the formation of anti-inflammatory metabolites *in situ*. These metabolites modulate the eicosanoid production by disrupting the arachidonic acid (AA) cascade, resulting in the formation of anti-inflammatory leukotrienes (such as LT_5, series-5 leukotriene) instead of pro-inflammatory leokotrienes (for example LT_4, series-4 leukotriene) (Marsella and Olivry, 2001; Larsson *et al.,* 2004). Secondly, a higher concentration of n-3 fatty acids would suppress the concentration of longer chained, pro-inflammatory n-6 fatty acids, such as the arachidonic acid. It is known that dogs readily convert linoleic acid to arachidonic acid compared to humans (Lloyd, 1990). However, the efficiency of this conversion can be inhibited by the presence of more n-3 fatty acid as both n-3 and n-6 fatty acids compete for the same elongase-desaturase enzyme system in the mammalian body (Gurr *et al.,* 2002). Collectively, presence of anti-inflammatory agents in the local tissues tends to suppress epidermal reaction and promote healthier hair coat growth (Goh *et al.,* 2004).

The tissue fatty acid composition and concentrations from the canine brain, liver and skin were very different from each other. The liver and brain had longer chain derivatives of the n-3 fatty acid which were not present in the skin, such as EPA, DPA and DHA. Although dietary fatty acid intake played an important role in determining the tissue fatty acid profile of the body (Campbell *et al.,* 1995), organ systems such as the brain is more resistant to dietary fatty acid changes (Anding and Hwang, 1986). This is due to the brain's functional requirement for long chain n-3 fatty acids to facilitate nervous functions (Poulos, 1995). This also explained the lack of correlation between plasma and brain fatty acid profiles seen in Tables 3 and 4.

Table 5 : Plasma and tissue n-3 and n-6 fatty acid profiles, and their correlations with hair coat scores

Fatty acid parameters	Correlation with hair coat scores
Plasma total n-3 fatty acid	$\rho = 0.512$, $P<0.05$ (n=35)[&]
Plasma total n-6 fatty acid	$\rho = 0.683$, $P<0.05$ (n=35)[&]
Plasma total (n-3 + n-6) fatty acid	$\rho = 0.401$, $P<0.05$ (n= 35)[&]
Plasma n-6 : n-3 ratio	Not correlated
Skin total n-3 fatty acid	$\rho = 0.322$, $P<0.05$ (n=12)[#]
Skin total n-6 fatty acid	$\rho = 0.309$, $P<0.05$ (n=12)[#]
Skin total (n-3 + n-6) fatty acid	$\rho = 0.239$, $P<0.05$ (n=12)[#]
Skin n-6 : n-3 ratio	$\rho = -0.101$, $P<0.05$ (n=12)[#]
Liver total n-3 fatty acid	Not correlated
Liver total n-6 fatty acid	$\rho = 0.182$, $P<0.05$ (n=12)[#]
Liver total (n-3 + n-6) fatty acid	Not correlated
Liver n-6 : n-3 ratio	Not correlated

[&] Inclusive of 23 UVH dogs & 12 LAS dogs
[#] 12 LAS dogs only

The liver is the principal site for fatty acid storage and synthesis prior to their distribution to other organs and tissues in mammals (Li *et al.,* 1992). It is an important site for n-3 and n-6 fatty acid elongation and therefore contained a sizable amount of long chain n-3 and n-6 fatty acids. In fact, the liver typically had the highest proportion of fatty acids as the arachidonic acid compared to the other organs (Park and Washington, 1993). Therefore, it is not surprising that the liver from LAS dogs had EPA and DHA, as well as the highest percentage of arachidonic acid among the three tissue samples.

The skin n-3 and n-6 fatty acid profiles were weakly correlated to the plasma fatty acid profiles, probably due to the fact that the skin derived most of its fatty acid supply from the plasma without further modification (Lloyd, 1989). This was unlike the fatty acid profiles observed in the metabolically active brain and liver tissues. The weak correlation may be due to the wide variation in plasma and tissue fatty acid profiles observed for the LAS dogs. However, the variation was necessary to enable a wider range of fatty acid values *vis-à-vis* skin scores to be correlated effectively (Heath, 1995). Thus, it can be concluded that the plasma n-3 and n-6 fatty acid profiles are good indicators for the skin n-3 and n-6 fatty acid status.

This study showed that both skin and plasma fatty acid profiles correlated significantly with the hair coat scores. This is understandable as the mammalian hair coat condition is very much dependent upon the existence of balanced n-3 and n-6 fatty acid metabolism as discussed earlier. The brain fatty acid profiles were not expected to be correlated to hair coat scores as its metabolic and functional demand for fatty acids was very different from that of the skin. However, it was a different scenario for the liver as it served as an organ for fatty acid storage and synthesis (Li *et al.,* 1992). Plasma n-6 fatty acids in the plasma, skin and liver seemed to have a stronger correlation with hair coat scores compared to the n-3 fatty acid probably due to their larger presence in these tissues. An increase in the total PUFA or total n-3 and n-6 fatty acids in plasma and skin samples was associated with better hair coat scores. This was similar to that reported by Rees *et al.* (2001). Hair coat scores were also noted to improve as the skin n-6:n-3 ratio decreased. In fact, the dietary n-6:n-3 ratio has been recommended at about 5 : 1 for good skin health in dogs (Abba *et al.,* 2005). This evidence further reaffirms the necessity of PUFA for hair coat health in dogs. This points to the benefits of adding n-3 and n-6 PUFA as part of the constituents in pet foods for better skin and hair-coat conditions in local dogs.

CONCLUSIONS

In conclusion, the n-3 and n-6 fatty acid profiles of the plasma and skin were correlated to each other, but not between plasma and brain. In fact, the n-3 and n-6 fatty acid profiles of the skin and plasma are the major determinants of hair coat conditions in dogs.

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REFERENCES

Abba, C., Mussa, P.P., Vercelli, A. and Raviri, G. (2005). Essential fatty acids supplementation in different-stage stopic dogs fed on a controlled diet. *Journal of Animal Physiology and Animal Nutrition* **89**:203 – 207.

Anding, R.H. and Hwang, D.H. (1986). Effects of dietary linolenate on the fatty acid composition of brain lipids in rats. *Lipids* **21**:697 – 701.

Campbell, K. (1993). Clinical use of fatty acid supplement in dogs. *Veterinary Dermatology* **4**:167–173.

Campbell, K.L., Czarnecki-Maulden, G. L. and Schaeffer, D.J. (1995). Effects of animal and soy fats and proteins in the diet on fatty acid concentrations in the serum and skin of dogs. *American Journal of Veterinary Research* **56**:1465–1469.

Donadio, J.V., Bergstralh, E.J., Offord, K.P., Spencer, D.C. and Holley, K.E. (1994). A controlled trial of fish oil in IgA nephropathy. *New England Journal of Medicine* **331**:1194–1199.

Fu, Z. and Sinclair, A.J. (2000). Increased alpha-linolenic acid intake increases tissue alpha-linolenic acid content and apparent oxidation with little effect on tissue docosahexaenoic acid in the guinea pig. *Lipids* **35**:395–400.

Goh, Y.M., Mohd-Azam, G.K., Sia, J.Y., Shri, K. and Law, F.L. (2004). Plasma n-3 and n-6 fatty acid profiles and their correlations to hair coat scores in horses kept under Malaysian conditions. *Jurnal Veterinar Malaysia* **16(1&2)**:31–37.

Gurr, M.I., Harwood, J.L. and Frayn, K.N. (2002). Lipid Biochemistry: An Introduction. 5th ed. Oxford, United Kingdom: Blackwell Science Ltd.

Haumann, B.F. (1997). Nutritional aspects of n-3 fatty acids. *INFORM* **8**:428–447.

Heath, D. (1995). An Introduction to Experimental Design and Statistics for Biology. London: UCL Press.

Hopewell, J.W., Robbins, M.E.C. and van den Aardweg, G.J.M.J. (1992). The modulation of radiation-induced damage to pig skin by essential fatty acids. *Cancer Research* **3**:703–727.

Lands, W.E.M.(1992). Biochemsitry and physiology of n-3 fatty acids. *FASEB Journal* **6**:2530–2536.

Larsson, S.C., Kumlin, M., Ingelman-Sundberg, M. and Wolk, A. (2004). Dietary long chain n-3 fatty acids for the prevention of cancer : a review of potential mechanisms. *American Journal of Clinical Nutrition* **79**:935–945.

Li, J., Wetzel, M.G., and O'Brien, P.J. (1992). Transport of n-3 fatty acids from the intestine to retina in rats. *Journal of Lipid Research* **33**:539–548.

Lloyd, D.H. (1989). Essential fatty acids and skin disease. *Journal of Small Animal Practice* **30**:207–212.

Lloyd, D. (1990). Essential fatty acids in dermatological disorders of dogs and cats. In: Omega-6 essential fatty acids: pathophysiology and roles in clinical medicine, ed. Horrobin D. New York: R.Liss Inc. pp. 113–20.

Marsella, R. and Olivry, T. (2001). The ACVD task force on canine atopic dermatitis: VII. Mediators of cutaneous inflammation. *Veterinary Immunology and Immunopathology* **81**:205–213.

Newton, I.S. (1997). Polyunsaturated fatty acids in diet and health. *Chemistry and Industry* **21**: 302–305.

Park, Y.W. and Washington, A.C.. (1993). Fatty acid composition of goat organ and muscle meat of Alpine and Nubian breeds. *Journal of Food Science* **58**:245–248.

Poulos, A. (1995). Very long chain fatty acids in higher animals : a review. *Lipids* **30**:1–14.

Rees, C.A., Bauer, J.E., Burkholder, W.J., Kennis, R.A., Dunbar, B.L. and Bigley, K. (2001). Effects of dietaryflax seed and sunflower seed supplementation innormal canine serum polyunsaturated fatty acids andskin and coat condition scores. *Veterinary Dermatology* **12**: 111–117.

SPSS. (2004). SPSS 13.0 Applications Guide. SPSS Inc. USA.

Thompson, G.A. (1992). The Regulation of Membrane Lipid Metabolism. 2nd ed. Boca Baton, Florida, USA: CRC Press Inc.

Watson, T.D.G. (1998). Diet and skin disease in dogs and cats. *Journal of Nutrition* **128**: 2783S–2789S.