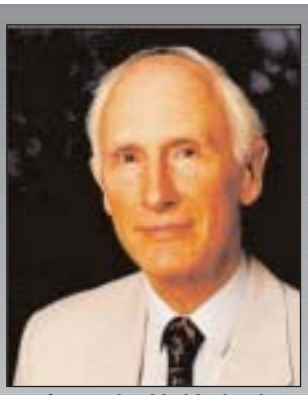
WALTHAM
FOCUS®
VOL 9 NO 2
1999

Optimizing skin and coat condition in the dog

David H. Lloyd PhD, BVetMed, FRCVS, DipECVD
Royal Veterinary College (University of London), UK
Katrina A. Marsh BSc, PhD
WALTHAM Centre for Pet Nutrition, UK



Professor Lloyd holds the chair of Veterinary Dermatology at the Royal Veterinary College, London, where he is Director of Clinical Research leading a clinical and research group in small and large animal dermatology and immunology. He is a former President of the ESVD and the ECVD, is Editor-in-Chief of Veterinary Dermatology *and is President of the Veterinary Wound Healing Association.*
Kate Marsh graduated from the Department of Life Sciences, Sunderland, with an honors degree in Pharmacology in 1986. In 1990, she was awarded a PhD in Pathology from the Royal Postgraduate Medical School in London before moving to the University of Nottingham to embark on post-doctoral research. In early 1997 Kate joined the WALTHAM Centre for Pet Nutrition, where she currently manages the Oral Health and the Skin and Coat research programs.

KEY POINTS

- Problems with skin and coat condition are a common source of concern for the dog owner.
- The coat and skin of an animal are designed to maintain homeostasis and provide protection from external insult.
- Nutritional imbalances and various environmental factors can have a major impact on skin and coat condition.
- Maintenance of a healthy skin and coat is important to the maintenance of a healthy body.
- Skin and coat problems can be managed by good nutrition, grooming, and ectoparasite control.

INTRODUCTION

Skin and coat problems are a common source of concern to dog owners, primarily because of the belief that a shiny well-groomed coat is an indicator of general health. This belief has a sound physiological basis. The skin is metabolically highly active and is the largest organ in the body. Thus its demands on bodily nutrition and metabolism are large.

It is estimated that one-quarter of the protein consumed daily is utilized by the skin in the production of new hairs and epidermis (1, 2). Protein is also secreted by the skin glands (3) and helps to remodel the dermis. The creation of new cells and skin secretory activity require an appropriate lipid supply and depend, in part, on lipid metabolism in the liver. Vitamins and minerals are also required as cofactors enabling and promoting epidermal metabolism and skin glandular secretion. Thus skin and coat condition reflects the level and quality of nutrition, gut function, and systemic metabolism, as well as skin health.

The skin is a major component of the body's immune system and maintains active surveillance of agents that are in contact with the skin surface (4). Failure in the skin's immunity can lead to a variety of problems, ranging from a low-grade skin infection or infestation to severe microbial disease and life-threatening neoplasia. The maintenance of a healthy skin and coat is therefore a primary objective in the maintenance of bodily health and warrants special attention both from owners and veterinary surgeons. This review examines the factors that influence skin health, highlighting those responsible for maintaining skin and coat condition.

THE NORMAL SKIN AND COAT

The normal skin of the dog is soft, flexible, smooth and of neutral temperature to the touch (skin temperature beneath the coat is 35–39°C) (5). Unpigmented skin, in the absence of hyperemia, is pale yellow or grayish in color and, where it is thin, as on the abdomen, cutaneous blood vessels are visible. The skin is supported by the dermis, which is largely composed of collagen and forms the great majority of the organ. However, the most metabolically active component is the epidermal tissue, including the interfollicular epidermis, the hair follicles, and the sweat and sebaceous glands **(Figure 1)** (1, 3). All of these elements are proliferative and undergo essentially holocrine secretory processes, which result in the continual production of squames, hairs, and glandular secretions (3).

The products of the three elements of the epidermis serve a series of coordinated protective functions at the skin surface before

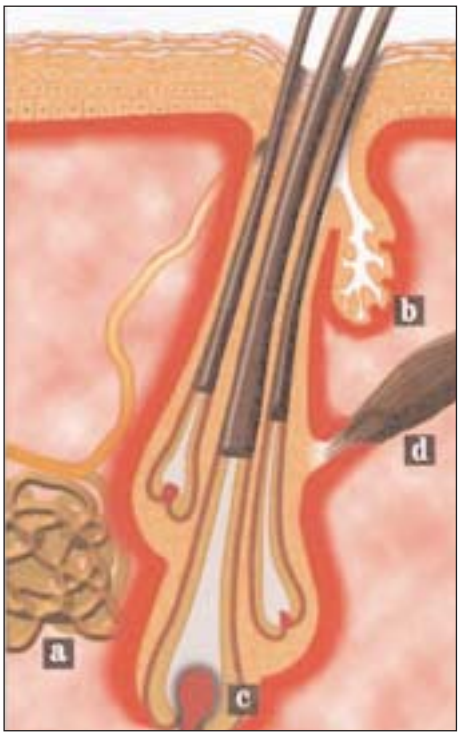


Figure 1
Diagrammatic representation of the anatomy of the canine compound hair follicle and surrounding structures. The coiled tubular sweat gland **(a)** *and sebaceous gland* **(b)** *are shown. Note the dermal papillar* **(c)** *source of vascular supply and the arrector pili* **(d)**.

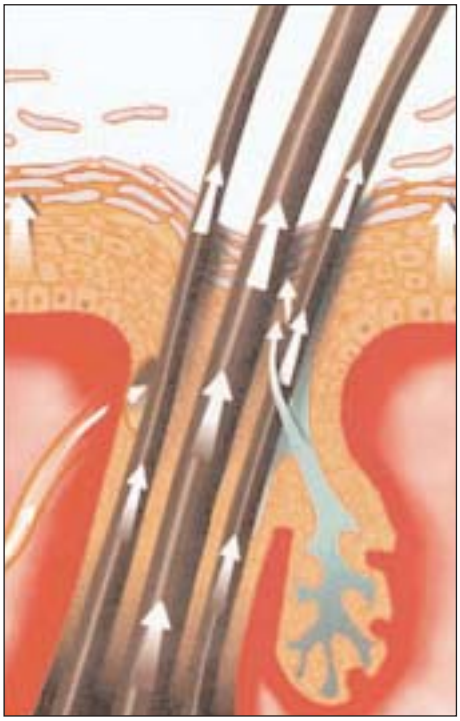


Figure 2
Growth of hairs and production of the stratum corneum depends on the proliferation of basal cells. These mature and develop into keratinized hair or flattened keratinized corneocytes. Both structures are shed. The moving staircase effect constantly renews and cleanses the coat and skin surface.

being shed and replaced **(Figure 2)**. The secretions of the sweat and sebaceous glands emerge at the hair follicle infundibula and permeate the superficial layers of the stratum corneum. Occasionally, discrete globules of secretion can be seen emerging from the edges of squames but generally the secretions are spread over the surface to form an even film **(Figure 3)** (6).

The secretions also coat the hairs and provide lubrication, allowing the hair fibers to move easily against each other. This facilitates grooming, reduces frictional damage, and encourages the hairs to maintain the pattern of alignment provided by the orientation of the hair follicles in the underlying skin. It is likely that two functions of grooming are to spread the skin secretions over the skin and coat and to aid the removal of dirt and debris trapped within the coat.

At the skin surface, the continuing production of keratinocytes

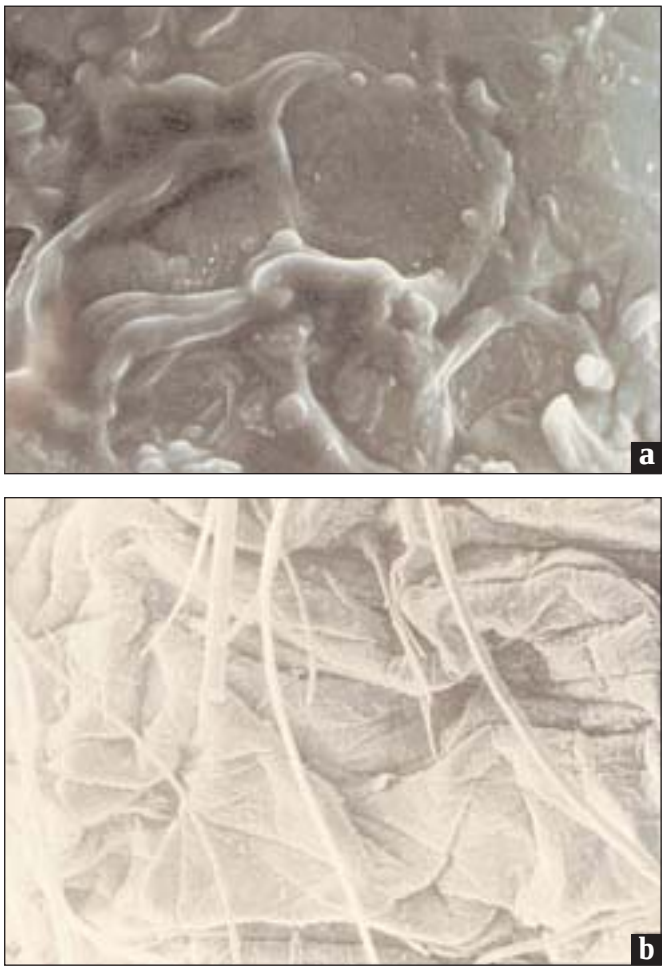


Figure 3 *Scanning electron micrographs of the surface of canine stratum corneum in the interfollicular region.* **(a)** *Globular secretions appearing at the edges of squames.* **(b)** *Lower power view illustrating the rather uneven texture of the skin surface with small hairs interspersed among the squames.*

and their differentiation and release as squames (7) (desquamation) ensures that cleanliness of the interfollicular epidermis is maintained. When the process of keratinocyte maturation is progressing normally, the surface remains smooth and loss of cells is macroscopically imperceptible. When this process is disrupted, skin barrier function is impaired, scaling occurs, skin surface microbial populations tend to increase, and the skin becomes susceptible to various disease processes.

The hairs are involved in protection against trauma, physical factors such as ultraviolet light and heat, and noxious chemicals. In consequence, the distal parts of the hairs tend to become eroded and roughened. However, the hairs are also replaced as the normal process of hair growth and shedding occurs and in healthy, well-nourished animals this ensures that the hair shafts are smooth and easily groomed – an important contribution toward coat condition.

Hair growth in dogs follows a cyclical process, with a period of active hair growth (anagen), a transitional period (catagen), and a resting period (telogen), when the hair remains in the follicle until shed. The cycle is controlled and modified by a variety of factors including hormones, photoperiod, temperature, nutrition, stress, and genetic influences. In dogs, hair replacement is influenced particularly by photoperiod, but also by ambient temperature and nutrition. Hair shedding is prominent in the spring and fall (1). Follicular activity is normally greatest in spring and early summer and least in winter when all primary and 50% of secondary follicles may be in telogen. Periods of extensive hair shedding and replacement put special nutritional and metabolic demands on the dog.

Figure 4 *A pair of Chinese Crested Dogs. One has a normal coat and the other has been selectively bred to have minimal hair.*

Figure 5 *Irish Water Spaniel showing hairless region on the neck and tail. These are breed characteristics.*

Events such as severe illness, stress, and pregnancy may cause the hair follicles to shut down, leading to dramatic but generally temporary hair loss. This usually becomes apparent some weeks after the event, when there is shedding of large numbers of hairs from follicles that were synchronously driven into telogen by the event. Certain diseases may also cause failure of hair follicular function during anagen. In such cases, abnormalities of the hair follicle and shaft lead to weakened hairs which are readily lost: hair loss becomes apparent within days (8). Excessive shedding of hair is also seen in some animals in the absence of clinical disease, but this is poorly understood (8). Changes in nutrition or in light exposure and ambient temperature are sometimes effective in restoring normal function.

The definition of normality of coat and skin is complicated by the existence of breeds of dogs where there has been deliberate breeding to promote certain features. In Cockers and other Spaniel breeds this has resulted in dense coats and a tendency toward epidermal hyperproliferation and seborrhea. In other breeds the aim has been to restrict the growth of normal hair in certain parts of the body or where abnormalities of the skin are encouraged. Examples are breeds such as the Chinese Crested Dog **(Figure 4)** and the Irish Water Spaniel (9) **(Figure 5)**, where lack of hair is a feature, and the Shar Pei and the Basset Hound, where skin folds are encouraged. Such breeds are at increased risk of skin disease and the maintenance of healthy skin often requires careful management. Diet has been shown to be an important factor in follicular dysplasia of the Irish Water Spaniel and fatty acid supplements have long been used to improve skin and coat condition in dogs (9, 10).

MAINTAINING SKIN AND COAT CONDITION

The importance of nutrition

Because of its size and high level of metabolic activity, the skin creates a heavy demand for protein, lipids, minerals, and vitamins. For this reason even subtle changes in the nutrient supply to the skin can have a severe impact on skin and coat condition. Since the advent of complete and balanced prepared petfoods, nutritional deficiencies are now rarely encountered in companion animals.

Table 1
Individual nutrients important to the maintenance of good skin and coat condition, their function and implications

Nutrient	*Functional role relating to skin and coat*	*Minimum* requirement*	*Signs of malnutrition*
Proteins	Structure and pigment of keratinocytes and hair, component of sebum and sweat	9.6 g	Depigmentation of skin and hair, dry coat, hair loss
Lipids	Energy, precursors of eicosanoids, component of membrane phospholipids	3.3 g	Dull, dry coat, alopecia, greasy skin, pruritus
Linoleic acid	Maintenance of effective cutaneous barrier	0.66 g	Dry, scaly skin
Zinc	Component of metalloenzymes, cofactor of RNA and DNA polymerases	3.0 mg	Crusting/scaling of skin, erythema, alopecia
Copper	Melanin and keratinocyte synthesis	0.3 mg	Hypopigmentation and dry, rough coat
Vitamin E	Antioxidant, stabilizer of cell membranes	1.8 IU	Scale, erythema, alopecia
Vitamin A	Cell growth and differentiation, keratinization process	245.5 IU	Hyperkeratinization, scaling, alopecia
Biotin	Metabolic enzyme cofactor	–	Facial alopecia and crusting
Riboflavin	Metabolic enzyme cofactor	0.15 mg	Dry, flaky dermatitis, swollen, cracked lips
Niacin	Metabolic enzyme cofactor	0.72 mg	Pruritic dermatitis
Pyridoxine	Metabolic enzyme cofactor	0.07 mg	Dull, waxy coat and facial alopecia

*WCPN nutritional guidelines for dogs (per MJ).

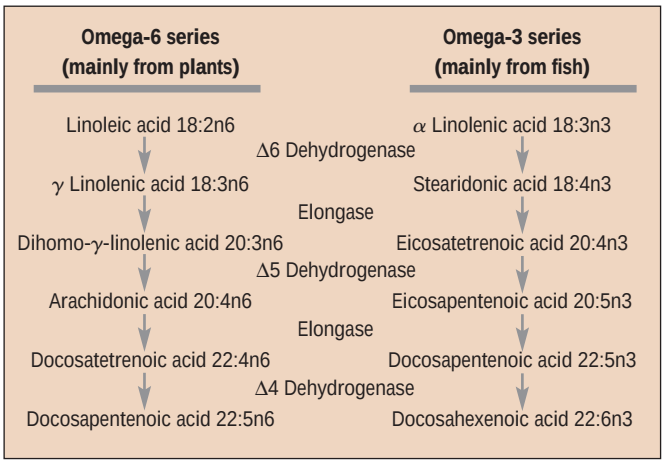


Figure 6 *Metabolic pathway of omega-6 and omega-3 fatty acids.*

Figure 7 *Scale is readily apparent on this animal. It reflects an abnormality in the normal maturation of the epidermis. Most cases are secondary and result from an acquired disease or nutritional deficiency.*

However, several factors can contribute to decreased nutrient delivery to the skin. These include feeding a nutritionally inadequate diet, oversupplementation of individual nutrients such as vitamins and minerals, poor storage conditions for diets, and the susceptibility of an individual animal to a particular condition because of genetic factors. The identification of specific deficiencies is often difficult as insufficiency of a number of different nutrients can result in similar clinical signs **(Table 1)** reflecting fundamental impairment of the processes involved in keratinization, sebum production, and hair growth.

Protein

Protein is required for replacement of both the hair and stratum corneum, and for pigmentation. It is also a component of the sweat and sebaceous gland secretions. Signs of protein malnutrition include depigmentation of the skin and the hair due to a deficiency of tyrosine, tryptophan, and cystine (11). In addition, the sulphur-rich amino acids, cysteine and methionine, are important for the production of keratin; a deficiency of these will result in hair loss. The hair becomes dry and brittle, and the coat rough and dry.

The body's requirement for protein is transiently increased during growth and in pregnant or lactating females. The loss of protein from the body can be increased during certain chronic disease states, such as pancreatic disease, protein-losing nephropathy, or protein-losing enteropathy. These situations can have a great impact on the level of protein available for the maintenance of skin turnover and hair production. It is therefore important to provide sufficient protein to the animal in order to prevent signs of protein deficiency.

Lipids

Much interest has been expressed in the role played by lipids, in particular the essential fatty acids (EFA), in the maintenance of good skin and coat condition. Indeed, there is much anecdotal evidence in the dog that supplementation of the diet with various oils and fats will increase the luster of the coat (12, 13).

EFAs are polyunsaturated fatty acids (PUFAs), which are important as a source of energy and improve the palatability of a diet. Their main functions, however, include a structural role as phospholipid components of cell membranes, the maintenance of an effective cutaneous barrier, precursor molecules for the eicosanoids (including prostaglandins and leukotrienes), and regulators of epidermal proliferation.

Two series of EFAs are important to the health of the skin and coat, both of them derived from and including two parent molecules – linoleic acid (omega-6 series) and alpha-linolenic acid (omega-3 series) **(Figure 6)** (14). The omega-6 and the omega-3 series of fatty acids are metabolized by the same enzyme series **(Figure 6)**, resulting in more biologically active metabolic derivatives – e.g., membrane phospholipids and the eicosanoids.

Dogs have a dietary requirement for linoleic acid, as they are unable to synthesize it themselves. Although an absolute dietary essentiality for the omega-3 fatty acids is not recognized, a deficiency of these during development can lead to impaired brain and retinal function (15). Typically, the omega-6 fatty acids are derived from plant seed sources (sunflower, safflower) or terrestrial animal flesh, whereas members of the omega-3 series are derived mainly from marine fish and some plant seeds (flax, linseed).

Provision of adequate levels of EFA can be achieved by avoiding poor quality, low-fat dry foods or inadequate home-prepared diets. Poor methods of diet storage or inadequate levels of antioxidants can lead to oxidation of PUFAs. The early signs of EFA malnutrition include the appearance of a fine scale and the development of a dull, dry coat that can lead to alopecia, greasy skin, pruritus, and often a secondary pyoderma (2, 16) **(Figure 7)**.

Dietary PUFA have also been used in the management of certain inflammatory conditions. Supplementation with gamma-linolenic acid in the form of evening primrose or borage seed oil and/or eicosapentenoic acid, as marine fish oil, may help attenuate the inflammatory processes when administered in relatively high doses. Currently there is debate over the importance of the omega-6 to omega-3 fatty acid ratio in the dietary management of inflammatory disease (17, 18). Recent evidence from human studies indicates that the absolute amount of omega-3 fatty acids drives the antiinflammatory potential of a diet rather than the ratio (19). The situation in dogs needs to be clarified.

Zinc

Zinc plays a critical role in regulating many aspects of cellular metabolism within the body, several of which are important in the maintenance of a healthy skin and coat. This widely distributed mineral is an integral component of many metalloenzymes in many different body systems and is also a cofactor for RNA and DNA polymerases. Zinc is particularly important in the rapidly dividing cells of the body, such as the epidermis. It is essential for the biosynthesis of fatty acids, has a role to play in the body's inflammatory and immune systems, and is also involved in the metabolism of vitamin A.

The availability of zinc from the diet can be reduced through decreased intestinal absorption that may occur as a result of nutrient interaction – in particular, oversupplementation with calcium, iron, or copper. This results in increased competition with zinc for absorption by the gut. In addition, high levels of dietary fiber or phytate, a zinc chelator found in cereal-based products, will inhibit zinc absorption. Certain individuals also have inherent defects in the zinc absorption processes that result in decreased availability of zinc to the body. Once zinc has been absorbed, individual serum levels of the mineral may be influenced by age, gender, and ambient temperature and may also be influenced in dogs suffering from hepatic disease, hypothyroidism, and infection (20). In the UK, historically, most cases of zinc-responsive skin diseases in dogs have resulted from feeding soya- or cereal-based diets, the effects of which could be exacerbated in animals already subject to inherent defects of zinc absorption (21).

Vitamin A

Vitamin A (retinol and its derivatives) has many functions in the body and is involved in the regulation of cell growth and differentiation. The retinoids are essential for the maintenance of the integrity of all epithelial tissue and in particular are important in the keratinization process of epidermal cells. A deficiency or an excess of vitamin A can give rise to similar cutaneous signs. Vitamin A deficiency is rare in companion animals and it is more common to see a toxicity state with its accompanying skeletal changes. Hypervitaminosis A may occasionally be seen when large amounts of liver are fed or when a diet is oversupplemented with vitamin A or cod liver oil.

Deficiency or excess of vitamin A can give rise to hyperkeratinization (of all epithelia) and scaling in addition to alopecia and increased susceptibility to microbial infections. Reports of vitamin A-responsive dermatoses in dogs have been restricted, almost exclusively, to Cocker Spaniels that appear to have been fed a nutritionally adequate diet (12, 20).

B-complex vitamins

The B-complex vitamins act as cofactors to enzymes in a number of metabolic functions; in particular, they are involved in the metabolism of fats, proteins, and carbohydrates. As water-soluble compounds, the B-complex vitamins are not stored in the body and they must therefore be taken daily. This requirement is generally met by a combination of dietary supply and by intestinal microbial biosynthesis. For this reason, natural deficiencies of these compounds are rare. However, following prolonged oral antibiotic therapy, in anorexia or, in conditions of increased water loss, signs of deficiency may become apparent. The signs exhibited in animals suffering from deficiencies in individual B-complex vitamins are similar and in general include keratinization defects and hair loss **(Table 1)**.

Vitamin E

Vitamin E describes a group of fat-soluble compounds known as the tocopherols that act as natural antioxidants in the body. The tocopherols protect the body from highly reactive oxygen metabolites known as free radicals. In their role as free radical scavengers, these compounds, together with selenium, are important in maintaining the stability of cell membranes. One of the major sources of free radicals is lipid metabolism and as such the dietary requirement for vitamin E is linked to the amount of PUFA in the diet (22).

High fat diets therefore can induce a relative deficiency of vitamin E. In a similar way, levels of vitamin E may be depleted following the oxidation of fat during processing or because of prolonged storage of food. Vitamin E deficiency in dogs is rare but can occur as a result of diets that are rich in PUFAs or foods that have been stored in inappropriate conditions. Cutaneous manifestation of vitamin E deficiency is shown by scale formation, erythema, secondary cutaneous infection, and hair loss (20, 23).

Environmental considerations

The coat and skin are designed to protect and maintain bodily homeostasis under natural conditions. However, the rapid pace of modern living and the exposure of animals to changing environments cause conditions that cannot be readily accommodated by the skin (24). Although sweating is a secretory process that can be altered in rate very rapidly, it is not a thermoregulatory mechanism in canine skin. Moisture levels at the skin surface influence the rate of epidermal keratinization and changes in epidermal kinetics compensating for high and low humidity are likely to require prolonged periods to cope with exposure to new environments. Similarly, animals with skin and hair that is unpigmented must be gradually adapted to exposure to sunlight.

These problems are compounded by the introduction of breeds of dogs developed for specific purposes, including specific outdoor environments, into city homes. Thus, heavily coated dogs such as the Chow Chow and the Old English Sheepdog cannot adapt to high temperatures. Spaniels, which have coats and skin that have been developed for water resistance, tend to suffer from seborrhea. The extreme breeds, such as the English Bulldog, the Shar Pei and the Mexican Hairless Dog, require constant attention to maintain a healthy skin and owners come to expect poor skin health as a feature of the breed.

Management of skin and coat problems

These skin problems, including those associated with breeding, can be eliminated or greatly ameliorated by changes in management, including nutrition. General bodily health is crucial, given the high metabolic demands of the skin. Ectoparasite control, particularly of fleas, is also of great importance, although elimination of fleas is not necessary except in cases of flea allergy.

Grooming is vital, firstly by the dog itself: if it is healthy it will recognize and point out skin problems to the observant owner and veterinary surgeon. Regular grooming by the owner – keeping the dog's coat clean and preventing matting and tangling – will also allow developing skin problems to be recognized while, at the same time, reducing the risk of skin disease. However, excessive grooming procedures, designed to achieve cosmetic effects, are counterproductive.

Clipping, even by experts, causes considerable trauma to the skin surface, rendering it more susceptible to environmental challenges and infection. The exposed skin is compelled to accelerate epidermal metabolism and to compensate by generating a thicker epidermis and new hair growth. Excessive use of grooming powder and moisturizers tends to contaminate the skin surface and may distort the patterns of normal glandular secretion by the sweat and sebaceous glands. Shampooing, particularly the use of shampoos designed for human use, is also contraindicated in clean, healthy skin.

Where skin problems are recognized, it is vital to attempt to identify the causative factors. Frank skin disease will require a dermatological work-up. However, where the problem is less severe and represented by scurfy or greasy skin or a harsh, thin, or dull coat, investigation of the causes is still important. These signs may be the first indications of more serious problems or they may point toward deficiencies in management.

Shampoos and moisturizers will often be required and it is important to realize that, as the skin problem comes under control, the type of topical therapy used may need to be altered with the

introduction of maintenance regimens or withdrawal. Thus, the use of an antiscaling shampoo and moisturizer may be followed by that of a cleansing and degreasing shampoo. Frequent shampooing initially may give way to infrequent or intermittent use. The aim should be to establish a normal skin and coat with minimal interference by the owner, other than regular attention to the coat (brushing, combing).

One of the most powerful methods of establishing and maintaining good skin and coat condition is to ensure that the dog has a well-structured diet. Most commercially available prepared petfoods provide a complete and balanced diet with respect to the nutrients required to maintain the health of the animal. These diets are based upon the published nutrient requirements – for example, the NRC nutrient requirements of dogs (25) and the recommendations of the Association of American Feed Control Officials (26), developed from numerous nutritional studies.

Nutritional imbalances can occur in animals fed high-quality complete diets when the diet is stored under inappropriate conditions, when it is supplemented with individual nutrients, or in animals fed home-prepared diets. As highlighted above, although many nutrients are important for the maintenance of a healthy skin and coat, unnecessary supplementation can lead to a detrimental imbalance of nutrition which becomes manifest in the skin and coat condition of the animal.

Problems with the skin and coat condition of a companion animal are among the most frequent reasons for veterinary consultation. On presentation of signs indicative of nutritional imbalance such as scaling or a dull brittle coat, it is important to establish what the animal is routinely fed. This needs to include main meals, snacks, treats, and dietary supplements. The owners should understand the implications of supplementing their pet's diet in any way and the possible impact that this may have on skin and coat condition. A good, nutritionally complete diet must be established and maintained throughout the lifetime of the animal, ensuring that the diet is appropriate for its life stage and lifestyle.

REFERENCES

1. Scott, D. W. The biology of hair growth and its disturbances. In: von Tscharner, C., Halliwell, R. E. W. (eds.) *Advances in Veterinary Dermatology*. Volume 1. London: Baillière Tindall. 1990: pp. 3–33.

2. Buffington, C. A. Nutrition and the skin. *Proceedings of the 11th Kal Kan Symposium* 1987: 11–16.

3. Jenkinson, D. McE. Sweat and sebaceous glands and their function in domestic animals. In: von Tscharner, C., Halliwell, R. E. W. (eds.) *Advances in Veterinary Dermatology*. Volume 1. London: Baillière Tindall. 1990: pp. 229–251.

4. Garthwaite, G., Lloyd, D. H., Thomsett, L. R. Location of immunoglobulins and complement (C3) at the surface and within the skin of dogs. *Journal of Comparative Pathology* 1982; **93**: 185–193.

5. Chesney, C. J. The microclimate of the canine coat: the effects of heating on the coat and skin temperature and relative humidity. *Veterinary Dermatology* 1997; **8**: 183–190.

6. Lloyd, D. H., Garthwaite, G. Epidermal structure and surface topography of canine skin. *Research in Veterinary Science* 1982; **33**: 99–104.

7. Suter, M. M., Crameri, F. M., Olivry, T., Mueller, E., von Tscharner, C., Jensen, P. J. Keratinocyte biology and pathology. *Veterinary Dermatology* 1997; **8**: 67–100.

8. Scott, D. W., Miller, W. H., Griffin, C. E. Muller and Kirk's Small Animal Dermatology. Philadelphia: W. B. Saunders. 1995.

9. Cerundolo, R., Lloyd, D. H., McNeil, P. E., Evans, H. An analysis of factors underlying hypotrichosis and/or alopecia in Irish water spaniels in the United Kingdom. *Veterinary Dermatology* 1999. In press.

10. Campbell, K. Clinical use of essential fatty acid supplements in dogs. *Veterinary Dermatology* 1993; **4**: 167–173.

11. Glatti, H.R., Schatzmann, H., Zinten, H. Skin diseases in the dog – the essential nutrients and miconutrients involved in dietetic treatment. *Kleintierpraxis* 1973; **18**: 203–210.

12. Ackerman, L. Nutritional supplements in canine dermatoses. *Can. Vet. J.*, 1980; **28**: 29–33.

13. Lloyd, D. H. Essential fatty acids and skin disease. *J. Small Animal Practice* 1989; **30**: 207–212.

14. Sinclair, H. M. History of essential fatty acids. In: D. F. Horrobin (ed.) Omega-6 Essential Fatty Acids: Pathophysiology and Roles in Clinical Medicine. New York: Wiley-Liss 1990: 1–20.

15. Neuringer, M., Connor, W. E. N-3 fatty acids in the brain and retina: evidence for their essentiality. *Nutr. Rev.* 1986; **44**: 285–294.

16. MacDonald, M. M., Rogers, Q. R., Morris, J. G. Role of linoleate as an essential fatty acid for the cat independent of arachidonate synthesis. *J. Nutr.* 1983; **113**: 1422–1433.

17. Vaughn, D. M., Reinhart, G. A., Swaim, S. F., Lauten, S. D., Garner, C. A., Beaudreaux, M. K., Spano, J. S., Hoffman, C. E., Conner, B. Evaluation of dietary omega-6 to omega-3 fatty acid ratios on leukotriene B synthesis in dog skin and neutrophils. *Vet. Dermatol.* 1994; **5**: 163–173.

18. Scott, D. W., Miller, W. H., Reinhart, G. A., Mohammed, H. O., Bagladi, M. S. Effect of an omega-3/omega-6 fatty acid-containing commercial lamb and rice diet on pruritus in atopic dogs: results of a single blinded study. *Canadian Journal of Veterinary Research* 1997; **61**: 145–153.

19. Hwang, D. H., Chanmugam, P. S., Ryan, D. H., Boudreau, M. D., Windhauser, M. M., Tulley, R. T, Brooks, E. R., Bray, G. A. Does vegetable oil attenuate the beneficial effects of fish oil in reducing the risk factors for cardiovascular disease? *Am. J. Clin. Nutr.* 1997; **66**: 89–96.

20. Miller, W. H. Nutritional considerations in small animal dermatology. *Vet. Clinics of North America: Small Animal Practice* 1989; **19**: 497–511.

21. Thoday, K. L. Diet-related zinc-responsive skin disease in dogs: a dying dermatosis? *J. Small Animal Practice* 1989; **30**: 213–215.

22. Putnam, M. E., Comben, N. Vitamin E. *Vet. Record* 1987; **121**: 541–546.

23. Scott, D. W., Sheffey, B. E. Dermatosis in dogs caused by vitamin E deficiency. *Companion Animal Practice* 1987; **1**: 42–46.

24. Lloyd, D. H. *The Influence of Environmental Factors on Health. Preventive Health Care in Companion Animals.* London: W. B. Saunders Co. Ltd. In press. 1999.

25. NRC. *Nutrient Requirements of Dogs.* Revised 1985. National Academy Press. Washington, DC.

26. AAFCO. *Association of American Feed Control Officials Inc.* 1997 Official Publication. Atlanta, GA.