Thoughts on the nutritional challenges faced by felines

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Felines are regarded as obligate carnivores as reflected by their nutritional requirements. Special needs exist for several amino and fatty acids and selected vitamins. Examination of the enzymatic pathways connected with supplying these nutrients indicate that over- or underactivity of enzymes is the primary cause of the problem. The question of how felines lost key biosynthetic capabilities on becoming wild can be answered partially by studying changes that occur in animals that have become tame. Taming of animals leads to changes in morphology, physiology (particularly relating to hormone levels) and behaviour. Feralization also leads to changes, but not necessarily the exact reverse. Modern genetics has shown that mutations of genes, gene duplication, changes in the promoter region, epigenetic alterations and other phenomena may be involved in alterations in enzymatic activity. Loss-of-function mutations may be responsible for the failure of cats to retain a well-recognized carbohydrate metabolism. A similar explanation may account for the apparent loss of one key enzyme needed for vitamin A biosynthesis.

The original arrangements made at the creation of the world are briefly sketched in the initial chapters of Genesis. By reference to the ideals outlined by Isaiah (11:6; 65:25) and the statement by the Apostle Paul (Romans 8:22), we conclude that there was an absence of pain and suffering in the beginning. As a consequence of this perceived general arrangement, in the paradise to come, those carnivorous animals represented will have alternative food sources; i.e. alternative to having to capture and consume feeling animals, birds, and the like.

This poses a potential problem for creationists in that a rational explanation needs to be formulated on how the transition to flesh eating took place. One possibility appears to be suggested in Job 38:39–41 and Psalms 104:21; 147:8, 9. The indication seems to be that God had a key involvement in the transition. All sorts of issues are faced when attempting to address these concerns using naturalistic explanations and one should not imagine that every enigma can be resolved. In some cases, the relevant scientific observations have not yet been made and in other instances associations have not been recognized. For these reasons, I have chosen to comment on the nutritional problems facing felines and how relatively small changes in gene functioning might be used to explain the acquisition of a carnivorous habit.

Special nutritional requirements

All members of the Felidae (cats: cheetahs, lions, tigers, leopards, etc.) are carnivorous and have facial nerve and taste buds that are not responsive to sugars, presumably on account of their adaptation to a meat diet.[1] Cats have special dietary requirements for the amino acids arginine and taurine and for vitamins A, D, and niacin (vitamin B_3). In addition, they have a high protein intake need and a requirement for linoleic acid (omega-6) and a conditional need for linolenic acid (omega-3) during gestation and lactation[2,3]—refer to table 1. Such requirements place them in the obligatory carnivore category of animals.[4]

For most of the nutrients mentioned above, biochemical pathways for synthesis and/or retrieval exist but their activity levels are either too low or over-expressed (table 1). The recitation of a few details will help with understanding. The high protein requirement of cats, due to the high demands made on amino acids to supply the glucose requirements of the animals, is unusual.[5] With most animals, when the level of dietary protein varies, there is a capacity to adapt the metabolic machinery to either dispose of excess material or conserve amino acids. Cats are able to make some adjustments in enzyme adaptation but are unable to fully adapt to changes in protein levels. The enzymes involved in the excretion of nitrogen products fail to reduce in activity when protein levels are lowered; hence, there is a greater level of loss of nitrogen from the body.

They also show a dietary need for taurine, which is a β-sulphonic amino acid found free in animal tissues. The amino acid cysteine is a precursor for taurine, but the level of activity of two critical enzymes (cysteine dioxygenase and cysteine sulfinate decarboxylase) in the pancreas limits its synthesis.[3–6] Taurine has a number of physiologic functions, one of which is the formation of bile salts. Placental animals sometimes use glycine to replace taurine for conjugation with bile acids to produce bile salts. The cat, however, is not able to do this on account of the low affinity of the requisite enzyme for this substrate, and in this respect

they are like the non-placental animals.[3,7] The level of wastage of taurine also is high as recovery by the kidney is not efficient by comparison to the pattern shown in other animals. Cats also have a requirement for arginine and are very susceptible to a deficiency in this amino acid. Arginine is synthesized from glutamine/glutamate. The issue is that cats have a low ability to reduce glutamate to pyrroline-5-carboxylate (a synthetase enzyme is involved). Also, the enzyme involved in the synthesis of citrulline from ornithine (ornithine aminotransferase; this represents the next step in the synthetic pathway) displays low activity in the intestine. Citrulline produced in the intestines is converted to arginine in the kidneys. Since cats can synthesize only minimal citrulline, arginine must be supplied in the diet. In practice, equal amounts of soy protein and casein can provide cats with sufficient arginine to prevent disease.[3,4]

The essential and conditionally essential fatty acid requirements of cats include linoleic (omega-6) and linolenic acids (omega-3), respectively. Cats have a limited ability to transform linoleic acid (in vegetable oils) to arachidonic acid,[8] which most other mammalian species have the ability to accomplish. The limited ability demonstrated is again due to poor enzymatic activity of the appropriate type, not its absence (table 1). Especially formulated diets containing maize oil supplemented with docosahexaenoic acid (omega-3) support balanced development.[3,4] A plant source (algal) of the docosahexaenoic acid also exists.[9]

Cats are unable to synthesize vitamin A from precursor molecules.[10] This is on account of the enzyme responsible not being present in tissues normally containing it in other animals. They can also tolerate high levels of the vitamin in their plasma without showing signs of toxicity. On the other hand, when it comes to vitamin D needs, the problem is that a dehydrocholesterol reductase enzyme that reduces dehydrocholesterol to cholesterol is present in the skin but it has high activity and hence reduces the availability of the appropriate substrate (dehydrocholesterol) from which the nutrient could be synthesized. Again, with niacin synthesis (vitamin B_3) all the enzymes required for its production are present, but the activity of a key enzyme in one branch of the degradative pathway (picolinic carboxylase, now 2-amino-3-carboxymuconate-6-semialdehyde decarboxylase) is extremely high. This enzyme ensures that there is little of the common substrate (aminocarboxymuconic semialdehyde) left from which niacin can be synthesized via the other branch of the pathway. This means that the production of meaningful quantities of the vitamin from dietary tryptophan is precluded in the cat (domestic animals studied).[3,11]

Reason for the observed deficits?

Evolutionary biologists explain the pressures of adopting a meat diet as being responsible for the apparent deletion

Table 1. Summary of the special nutritional requirements shown by the Felidae, the key enzymes involved, and aspects of their activity levels

Special nutritional requirements	Key enzymes involved	Level of enzyme activity	Reference
Arginine	Ornithine aminotransferase; proline-5-carboxylase synthetase	Both low activity	Morris, ref. 3; Verbrigghe and Bakovic, ref. 4.
Taurine	Cysteine dioxygenase; cysteine sulfinic acid decarboxylase	Both low activity	Knopf *et al.*, ref. 6; Morris, ref. 3; Verbrigghe and Bakovic, ref. 4; Vessey, ref. 7.
Vitamin A	β carotene to retinol conversion (a carotene oxygenase)	None apparent	Knopf *et al.*, ref. 6; Morris, ref. 3; Zoran, ref. 10.
Vitamin D	Dehydrocholesterol reductase enzyme	High activity*	Morris, ref. 3
Vitamin B_3	Picolinic carboxylase	High activity*	Morris, ref. 3
Linoleic acid (omega-6)	Δ5 desaturase; Δ6 desaturase	Both low activity	Pawlosky *et al.*, ref. 8; Trevizan *et al.*, ref. 8.
Linolenic acid (omega-3)—conditional	Docosahexaenoic pathway enzymes	Low activity of some enzymes	Morris, ref. 3; Verbrigge and Bakovic, ref. 4; Bauer, ref. 2; Filburn and Griffin, ref. 2.
High protein intake	Aminotransferases, urea cycle enzymes	Fail to adapt fully to changes in protein levels	Eisert, ref. 5; Morris, ref. 3; Verbrigghe and Bakovic, ref. 4.

* High enzyme activity results in less vitamin D and B_3 due to reduced availability of the appropriate substrate material on account of alternative pathway utilization.

(affecting one nutrient) or changes in enzyme activity (affecting four nutrients) seen in cats.[3] The basic proposal that dietary changes have exerted selective pressures, resulting in obligate nutrient requirements now being shown could be accepted by creationists too.

The regulation of gene expression can be accomplished through the operation of multiple mechanisms. For example, the loss of a functional enzyme required in vitamin A synthesis could be the result of disabling mutations in the gene or its promoter, or it could be accomplished through gene silencing. With the other nutrients, the over- and underexpression of enzymatic activity might be explained by changes in the promoter region of the DNA (mutations in promoter elements may alter the transcription rate), changes in gene enhancers, in specific hormone receptors, or to the activity of micro- and circular-RNAs, and aberrations in gene arrangement, and possibly other mechanisms.[12]

One very real issue with providing an entirely satisfactory account of how changes in enzymatic activity might have occurred is that few studies have been completed on felines outside the domestic cat (*Felus silvestris catus*). This means that studies with other animals must be relied upon to provide possible clues. If the vitamin D deficiency experienced by cats is taken as an example, the overactivity of the dehydrocholesterol reductase enzyme is problematic (table 1). If the activity of this enzyme is reduced experimentally by feeding an enzyme inhibitor in the diet, then adequate dehydrocholesterol is found in the skin and vitamin D is able to be synthesized in adequate quantities.[3] Studies using rat cells have shown that the activity of the same enzyme in this animal can be changed through point mutations introduced into the promoter region of the gene involved. Depending on the position of the mutation, sterol synthesis can be up or down regulated.[13] Among the human population, variations in dehydrocholesterol levels have been linked with mutations in the 7-dehydrocholesterol reductase gene. Furthermore, the position of mutation (amino acid affected) varied with geographical location. In northern climates there was a more frequent appearance of variants, allowing higher levels of dehydrocholesterol in the skin and hence permitting a greater ability for its conversion to vitamin D on exposure to the limited ultraviolet light found at those latitudes. Accordingly, it has been noted that not all mutations linked to this gene are associated with disease.[14] Such mutations in the promoter region of the cat's gene conceivably could have produced similar dampening effects on enzyme activity. Understandably such changes would have to exert minimal changes on other metabolic pathways.

Generally, humans and many mammals are able to synthesize vitamin A from provitamin A carotenoids available in plants. The absence of carotene monooxygenase/dioxygenase activity in domestic cats precludes their ability to cleave the carotene molecule and hence negates their capacity to synthesize vitamin A. Many felines show moderate to high serum levels of precursor molecules, but their ability to convert these to vitamin A is unknown.[19] Until the genome and enzyme function in a number of felines has been studied in detail, the question will be

Table 2. Some alterations of enzyme activity noted in placental animals following artificial or natural changes in heritable material

Nutrient	Key enzymes implicated	Level of enzyme activity found in felines	Events altering enzyme activity	Animal involved
Arginine	Ornithine aminotransferase; proline-5-carboxylase synthetase	Both low activity	Transgenic alterations increase activity; autosomal recessive state or mutations decrease activity.[15]	Mice, humans
Taurine	Cysteine dioxygenase; cysteine sulfinic acid decarboxylase	Both low activity	Selective breeding lowers activity.[24]	Dogs
Vitamin A	β carotene to retinol conversion (a carotene oxygenase)	None apparent	Mutations deliver losses of activity. Knock-out mice lack activity.[20,22]	Cows, humans, mice, sheep
Vitamin D	Dehydrocholesterol reductase enzyme	High activity	Promoter mutations/ other mutations produce increase/decrease activity.[14,15]	Humans, rats
Vitamin B_3	Picolinic carboxylase	High activity	Targeted promoter changes increase/decrease activity.[16]	Mice
Linoleic acid (omega-6)	Δ5 desaturase; Δ6 desaturase	Both low activity	Transgenic alterations increase/decrease activity, Insertion/deletion polymorphisms influence activity. [17,18]	Mice, humans

unresolved as to whether the appropriate gene for vitamin A synthesis has been deleted, inactivated, or simply displays extremely low activity.

In other animals, mutations in the gene coding for the carotene dioxygenase enzyme have been noted (chickens, cows and sheep), which caused a deep yellow colouration of their tissues.[20] In fact, in chickens the appearance of a yellow skin was indicative of mutations rendering the dioxygenase enzyme ineffective in that location.[21] In humans, severe biochemical vitamin A deficiency has been noted as a result of specific missense mutations. However, these may lead only to mild clinical symptoms, such as night blindness. No systemic disease symptoms were noted in one of these studies, suggesting that the mutations were affecting other pathways than those usually considered in the cellular supply of vitamin A to tissues.[22]

Taurine is an abundant free amino acid, found in the tissues of mammals, that protects cells from various categories of injury. The taurine requirement of felids is well known (figure 1). They possess the requisite biochemical pathway in the liver for the synthesis of taurine but the activity of the two key biosynthetic enzymes (cysteine dioxygenase and cysteine sulfinate decarboxylase) is low. The problem is heightened as there is no capacity to substitute proline for taurine in the conjugation of bile acids to produce bile salts either. In addition, reutilization of taurine is regulated by a taurine transporter (kidney) and this is not as efficient as desirable.[3]

In animal studies, key enzyme activity affecting taurine status is regulated by the dietary proteins, methionine and cysteine. For example, the presence of cysteine or methionine in the diet upregulates cysteine dioxygenase activity. Besides dietary factors, hormone levels influence cysteine sulfinate activity. Thyroid hormone levels have been found to exert a differential effect on activity of this enzyme in the liver as against the kidney. Finally, the taurine transporter gene contains a promoter region that possesses several regulatory elements that can influence transport activity so that it can be up- or down-regulated by manipulation of nutrients and salts. In humans, activation has been shown to be hormone associated.[23] What influence changes in coding sequence in this region might have on the uptake of taurine in cats awaits discovery.

Of relevance to our discussion on taurine is the observation that certain breeds of dog (American Cocker Spaniels, Newfoundlands and Golden Retrievers) have poor taurine synthetic capacity in comparison to many other breeds, which makes them susceptible to cardiopathy (chronic disease of the heart muscles). The feature is shared with foxes.[24] This suggests that selective breeding has been responsible for the emergence of poor taurine synthetic ability in the breeds of dog mentioned and further indicates that their progenitors were functionally more robust.

Arginine is a nutrient of particular significance to cats on account of their low synthetic ability, which leads to the development of hyperammonaemia. This condition is characterized by excess ammonia in the blood, leading to neurological and other disorders. There may be differences in the expression of deficiencies among animal groups. For example, hyperammonaemia is capable of developing in dogs in the absence of arginine, but in rats only appetite depression is seen.[25] Mutations may change the activity of one key enzyme involved in supplying arginine in selected animals (table 2). Whether restorative changes are possible in cats awaits discovery. Strong selective pressures have been exerted on cats as a result of domestication and selective breeding. For example, mutations have been identified associated with coat colour changes, and recombination events have been implied in explaining retinol metabolism and dark adaptation capabilities.[26]

Transgenic manipulations are used to research biochemical pathways. Increases and decreases in key enzyme activity levels can be achieved through such manipulations (table 2), and are indicative of possibilities in the natural world. Besides changes in the gene sequences, the up- or down-regulation of various biosynthetic pathways can be altered by nutrients, salts, hormones, and drugs (examples: table 2, references for vitamins D and B_3). Information relevant to felines is largely absent, but from the information available with other placental animals, it would not be surprising to find similar associations.

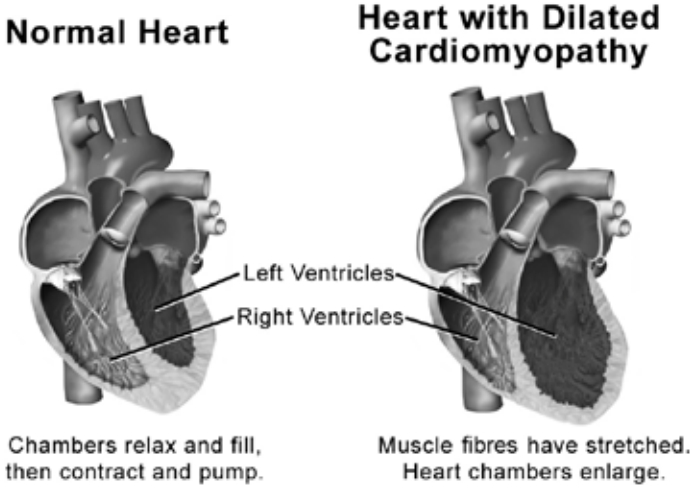

Figure 1. Dilated cardiopmyoathy in a human heart. The ventricles have been remodelled as a consequence of disease progression. A similar condition is shown in cats as a result of taurine deficiency.

Table 3. Effect of domestication on morphology, physiology, and behaviour found in some rodent, canine and feline lines in nature

Feature involved	Animal involved		
	Rats	**Fox and other Canidae**	**Cats and other Felidae**
Morphology	Smaller adrenal glands; changes in spleen and smaller brain size, reduced ears and adrenal glands, depigmentation.[30,52]	Tail curling, shorter tails and legs, reduced and drooping ears, cranial feature change, smaller brain, teeth, and adrenal glands, right heart ventricle enlarged, depigmentation.[27,44,52]	Reduced robustness, shrinking of teeth and jaws, shortening of limbs, reduction of braincase, modification of tail.[29] Longer intestines, depigmentation.[26,45]
Physiology	Hormone down-regulated with lowering of aggression; mutation also changes levels.[30] Polyoestrous.[45]	Hormone levels down-regulated with lowering of aggression. Changes noted in selected enzyme activities and receptor density.[27] Polyoestrous.[45]	Hypothalamic stimulation increases aggression.[31] Changes noted in neuro-transmission receptors.[26] Polyoestrous.[45]
Behaviour	Seek human contact, lack of aggression displayed; brain gene expression changed.[32]	Docility displayed, seek human contact, sniff, lick, and whimper to attract attention.[27,45]	Docility and gracefulness shown.[26] Friendliness (approaching, sniffing, rubbing)—inherited.[33] Aggression heightened by inbreeding.[34]

Consequences of animals becoming wild?

We well remember that after the universal Flood experience, God put the fear of humans into members of the animal kingdom (Genesis 9:2). This presumably resulted in friendly relationships turning first to uneasy ones and ultimately to the emergence of lines of animals focused on avoiding humans and perhaps hunting for their food for the first time. Theoretically, the reverse process should be possible (taming). Indeed, taming has been shown with foxes, otters, rats, and other animals, although I am not inferring that becoming tame involves an exact reversal of events occurring in animals becoming wild.

Figure 2. The common white (albino) laboratory rat characterized by its docility

Experiments with the silver fox (*Vulpes vulpes*), begun by a Russian scientist, Belyaev, have shown conclusively that selection for temperament alone will lead to changes in morphology, physiology, and behaviour (table 3). The expression of hormones and neurochemicals (corticosteroids and serotonin) governing the new-found behaviour in these animals is also different from that in their wild relatives. These features involve changes in the regulatory mechanisms of the body and hence the developmental pathways. The changes were found in a population where mating was strictly controlled to prevent inbreeding. And, furthermore, some of the features noted were determined not by recessive genes but by dominant or incompletely dominant ones, such as in tail curling, drooping ears, and brown spots on the neck and ears.[27] One unusual coat colouring pattern (piebald) appears to be due to gene activation as a result of selection for tameness.[28]

Selection for tameness influences hormonal control, and this could account for some of the features observed (table 3). Such changes regulate gene function and development. Selection is thought to eliminate mutations that interfere with the phenotype being selected for rather than induce them. This also means that characteristics that were muted previously might now be expressed.[27] In other animals, such as rats (table 3, figure 2), tameness is also associated with changes in

brain biochemistry, involving signalling molecules and their appropriate receptors. Furthermore, some of the changes noted with foxes involved greater enzyme activity (tryptophan hydroxylase) being displayed in the midbrain and hypothalamus in the tame animals. Serotonin receptor density also was greater in the domestic than in the wild specimens.[35] A linkage point between experiments in tameness and aggression in response to nutritional stress is that selective pressures are capable of altering the level of enzyme expressed. Also, alterations in hormone levels exert wide-ranging effects.

Two further approaches have provided limited insights into the possible effects of selective pressures on nutritional requirements. The first relates to carbohydrate utilization. In omnivores and vegetarian animals, carbohydrate metabolism is of considerably greater significance than in carnivores. The activity of glucokinase is lower in the liver of cats than in that of omnivorous animals. Further, pancreatic amylase activity and intestinal amylase activity is much higher in dogs than cats. Phosphoenolpyruvate carboxykinase activity, which is vital in the synthesis of glucose, is not stimulated by high protein levels. This and other observations indicate that the metabolic machinery of cats is more responsive to the presence of amino acids than to glucose.[25]

An interesting feature of phosphoenolpyruvate carboxykinase is that the expression of the gene can be influenced by transcription factors in the promoter region that responds to the dietary and hormonal status of the animal. Hormonal control is exerted by glucocorticoids, glucagon, thyroid hormone response element, and insulin. Levels may be overexpressed by some activators.[36] In humans, dehydroepiandrosterone-adrenal hormone activity changes gene expression of the phosphoenolpyruvate carboxykinase enzyme.[37] The hormone is involved in the stress response and hence is influenced by the level of tameness/aggression.[38] It would be interesting to follow the response of this enzyme in cats to variations in hormone levels.

Another aspect of the phosphoenolpyruvate carboxykinase enzyme is that maternal nutrition may have marked effects on expression of the gene regulating the enzyme in the foetus and even influence renal structure of some placental animals. The influence of nutrients on gene expression is considered in the field of epigenetics. Here it is found that gene activity and expression are influenced by such events as the methylation of DNA and histone modifications rather than through changes in the DNA sequence.[39] For example, with phosphoenolpyruvate carboxykinase enzyme activity in baboons, methylation status was reduced following maternal nutrient reduction. Epigenetic effects may persist after birth and beyond the initial generation.[40] Evidence is becoming strong that the periconception nutrition environment can exert trans-generation, or perhaps even permanent, changes.[41] Epigenetic modifications influence hypothalamic neurons and hormone receptors among other features, which means that nutritional events occurring in dams may exert significant effects in the offspring.[42] No information is yet available on the significance of this phenomenon for the Felidae. The imposition of nutritional stress at the same time as other stressors were operating would exert unique selective pressures on animals.

Another approach is to compare the genomes of animals sharing a common ancestry. For example, if the assumption is correct that grey wolves and domestic dogs (diversity of breeds) share a common ancestry,[43] then recent analyses of wolf and dog genomes are significant. A number of genomic regions have been identified where selection ostensibly took place (nineteen dealing with brain function, eight with nervous system developmental pathways, and ten with starch digestion and fat metabolism). The changes dealing with starch metabolism are particularly interesting. The process involves the activities of first an amylase, then maltase-glucoamylase and other enzymes, and finally uptake of glucose through a transporter. For example, the portion of the DNA sequence determining amylase activity appears to be represented by multiple copies in the dog compared to much lesser numbers in the wolf. This resulted in an increase of amylase activity by a factor of almost five in dogs. When the maltase-glucoamylase enzyme was investigated, the most likely candidate phenomenon was identified as mutational change affecting nucleotides that are part of the protein-coding sequence, the position of the stop codon, or a change in the binding site of a regulator protein. The last mentioned change appeared the one most likely to allow an explanation for the alterations in enzyme activity. Transporter activity also was higher in dogs than wolves, and a one amino acid substitution mutation in the protein primarily involved is thought to be responsible. The authors considered that a change in the ecological niche, giving expanded feeding opportunities near human habitation, may have been the catalyst for the mutational changes being selected for and hence allowed dogs to thrive on a starch-rich diet rather than on meat.[44] These observations have general relevance to cats.

Cat domestication is considered to have occurred in the Near East region and is considered to be a result of natural rather than artificial selection as found in dogs and other animals. Cat breeds appear to have received genetic markers from five wild cat (*F. silvestris*) subspecies (*bieti*, *cafra*, *lybica*, *ornate*, *silvestris*—figure 3) from various locations.[45,46] The development of carbohydrate metabolic machinery is not as well-developed in cats as in some other animals.[47] One possible reason for this could be that felids lack the ability to detect sweet stimuli on account of

Figure 3. One of the contributors to the emergence of the domestic cat (*Felis silvestric catus*), the European wildcat (*F. silvestris silvestris*)

a defect in a gene (microdeletion has occurred) disabling receptor functioning.[48] Also, it has been suggested that the development of the longer intestinal tract in domestic, in contrast to wild, cats may be a consequence of feeding them with domestic scraps. Further advances will undoubtedly come with the acquisition of detailed nutritional genomics information. Current evidence suggests an enrichment of genes related to protein and lipid metabolism represents adaptation to the strictly carnivorous diet. The role of recombination events has not been investigated, but has been suggested as of potential significance.[26,45,49] Multiple genes are likely to be involved in domestication and the reverse process—feralization. One attempt to explain domestication in general posits that the changes noted in mammals have occurred on account of deficits developing in neural crest cell representation. These stem cells give rise to precursor cells that are involved in the development of many tissues and cells. Multiple genes are thought to be involved in the changes. Loss-of-function mutations, recombination events, generation of repeat elements, and epigenetic phenomena possibly have been involved, including changes in gene behaviour consequential on changes in methylation status (epimutation).[50]

Concluding comments

The nutritional challenges faced by members of the Felidae can be accounted for in part. Observations on animals undergoing domestication and feralization have provided some answers. Selection for tameness gives rise to some profound changes in physical, developmental, and physiologic characters. It might be expected that over time a reverse process (selection for wildness; lack of ease with humans—feralization) could be observed with these animals. This appears to be the case when generalized behaviours are considered with a selection of small animals (e.g. rats, gerbils, hamsters, dogs).[51] Even though the small felines appear to be somewhat different in that they have a tendency to tameness (i.e. tolerate proximity to humans, show rubbing, and licking behaviour),[52] it is a common observation that domesticated cats also readily become feral (return to the wild). This is not to suggest, however, that feralization is the exact reverse of domestication. When complex traits are involved, adaption to new conditions may follow independent pathways involving different loci than those targeted during domestication. This might be considered a reasonable outcome as the gene pool available and environmental conditions are different.[53]

The pressures of competition for food resources, mate selection, and the peculiar aspects of the environment after the Flood would have led to the selection of variants better suited to survive in the new, harsh habitat and perhaps the need to avoid predation themselves. It is also possible that the founder population of felids emerging from the Ark may have already diverged remarkably from the original and that they were already part way along the pathway of animals formerly socialized to humans, becoming less comfortable in their presence. It is important to emphasize that the gene pool represented in the Flood survivors was much reduced over that represented before the catastrophic event for the simple reason that few animals were preserved from the multitude presumably available. It is suggested that opportunity and/or necessity drove the first felids to seek an alternative food source, perhaps much like the vampire finches of the Galápagos now feed on blood from pecking the juvenile feathers of sea birds.[54]

Emotional, nutritional, and other pressures (stress) possibly enabled selection among genetic traits already present to deliver changes in morphology, physiology, and behaviour. Changes in neural crest numbers, their distribution and activity due to genetic modifications appear to provide a unifying basis for the root cause of tendencies towards and away from docility. Variable interactions among genes are also possible and can help to account for the (sometimes) dramatic changes observed.[26,49] Other genetic events outside the neural crest cells' domain may also be involved. A great deal of detective work is still required to determine the genes involved in domestication/feralization and how they interact to influence physiology, behaviour, and the morphology of animals. It would be interesting to undertake in-depth studies on the genetic profile of ostensibly vegetarian felines[55] and complete a raft of enzyme activity studies.

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