As a nutritional supplement, carnitine may be beneficial in treating such conditions as feline hepatic lipidosis and obesity.

Carnitine: A Review

Angell Memorial Animal Hospital, Boston
Maureen C. Carroll, DVM
Etienne Côté, DVM

Abstract: L-carnitine is an amino acid derivative required for the β-oxidation of long-chain fatty acids, a process necessary for deriving energy from fat. Carnitine deficiency has been shown to cause dilated cardiomyopathy in a small population of dogs, and effects of carnitine deficiency on other tissue are being explored. Preliminary evidence reveals that feline hepatic lipidosis may result from a relative carnitine deficiency and may respond to supplementation. Carnitine supplementation also has been shown to alter body composition in swine by increasing lean body mass and decreasing fat mass, an important characteristic that may be applicable to the treatment and prevention of obesity in dogs and cats.

Historically, the use of carnitine in veterinary medicine has been limited to cardiology, in which carnitine deficiency has been demonstrated to cause dilated cardiomyopathy (DCM) in some dogs. Recent research is helping identify noncardiac conditions that may respond to carnitine therapy, including feline hepatic lipidosis (HL) and obesity. Although the current body of knowledge regarding carnitine is rapidly expanding, well-controlled therapeutic trials, especially in the areas of HL and obesity, are lacking to date. This article outlines the role of carnitine and fatty acid (FA) metabolism in cellular physiology, discusses the conditions potentially associated with carnitine deficiency, and reviews important information on carnitine supplementation.

Functions of Carnitine

Fat Metabolism

Carnitine plays a central role in many cellular processes, most of which are related to fat metabolism and energy production. The primary function of carnitine is mitochondrial transport and subsequent β-oxidation of long-chain fatty acids (LCFAs), which results in ATP production.

When fat is mobilized from peripheral body stores to be used for energy production (lipolysis), hormone-sensitive lipase catalyzes the breakdown of stored triglycerides into glycerol and free fatty acids (FFAs). FFAs are bound to albumin in the circulation and are a major energy source for many tissues. FFAs taken up by the liver are either (1) esterified with glycerol to form triglyceride, which is transported to extrahepatic tissue via very-low-density lipoprotein (VLDL), or (2) “activated” to fatty acyl coenzyme A (CoA), which then undergoes β-oxidation in the mitochondria. β-Oxidation results in the production of acetyl CoA, which can be converted to ketone bodies or enter the Krebs cycle for the production of ATP. The latter process is essential for the fundamental metabolic reaction of converting fat to energy. Short- and medium-chain FAs...
can enter the mitochondria freely, whereas LCFAs must be bound to carnitine in an ester linkage (forming acyl carnitine) to cross the inner mitochondrial membrane for oxidation\(^2,5\) (Figure 1). Free carnitine is regenerated in the mitochondrial matrix, thereby releasing the acyl-CoA, which goes on to \(\beta\)-oxidation.

Because of the pivotal role of fat metabolism in energy production, carnitine is essential for proper functioning of most tissues, particularly skeletal and cardiac muscles (which utilize FA as a primary energy source\(^5,6\)) and the liver (where regulation of lipid transport and FA metabolism occur). Absence of carnitine therefore causes a deficiency in \(\beta\)-oxidation and adversely affects both energy production and fat metabolism.\(^5\)

**Other**

Additional important functions of carnitine include buffering and eliminating membrane-toxic acyl-CoA molecules from mitochondria\(^5,7\); these molecules could otherwise hinder optimal functioning of such oxidative pathways as the Krebs cycle.\(^6\) Carnitine is important in regulating biologic processes, including the urea cycle; gluconeogenesis; stimulation of FA synthesis; and the metabolism of ketones, branched-chain amino acids, triglycerides, and cholesterol.\(^7\) Finally, carnitine supplementation may affect muscle and bone mass as well as bone density in growing large-breed puppies.\(^8\) Carnitine may help increase lean body mass, which in turn could prevent the excess fat deposition that possibly predisposes these animals to obesity and potentially orthopedic disease.\(^8\)

**CARNITINE METABOLISM**

An amino acid derivative, carnitine is a natural component of all animal cells. The active form is the \(L\)-stereoisomer. Endogenous synthesis from methionine and lysine occurs in the liver of higher mammals and the kidney of cats\(^5,6\); the synthetic pathway requires
ascorbic acid, pyridoxine, niacin, and iron. Carnitine can also be supplied through dietary intake of meat and dairy products; ingested carnitine enters the portal system and eventually the systemic circulation and is ultimately actively transported into cells.

In tissue and body fluids, carnitine has three forms: free carnitine (the largest fraction) and two esterified forms (short- and long-chain acyl carnitine). Free carnitine shuttles LCFA across the inner mitochondrial membrane. Total carnitine concentration in tissue can be 10- to 50-fold greater than in plasma. Skeletal and cardiac muscles contain approximately 95% of total body carnitine stores; most of the remaining fraction is located in the liver.

Carnitine is well conserved in the body because there are no important catabolic pathways in mammals. Ninety-five percent of renally filtered carnitine is reabsorbed in the tubules, although this percentage may be lower in dogs. Both carnitine biosynthesis and renal conservation are efficient mechanisms for maintaining total body carnitine levels when dietary intake is low.

**Carnitine Deficiency**

Carnitine is considered a “conditionally essential” nutrient because endogenous synthesis of carnitine is insufficient to meet physiologic demands in metabolic conditions in which energy production largely relies on β-oxidation. Primary carnitine deficiencies can result from inadequate dietary intake; defective tissue retention or uptake; excessive renal excretion related to impaired reabsorption; or a reduced capacity for biosynthesis secondary to a limitation in amino acid precursors and cofactors, liver disease (or renal disease in cats), or a congenital pathway defect.

In human adults and children, carnitine deficiency can result in hepatic lipid accumulation and clinically apparent liver dysfunction as well as skeletal and/or cardiac myopathies caused by defective lipid transport and subsequent lipid accumulation in these tissues. Similar conditions are being studied in animals. Carnitine-responsive DCM in dogs has been described, and the role of carnitine deficiency in the pathogenesis of feline HL and the use of carnitine in the treatment and prevention of obesity are currently under investigation.

**Cardiomyopathy**

Carnitine deficiency is a proven cause of DCM in dogs and humans. In some carnitine-deficient dogs with DCM, carnitine supplementation is associated with a dramatic increase in cardiac contractility and relief of clinical signs (Figure 2); if supplementation is stopped, cardiac decompensation recurs. Despite these known benefits, carnitine supplementation has been adopted only sparingly in veterinary cardiology, likely for the following reasons: (1) Most cases of DCM in dogs are probably caused by mechanisms that do not involve carnitine deficiency; (2) low myocardial levels of carnitine have been a result, rather than the cause, of myocardial failure in an experimental model; (3) plasma carnitine levels in patients with DCM do not necessarily predict whole-body carnitine status, and thus serum levels may be in the normal range (8 to 36 µmol/ml for dogs) while myocardial levels are actually deficient; (4) endomyocardial biopsy, used to diagnose myocardial carnitine deficiency, is not a routine clinical procedure in veterinary medicine; (5) long-term carnitine supplementation can be expensive; (6) supplementation typically needs to be sustained for weeks before improvement can be noted; and (7) carnitine is not a proprietary substance that can be patented, and pharmaceutical companies have been loath to investigate its clinical effects in the absence of the profit motive.

These limitations make any assessment of the role of carnitine in veterinary cardiology subjective. Without question, dogs with carnitine deficiency (documented through analysis of plasma or tissue samples) and evidence of cardiac dysfunction relating to DCM need supplemental carnitine (1 or 2 g carnitine for medium- to large-breed dogs, respectively, given with food every 8 to 12 hours); a higher dose of 50 to 200 mg/kg has also been proposed. The difficulty is detecting dogs that are carnitine deficient at the tissue level despite having normal or elevated plasma carnitine concentrations.

At present, conducting a therapeutic trial with carnitine (i.e., providing supplemental carnitine for 3 to 6 months and assessing clinical status and echocardiographic measurements for signs of response) is the most practical way to evaluate carnitine’s role in the management of a dog with DCM. Such a therapeutic trial is warranted in boxers with DCM and any dogs with clinical signs of DCM in which the cost of carnitine does not compromise standard care. Overall, approximately 5% of dogs with DCM (all breeds pooled) are expected to respond positively to carnitine supplementation.

A gene for carnitine deficiency has been located in some humans with DCM, which could lead to a genetic test to screen for the deficiency before the onset of physical signs. Carnitine supplementation is used in most cases of DCM in dogs and humans. In some carnitine-deficient dogs with DCM, carnitine supplementation is associated with a dramatic increase in cardiac contractility and relief of clinical signs (Figure 2); if supplementation is stopped, cardiac decompensation recurs. Despite these known benefits, carnitine supplementation has been adopted only sparingly in veterinary cardiology, likely for the following reasons: (1) Most cases of DCM in dogs are probably caused by mechanisms that do not involve carnitine deficiency; (2) low myocardial levels of carnitine have been a result, rather than the cause, of myocardial failure in an experimental model; (3) plasma carnitine levels in patients with DCM do not necessarily predict whole-body carnitine status, and thus serum levels may be in the normal range (8 to 36 µmol/ml for dogs) while myocardial levels are actually deficient; (4) endomyocardial biopsy, used to diagnose myocardial carnitine deficiency, is not a routine clinical procedure in veterinary medicine; (5) long-term carnitine supplementation can be expensive; (6) supplementation typically needs to be sustained for weeks before improvement can be noted; and (7) carnitine is not a proprietary substance that can be patented, and pharmaceutical companies have been loath to investigate its clinical effects in the absence of the profit motive.

These limitations make any assessment of the role of carnitine in veterinary cardiology subjective. Without question, dogs with carnitine deficiency (documented through analysis of plasma or tissue samples) and evidence of cardiac dysfunction relating to DCM need supplemental carnitine (1 or 2 g carnitine for medium- to large-breed dogs, respectively, given with food every 8 to 12 hours); a higher dose of 50 to 200 mg/kg has also been proposed. The difficulty is detecting dogs that are carnitine deficient at the tissue level despite having normal or elevated plasma carnitine concentrations.

At present, conducting a therapeutic trial with carnitine (i.e., providing supplemental carnitine for 3 to 6 months and assessing clinical status and echocardiographic measurements for signs of response) is the most practical way to evaluate carnitine’s role in the management of a dog with DCM. Such a therapeutic trial is warranted in boxers with DCM and any dogs with clinical signs of DCM in which the cost of carnitine does not compromise standard care. Overall, approximately 5% of dogs with DCM (all breeds pooled) are expected to respond positively to carnitine supplementation.

A gene for carnitine deficiency has been located in some humans with DCM, which could lead to a genetic test to screen for the deficiency before the onset of physical signs. Carnitine supplementation is used in most cases of DCM in dogs and humans. In some carnitine-deficient dogs with DCM, carnitine supplementation is associated with a dramatic increase in cardiac contractility and relief of clinical signs (Figure 2); if supplementation is stopped, cardiac decompensation recurs. Despite these known benefits, carnitine supplementation has been adopted only sparingly in veterinary cardiology, likely for the following reasons: (1) Most cases of DCM in dogs are probably caused by mechanisms that do not involve carnitine deficiency; (2) low myocardial levels of carnitine have been a result, rather than the cause, of myocardial failure in an experimental model; (3) plasma carnitine levels in patients with DCM do not necessarily predict whole-body carnitine status, and thus serum levels may be in the normal range (8 to 36 µmol/ml for dogs) while myocardial levels are actually deficient; (4) endomyocardial biopsy, used to diagnose myocardial carnitine deficiency, is not a routine clinical procedure in veterinary medicine; (5) long-term carnitine supplementation can be expensive; (6) supplementation typically needs to be sustained for weeks before improvement can be noted; and (7) carnitine is not a proprietary substance that can be patented, and pharmaceutical companies have been loath to investigate its clinical effects in the absence of the profit motive.

These limitations make any assessment of the role of carnitine in veterinary cardiology subjective. Without question, dogs with carnitine deficiency (documented through analysis of plasma or tissue samples) and evidence of cardiac dysfunction relating to DCM need supplemental carnitine (1 or 2 g carnitine for medium- to large-breed dogs, respectively, given with food every 8 to 12 hours); a higher dose of 50 to 200 mg/kg has also been proposed. The difficulty is detecting dogs that are carnitine deficient at the tissue level despite having normal or elevated plasma carnitine concentrations.

At present, conducting a therapeutic trial with carnitine (i.e., providing supplemental carnitine for 3 to 6 months and assessing clinical status and echocardiographic measurements for signs of response) is the most practical way to evaluate carnitine’s role in the management of a dog with DCM. Such a therapeutic trial is warranted in boxers with DCM and any dogs with clinical signs of DCM in which the cost of carnitine does not compromise standard care. Overall, approximately 5% of dogs with DCM (all breeds pooled) are expected to respond positively to carnitine supplementation.

A gene for carnitine deficiency has been located in some humans with DCM, which could lead to a genetic test to screen for the deficiency before the onset of physical signs. Carnitine supplementation is used in most cases of DCM in dogs and humans. In some carnitine-deficient dogs with DCM, carnitine supplementation is associated with a dramatic increase in cardiac contractility and relief of clinical signs (Figure 2); if supplementation is stopped, cardiac decompensation recurs. Despite these known benefits, carnitine supplementation has been adopted only sparingly in veterinary cardiology, likely for the following reasons: (1) Most cases of DCM in dogs are probably caused by mechanisms that do not involve carnitine deficiency; (2) low myocardial levels of carnitine have been a result, rather than the cause, of myocardial failure in an experimental model; (3) plasma carnitine levels in patients with DCM do not necessarily predict whole-body carnitine status, and thus serum levels may be in the normal range (8 to 36 µmol/ml for dogs) while myocardial levels are actually deficient; (4) endomyocardial biopsy, used to diagnose myocardial carnitine deficiency, is not a routine clinical procedure in veterinary medicine; (5) long-term carnitine supplementation can be expensive; (6) supplementation typically needs to be sustained for weeks before improvement can be noted; and (7) carnitine is not a proprietary substance that can be patented, and pharmaceutical companies have been loath to investigate its clinical effects in the absence of the profit motive.

These limitations make any assessment of the role of carnitine in veterinary cardiology subjective. Without question, dogs with carnitine deficiency (documented through analysis of plasma or tissue samples) and evidence of cardiac dysfunction relating to DCM need supplemental carnitine (1 or 2 g carnitine for medium- to large-breed dogs, respectively, given with food every 8 to 12 hours); a higher dose of 50 to 200 mg/kg has also been proposed. The difficulty is detecting dogs that are carnitine deficient at the tissue level despite having normal or elevated plasma carnitine concentrations.

At present, conducting a therapeutic trial with carnitine (i.e., providing supplemental carnitine for 3 to 6 months and assessing clinical status and echocardiographic measurements for signs of response) is the most practical way to evaluate carnitine’s role in the management of a dog with DCM. Such a therapeutic trial is warranted in boxers with DCM and any dogs with clinical signs of DCM in which the cost of carnitine does not compromise standard care. Overall, approximately 5% of dogs with DCM (all breeds pooled) are expected to respond positively to carnitine supplementation.

A gene for carnitine deficiency has been located in some humans with DCM, which could lead to a genetic test to screen for the deficiency before the onset of physical signs. Carnitine supplementation is used in
humans with primary carnitine deficiency and to manage myocardial infarction and other cardiac diseases. These novel approaches have not been addressed in veterinary cardiology; along with development of a minimally invasive or noninvasive test to determine tissue carnitine levels, they represent future directions for the use of carnitine in veterinary cardiology.

Hepatic Lipidosis

In healthy animals, the liver maintains a balance between lipids entering the liver through diet and metabolic processes and lipids removed from the liver by β-oxidation or exportation to other tissue. HL develops when the amount of fat mobilized to the liver exceeds that exported from it. In humans, cats, rabbits, guinea pigs, rats, and Rhesus monkeys, this process can be associated with overt liver dysfunction. In cats, partial or complete loss of appetite and obesity are often associated with HL. The resulting lipolysis causes a pathologic increase in the amount of FFA presented to the liver, and the FFA apparently cannot be metabolized and/or exported efficiently.

Although some sources describe protein malnutrition and peroxisome impairment as contributors to hepatic lipid accumulation, more recent reports have examined the role of carnitine deficiency in the pathogenesis of clinical HL. Studies in children and rats have shown that dietary carnitine levels at 30% of recommended levels or below result in severe fatty liver disease, which mirrors the changes seen with feline HL. It is postulated that in anorectic cats, fats released during lipolysis are stored in the liver instead of entering the pathway for β-oxidation or being exported out of the liver as VLDL. Although functional, the normal pathways may be unable to handle pathologically increased amounts of fat delivered to the liver. As a result, carnitine’s function in the linkage and transport of LCFA into the mitochondrial matrix for β-oxidation may become overwhelmed, resulting in intracellular fat accumulation and thus HL and liver dysfunction. Although a marked research effort is in progress, the current evidence pertaining to the role of carnitine in HL is preliminary; and blinded, controlled clinical trials conducted in cats are lacking.

In a study comparing plasma, liver, and skeletal muscle carnitine concentrations in healthy cats versus those with HL, carnitine appeared to play a lesser role in HL because free and acyl carnitine levels in plasma and tissue were actually higher in affected cats. These findings have since been interpreted to suggest that carnitine may be deficient in the mitochondria (where it is required for β-oxidation to occur) or, despite an increase in biosynthesis, may still be relatively deficient given the markedly increased oxidative demand. The higher acyl carnitine concentrations observed may reflect hepatic spillover of accumulated acyl carnitine that is either awaiting β-oxidation (which may be rate limiting) or remaining at a “standstill” in a partially oxidized state in the mitochondria; both pools of accumulated acyl carnitine draw from the intracellular free carnitine

Figure 2—M-mode echocardiogram through the left ventricle (LV) of a dog with carnitine-deficient dilated cardiomyopathy before (A) and after (B) carnitine supplementation for 3 months. The shortening fraction, or change from end-diastolic diameter (edd) to end-systolic diameter (esd), is much less in A than in B, showing that the LV is contracting poorly before (A) and is markedly improved after (B) carnitine supplementation. Over the 3-month period, overt clinical signs of heart disease resolved and a return to sinus rhythm (from atrial fibrillation) was seen. (Reprinted with permission from Keene BW, Panceria DP, Atkins CE, et al: Myocardial l-carnitine deficiency in a family of dogs with dilated cardiomyopathy. JAVMA 198(4):647-650, 1991.)
supply. Furthermore, plasma l-carnitine levels are an insensitive indicator of myocardial and skeletal muscle deficiency in humans with such diseases as DCM, and levels in the normal to supranormal range do not eliminate the possibility of a carnitine deficiency at the tissue level. Therefore, even the measurement of normal carnitine levels in plasma or tissue may be misleading because of the possibility of a relative carnitine deficiency in cats with HL.

Recent efforts to explore the role of carnitine supplementation in the treatment of feline HL suggest an association between HL and carnitine deficiency; this is because dietary supplementation with carnitine may have hastened the recovery and increased survival rates of cats suffering from the disease. Other studies suggest that carnitine has a protective effect in preventing hepatic lipid accumulation in otherwise healthy obese cats undergoing substantial weight loss. Thus dietary supplementation with carnitine may eliminate inadequate FA oxidation as a contributing factor to the pathogenesis of feline HL.

CARNITINE AND CHOLINE

In addition to the rate-limiting role of FA β-oxidation in metabolizing fat that reaches the liver, a deficiency in FA exportation from the liver may contribute to the pathogenesis of HL. Because VLDL is the major vehicle for the release of hepatic triglycerides (FFA plus glycerol) into plasma, a defect in VLDL synthesis or transport may contribute to hepatic lipid accumulation. Choline is a nutrient added to all pet foods and is an important methyl donor for the packaging phase of VLDL synthesis. Because of their lack of dietary intake, cats with HL may suffer from a relative deficiency in choline, which in the face of overwhelming lipid delivery to the liver could impede triglyceride export and therefore contribute to hepatic lipid accumulation. Rats, for example, have been shown to develop fatty infiltration of the liver after being fed a choline-deficient diet for 7 days; this change was reversed with choline supplementation.

In addition, dietary choline deficiency in rats can decrease hepatic, cardiac, and skeletal muscle levels of carnitine, suggesting an interdependence between the two. Choline may have effects on carcass composition. Dietary choline is required for the production of choline-containing phospholipids, a necessary component of cell membranes. It is necessary for the synthesis of acetylcholine, which is a transmitter in the central nervous system.

Without question, the role of choline and carnitine homeostasis in the pathogenesis of feline HL remains unclear because of the paucity of information. Angell Memorial Animal Hospital, Boston, is currently enrolling cats into a placebo-controlled, double-blinded clinical nutritional trial evaluating the effect of dietary supplementation with carnitine and/or choline on the outcome of naturally occurring HL.

CARNITINE AND OBESITY

The relationship between carnitine and obesity is being actively researched. Similar to the situation with HL, well-controlled clinical studies in dogs and cats are lacking, but preliminary findings suggest that further study is warranted. Carnitine has been implicated to favorably affect body composition by allowing more efficient use of dietary fat. For example, metabolic efficiency increases in carnitine-supplemented pigs, which in turn leads to a loss of fat mass and a gain of lean body mass; this characteristic could enhance the usefulness of weight-loss programs in obese cats and dogs if the effects of carnitine supplementation are similar in these species. Preliminary studies in small animals have shown that during weight reduction, obese cats given carnitine experience a faster rate of weight loss and significantly increase their percentage of lean body mass compared with nonsupplemented animals (dogs and cats). Because lean tissue uses more calories at rest than fat does, increasing lean body mass could be of benefit in preventing the recurrence of obesity.

CARNITINE SUPPLEMENTATION

Dietary carnitine supplementation has few drawbacks other than cost. Pet foods have historically been relatively low in carnitine because of its water solubility and subsequent leaching from meat products during processing. In addition, carnitine was not approved for use in pet foods in the United States until 1999. Unpublished data in normal dogs and cats suggest a linear relationship between dietary levels of carnitine and plasma and muscle concentrations and that the minimum dietary concentration required to confer a nutritional benefit (e.g., correcting a deficiency, reducing hepatic lipid accumulation, increasing lean body mass) is 300 and 500 ppm on a dry-matter basis (DMB) in dogs and cats, respectively. However, the actual l-carnitine level in more than 100 dog and cat foods varied widely (30 to 1750 ppm DMB), and exact values are not readily available from manufacturers. Specifically formulated therapeutic diets in which carnitine has been added at levels ranging from 300 to

60,33,34

1000 ppm are commercially available.\textsuperscript{4}

The Association of American Feed Control Officials limits the “nutritional” dose of carnitine in dog food to 750 ppm DMB (no limit has been established for cat food). To achieve pharmacologic doses of carnitine in patients, however, administration in capsule or tablet form (purchased over the counter or through the Internet) would be required.\textsuperscript{4} For example, medium- to large-breed dogs with carnitine-responsive DCM require 1 to 2 g of carnitine every 8 to 12 hours,\textsuperscript{19} but a 50-lb dog would receive only approximately 200 mg of carnitine daily by eating a food containing 750 ppm DMB. Carnitine supplements are not uniformly controlled in terms of purity and content, reinforcing the fact that incorporation in food will likely prove to be the most controlled means of administration. Pet foods allowed to contain sufficient carnitine to be used as a drug would have to undergo rigorous FDA drug trials for approval.

SUMMARY
Carnitine is essential for the proper functioning of cellular metabolism. Because carnitine is required for the transport of LCFA into mitochondria, it is of utmost importance in reactions in which the production of energy largely relies on β-oxidation of fat (e.g., in muscle) and where the majority of lipid transport and FA metabolism occur (i.e., the liver). The potential benefits of providing supplemental carnitine in food are currently being studied, especially because carnitine may be viewed as a conditionally essential nutrient in disease processes in which endogenous carnitine synthesis may be inadequate.\textsuperscript{5}

In veterinary medicine, carnitine has been shown to benefit some dogs with DCM. Ongoing research suggests that carnitine may aid in the recovery of cats with HL.\textsuperscript{4,7,25} Finally, published evidence shows that carnitine can accelerate the rate of weight loss in swine and may increase lean body mass during weight loss in dogs,\textsuperscript{35,36} potentially reducing the future risk for obesity. As a conditionally essential nutrient, carnitine may be essential in some recovery states; its exact role in these conditions remains to be elucidated.

ACKNOWLEDGMENTS
The authors thank Kathy Gross, PhD, PAS, Hills Science and Technology Center, Topeka, KS, for her helpful comments and contributions and Rebecca Remillard, PhD, DVM, Angell Memorial Animal Hospital, Boston, for her contributions and critical review of this manuscript.

\textsuperscript{4}Hill’s Prescription® Diets r/d® and l/d® (Hill’s Pet Nutrition, Topeka, KS).

REFERENCES

About the Authors
Dr. Carroll is affiliated with the Department of Medicine and Dr. Côté with the Department of Cardiology, Angell Memorial Animal Hospital, Boston. Dr. Côté is a Diplomate of the American College of Veterinary Internal Medicine (Cardiology).

ARTICLE #3 CE TEST

The article you have read qualifies for 1.5 contact hours of Continuing Education Credit from the Auburn University College of Veterinary Medicine. Choose only the one best answer to each of the following questions; then mark your answers on the test form inserted in Compendium.

1. l-Carnitine can be found in the highest levels in
   a. plants.  c. meat and dairy products.
   b. most pet foods.  d. a and c

2. What is the most important function of carnitine during fat catabolism?
   a. shuttling short-chain FAs out of the mitochondria via VLDL
   b. transporting LCFAs across both the outer and inner mitochondrial membranes for entry into the mitochondrial matrix
   c. aiding in the exportation of VLDL from the hepatocytes
   d. transporting LCFAs across only the inner mitochondrial membrane for entry into the mitochondrial matrix

3. Identifying carnitine as a “conditionally essential” nutrient indicates that
   a. it is an essential nutrient only in patients with HL and DCM.
   b. a deficiency results when endogenous carnitine biosynthesis is insufficient to meet physiologic demands.
   c. it is required only in situations in which fat turnover is increased.
   d. carnitine is essential only in cats.

4. Which of the following statements does not explain why carnitine-responsive DCM in dogs may be difficult to document?
   a. Endomyocardial biopsy is not a routine clinical procedure in veterinary practice.
   b. Carnitine supplementation is contraindicated in many canine breeds.
   c. A dog may have normal serum carnitine levels and still be carnitine deficient at the tissue level.
   d. The cost of carnitine limits its use.
   e. Supplementation for less than weeks to months may not produce appreciable change.

5. Which of the following physiologic mechanisms is not a possible explanation of the pathogenesis of feline HL?
   a. defective VLDL synthesis or transport
   b. protein malnutrition and peroxisome impairment
c. defective triglyceride synthesis
d. relative choline deficiency

6. Which of the following statements regarding carnitine and DCM is true?
a. Of dogs with DCM, 25% to 50% are expected to respond to carnitine supplementation.
b. A genetic test for carnitine deficiency is currently a major tool for identifying dogs with carnitine-deficient DCM.
c. A therapeutic trial of carnitine supplementation is probably the most practical method to determine the potential benefit of carnitine in a dog.
d. Carnitine administration can be discontinued in dogs with carnitine-deficient DCM that respond to supplementation.
e. Dogs with DCM and carnitine deficiency have been shown to benefit from supplementation with choline.

7. Which of the following statements regarding choline is false?
a. Choline is required for VLDL synthesis and subsequent transport from the hepatocytes.
b. Similar to the situation with carnitine, choline can be considered a “conditionally essential” nutrient in patients in which physiologic demand exceeds synthesis or intake.
c. Choline is proven to contribute to the pathogenesis of feline HL.
d. Choline may play an important role in facilitating carnitine uptake in tissue.

8. Conditions in which fat mobilization to the liver exceeds fat exportation from the liver have been shown to result in overt liver dysfunction in all of the following species except
a. dogs. c. guinea pigs.
b. cats. d. rats.

9. Which of the following statements regarding carnitine supplementation is false?
a. Carnitine has been an approved pet food additive since 1999.
b. Food is an adequate delivery system for carnitine.
c. As a supplement, carnitine confers a nutritional benefit only when administered in conjunction with choline.
d. The Association of American Feed Control Officials has set an upper limit for carnitine supplementation in dog food but not in cat food.

10. On a DMB, the minimum level of carnitine required to raise plasma concentrations to confer a nutritional benefit (i.e., to correct a deficiency) is _________ ppm in dog and cat food, respectively.
a. 500 and 300 c. 300 and 500
b. 1000 and 500 d. 300 and 1000