Feline Diabetes Mellitus: Diagnosis, Treatment, and Monitoring*

Lori Rios, DVM, PhD, DACVIM
Veterinary Referral and Critical Care
Manakin-Sabot, Virginia

Cynthia Ward, VMD, PhD, DACVIM^a
The University of Georgia

ABSTRACT: As the prevalence of diabetes mellitus increases in humans, dogs, and cats, advances in monitoring and treating human disease are being applied to veterinary medicine. This article reviews the diagnosis and treatment of feline diabetes and discusses the latest developments in treating and monitoring this disease. New technology is increasing the accuracy of glucose control and assessment of insulin response, thereby improving the opportunities to achieve diabetic remission in many cats.

Diabetes mellitus is a frequently encountered disease in small animal practice. Both dogs and cats appear to be affected by the disease at similar frequencies. However, cats, more commonly than dogs, experience a form of diabetes most closely related to type 2 diabetes mellitus in humans. In addition, some cats may not need insulin therapy to regulate their blood glucose. This has led to the use of the terms insulin–dependent diabetes mellitus and non–insulin–dependent diabetes mellitus to describe the clinical entities and treatment modalities needed in these patients. However, when diagnosing and treating diabetic cats, it is important for practicing clinicians to be aware of the pathogenesis and not simply the clinical response to insulin therapy, as the rationale for various treatment strategies is based on the type and extent of disease.*

DIAGNOSIS
A diagnosis of diabetes mellitus is established through demonstration of appropriate clinical signs, persistent hyperglycemia, and glucosuria. When cats with suspected diabetes are evaluated, a thorough history, careful physical examination, complete blood count, serum biochemistry, urinalysis (preferably by cystocentesis), and urine culture are part of a minimum database. Given that most cats suspected of having diabetes are middle aged or older, the serum thyroxine concentration is also part of the initial diagnostic workup. Abdominal ultrasonography may be useful in evaluating diabetic cats because of the prevalence of concurrent pancreatitis. Feline pancreatic lipase immunoreactivity concentra-

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* A companion article on pathogenesis, risk factors, and the distinction between insulin–dependent and non–insulin–dependent diabetes mellitus is available at CompendiumVet.com.

^a Dr. Ward discloses that she has received financial support from Morris Animal Foundation and Nestlé Purina PetCare Company.
tion has also been shown to be a sensitive and specific indicator of feline pancreatitis.¹

**Clinical Signs**

The most common clinical signs of feline diabetes mellitus are polyuria, polydipsia, polyphagia, muscle wasting, and weight loss, although cats may also be obese.² Unkempt haircoat, lethargy, and progressive weakness are also typical presentations. The polyphagia that is seen in diabetic cats is incompletely understood. Murine models have implicated decreased circulating levels of insulin and leptin and increased release of ghrelin as triggers for diabetic polyphagia.³,⁴

Diabetic neuropathy occurs in approximately 10% of diabetic cats.² The etiology is unknown but may involve alteration in the sorbitol metabolic pathway. Cats display a range of neurologic signs, of which a plantigrade stance is most evident. The hocks touch the ground when walking, and jumping ability is often impaired. Hindlimb weakness and muscle atrophy may also be identified. Although the hindlimbs are affected first, signs can progress to the thoracic limbs. Results of electrophysiologic assessment and analysis of nerve and muscle biopsy samples reveal decreased motor and sensory nerve conduction velocity, pervasive Schwann cell injury with myelin deficits, and axonal degeneration. The severity of clinical signs is correlated with the severity of histopathologic lesions.⁵ There is no specific treatment for diabetic neuropathy, but strict glycemic control may improve clinical signs in diabetic cats.⁶

Cataract formation, an important complication of diabetes mellitus in dogs, is comparably rare in cats.⁷

**Laboratory Findings**

**Complete Blood Count**

Results of the complete blood count in a cat with uncomplicated diabetes are typically within normal limits. Dehydration may lead to a slight increase in hematocrit; conversely, a mild nonregenerative anemia may reflect anemia of chronic disease. A stress leukogram, characterized by a mature neutrophilia and mild lymphopenia, may also be present but is not specific for the diagnosis of diabetes. Concurrent infection or inflammation may also be suspected based on an elevated white blood cell count.

**Serum Biochemistry**

Serum biochemistry abnormalities vary in diabetic cats. Nondiabetic, unstressed cats typically have blood glucose levels less than 171 mg/dL.⁸ A single blood glucose value above the reference range is not sufficient for a diagnosis of diabetes. Persistent hyperglycemia can be difficult to ascertain in cats because of their tendency to develop stress hyperglycemia. It has been demonstrated that healthy cats subjected to a brief stressful event (a bath)
had significant changes in blood glucose, with a mean rise of 79 mg/dL and individual increases as high as 194 mg/dL. Some of the cats continued to have blood glucose values over 200 mg/dL for at least 90 minutes after the event. Hyperglycemia as a result of venipuncture can persist throughout an entire day, invalidating results of an in-hospital blood glucose curve.

If stress hyperglycemia is suspected, keeping the cat in the hospital in a quiet, stress-free area for several hours before rechecking the blood glucose level may be helpful. The owner can also be sent home with strips to monitor urine glucose to document glucosuria. Additionally, a serum fructosamine level can be obtained. Fructosamine is a glycosylated protein that results from an irreversible, nonenzymatic reaction that binds glucose to amino acid residues, especially albumin, in circulation. The concentration of fructosamine in serum is a reflection of mean blood glucose level over the preceding 1 to 3 weeks. The reliability of the fructosamine assay has been documented in numerous studies. Values above the reference range help confirm the diagnosis of diabetes. The normal reference range used at The University of Georgia Veterinary Medical Teaching Hospital is 175 to 400 µmol/L in cats, but reference intervals vary between laboratories, and each laboratory should establish its own reference interval. Hypoproteinemia and hyperthyroidism have been demonstrated to decrease fructosamine levels in cats.

In addition to hyperglycemia, the most common biochemical abnormalities are increases in alanine aminotransferase and alkaline phosphatase and hypercholesterolemia.

**Urinalysis**

Glucosuria is invariably present in diabetic cats. Ketonuria may be present and signals a need to carefully evaluate for diabetic ketoacidosis. Refractometry results may reflect moderately concentrated urine despite polyuria because glucose increases urine specific gravity as measured by refractometer. Proteinuria may indicate bacterial infection or damage to the glomerular membrane as a consequence of diabetes. Red or white blood cells may also be present. A recent study found that 13% of diabetic cats had urinary tract infections, with female cats having an increased risk of infection. More than half of culture-positive cats had no clinical signs as reported by their owners. Periodic monitoring with urinalysis or urine culture is advisable in diabetic cats.

**TREATMENT**

Once the diagnosis is confirmed, veterinarians face a myriad of choices for treating and monitoring a diabetic cat. Owner education and compliance are essential for effective treatment as well as to minimize the risk of life-threatening complications. Fortunately, most owners are aware of diabetes because of its prevalence in humans. Unfortunately, personal or anecdotal experience of the disease in humans can make owners wary of undertaking the challenge of treating their cat. It is a delicate balance for the veterinarian to fully inform clients of the dedication and surveillance necessary to treat this disease while not unduly frightening them or making them feel unable to attempt home medical care. Given the time necessary to help owners learn to manage this disease, we recommend having a checklist for the veterinarian to go over to make sure all details are covered. Handouts explaining the disease; instructions for drugs, diet, and insulin therapy; urine and blood glucose monitoring instructions; details on emergency treatment of hypoglycemia; and emergency numbers for owners to call should be part of a diabetes packet.

The goals of treatment for all diabetic cats are to minimize or eliminate clinical signs of the disease, prevent hyperosmolality or diabetic ketoacidosis, and decrease the occurrence of secondary or concurrent diseases such as diabetic neuropathy, recurrent infections, chronic pancreatitis, and glomerulonephropathy. The most common long-term complications in diabetic cats are diabetic neuropathy and diabetic ketoacidosis. In addition, awareness of the risk of hypoglycemia and the need to carefully adjust treatment protocols is essential in monitoring diabetic cats. Ideally, for cats with non–insulin-dependent diabetes mellitus, treatment should be designed to reverse glucose toxicity, slow or halt progressive destruction of β cells, and reverse insulin resistance at the peripheral level so that reduction or elimination of insulin therapy is possible.

Close monitoring is essential to determine which cats may achieve diabetic remission after diet change with or without insulin.
Insulin therapy is frequently the initial starting choice for treatment and is often necessary and appropriate for long-term management as well. However, new research on dietary manipulation and the impact of dietary management may enable more cats to be treated successfully without insulin therapy.

**Dietary Management**

A decision to begin treatment in diabetic cats with dietary management alone must be carefully based on clinical signs, level of blood glucose dysregulation, and excellent client compliance. Similarly, initiating insulin therapy and dietary management simultaneously necessitates close monitoring because research clearly indicates that many cats have a reduction in insulin requirement just from response to diet change. Cats that do not respond to dietary management alone may have permanently lost significant β-cell function.

Dietary manipulation has been a mainstay of diabetic treatment for humans, cats, and dogs. Historically, dietary recommendations for cats have been similar to those for humans and dogs. In humans and dogs, high-fiber diets are recommended because they have been demonstrated to decrease postprandial hyperglycemia. Increased levels of fiber decrease intestinal carbohydrate absorption. One study of the use of a high-fiber diet demonstrated improved glycemic control in cats compared with low-fiber diets. However, many of the high-fiber diets formulated for cats also contained high levels of carbohydrates, and there is evidence that cats are not well equipped to handle high carbohydrate loads. Cats, being obligate carnivores, have a different metabolism from dogs and humans.

In the wild, cats typically eat 10 to 20 small, high-protein meals (e.g., mice) throughout the day. The feline gastrointestinal tract is therefore geared away from carbohydrate metabolism. Disaccharidase activity in cats cannot up-regulate on demand and is only 40% of the activity in dogs. In dogs, hexokinase and glucokinase are responsible for glucose phosphorylation in the liver, trapping glucose inside hepatocytes and setting the stage for glucose oxidation. Cats have no hepatic glucokinase activity, which minimizes their ability to metabolize large glucose loads.

However, cats, like other animals, need glucose as a substrate for metabolic activity. Their natural high-pro-
tein diet provides a supply of amino acids that serve as building blocks for gluconeogenesis. In cats, amino acids are powerful insulin secretagogues, and thus cats continuously produce glucose as a way to maintain adequate blood glucose levels. Because cats produce glucose continuously, they do not experience postprandial hyperglycemia under natural feeding conditions, nor do they experience drops in blood glucose when deprived of food over a period of several days. However, when exposed to a high carbohydrate load, they are less able to adapt to the postprandial glucose surge and experience significant increases in blood glucose concentration.

Current recommendations support the use of a high-protein, low-carbohydrate diet for management of feline diabetes. Several studies have demonstrated an improvement in blood glucose levels and a decreased need for insulin therapy after implementation of such a diet. In a recent study, although both a moderate-carbohydrate, high-fiber diet and a low-carbohydrate, low-fiber diet were found to revert cats to a non–insulin-dependent state, the cats fed a low-carbohydrate, low-fiber diet were significantly more likely to revert (68% versus 41% of cats). There are several excellent low-carbohydrate commercial diets available for cats with diabetes mellitus, and owners should be encouraged to try available choices if an initial choice is not palatable to their cat.

Weight loss is also an essential component of diabetic management. Initial goals of treatment should be an improvement in glycemic control and clinical signs of disease. Cats should be given some time to adjust to a diet change and the addition of insulin therapy. Owners should then be encouraged to implement a weight-loss program developed by their veterinarian. Weight loss should be at a rate of 1% to 2% of total body weight per week. Owners should be encouraged to precisely measure the food they give and weigh their cats on a baby scale weekly. As the cat's weight decreases, insulin requirements will probably also decrease; therefore, these cats should be closely monitored.

**Oral Hypoglycemic Agents**

Oral hypoglycemic agents are a mainstay of treatment for type 2 diabetes in humans. Hypoglycemic agents work by decreasing intestinal absorption of glucose, improving peripheral sensitivity to insulin, inhibiting hepatic glucose output, or increasing insulin secretion from the pancreas. Their use in veterinary medicine has been limited for a number of reasons. First, many cats are difficult to pill. In addition, for most cats, adequate diabetic control cannot be achieved with oral hypoglycemic agents alone. There is also evidence that use of these medications to treat diabetes mellitus may worsen pancreatic amyloidosis in cats.

Glipizide, an oral sulfonylurea, is the main hypoglycemic agent studied in cats. This drug directly stimulates the pancreas to secrete insulin; therefore, it is only helpful in cats that retain some ability to secrete insulin. Overall, approximately 30% of cats appear to have a positive response to glipizide, which probably depends on the percentage of functional β cells. Adverse reactions include vomiting shortly after drug administration, hypoglycemia, and elevated levels of liver enzymes. Monitoring of liver enzymes is recommended if glipizide is used. Hypoglycemia and liver enzyme elevation resolve if the drug is discontinued. Additionally, glipizide may exacerbate formation of amyloid deposits and thus contribute to destruction of β cells. The role of glipizide is therefore unclear; however, glipizide may be helpful for owners who cannot give insulin injections to their cat and for whom an oral agent is the only option. Glipizide is typically given at 2.5 mg PO bid with a meal. This dose is increased to 5.0 mg PO bid if adverse effects do not occur. Careful monitoring of clinical signs, blood glucose regulation, and liver enzymes dictates future dose adjustments.

Other oral hypoglycemic agents that have been used in cats include α-glucosidase inhibitors (e.g., acarbose), biguanides (e.g., metformin), and the trace elements chromium and vanadium. Acarbose competitively inhibits α-glucosidase and α-amylase in the small intestine, thereby delaying digestion of carbohydrates and glucose absorption. Metformin reduces hepatic gluconeogenesis and glycogenolysis and enhances insulin-stimulated uptake of glucose by muscle and adipose cells. The mechanisms of action of chromium and vanadium are not completely understood, but chromium...
exerts its effects by increasing insulin sensitivity, and vanadium acts at postreceptor sites to stimulate glucose metabolism.24,25 There are limited studies demonstrating the efficacy of oral hypoglycemic agents in cats.

**Insulin Therapy**

Despite the positive impact of dietary management in reverting cats to a non–insulin-dependent state, most diabetic cats still need insulin therapy, whether temporarily or long term. Several available insulins have demonstrated a good response in cats (Table 1).

**Glargine**

Glargine is a long-acting human recombinant insulin designed for human use. It is marketed to give 24-hour basal control of insulin circulation. In humans, glargine is often used in a basal-bolus pattern with injection of another insulin preparation at mealtimes. This is designed to most closely recreate the human body’s natural pattern of insulin release. Glargine has no pronounced peak of activity in humans, which means it is released into the bloodstream at a relatively constant rate. In cats, glargine has been demonstrated to have peak activity at about 16 hours and to effectively suppress blood glucose levels for 24 hours, although twice-daily dosing seemed to be most effective in one study.26

In our experience, this peak does not require different monitoring from other insulins. A recent study demonstrated that diabetic cats treated with glargine had lower serum fructosamine levels and achieved diabetic remission earlier than cats treated with protamine zinc insulin (PZI) or lente insulin.27 Initial dosing should be started at 0.25 to 0.5 U/kg bid. Given that cats appear to respond well to glargine and that normoglycemia and diabetic remission are real possibilities, it may be prudent to begin treatment at the low end of the dosage range to minimize the risk of hypoglycemia. Additional advantages of glargine are that it is available at any human pharmacy and at a concentration of 100 U/mL, which is compatible with easily available U-100 insulin syringes.

**Protamine Zinc Insulin**

Protamine zinc insulin (PZI) is insulin combined with zinc and protamine (a protein extracted from salmon testes). PZI contains more protamine than NPH, which gives it a longer duration of action than NPH. Until recently, the product used most commonly for cats was made from 90% bovine and 10% porcine insulin (PZI Vet, Idexx Pharmaceuticals), although PZI can also be formulated from human recombinant insulin or from bovine insulin only. Feline insulin differs from bovine insulin by one amino acid and from porcine insulin by three amino acids. PZI can be formulated at a concentration of 40 or 100 U/mL.

PZI was originally thought of as a long-acting insulin in cats; however, most cats need twice-daily dosing to attain good glycemic control. One study demonstrated that PZI was effective in reducing blood glucose levels and clinical signs of diabetes within 45 days of initiating treatment.28 However, clinical signs of hypoglycemia developed in 7% of the cats, and there was considerable

<table>
<thead>
<tr>
<th>Product</th>
<th>Manufacturer</th>
<th>Insulin Source</th>
<th>Duration</th>
<th>Recommended Dose</th>
<th>Concentration</th>
<th>Syringe Type</th>
<th>Number of Amino Acids Different from Feline Insulin</th>
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<tr>
<td>Glargine</td>
<td>Sanofi</td>
<td>Recombinant human</td>
<td>Long acting</td>
<td>0.25–0.5 U/kg bid</td>
<td>100 IU/mL</td>
<td>U-100</td>
<td>4</td>
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<tr>
<td>PZI</td>
<td>Several</td>
<td>Varies</td>
<td>Long acting</td>
<td>Consult product information</td>
<td>Varies</td>
<td>Varies</td>
<td>1 (bovine), 3 (porcine)</td>
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<tr>
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<td>Several</td>
<td>Recombinant human</td>
<td>Intermediate acting</td>
<td>0.25–0.5 U/kg bid</td>
<td>100 IU/mL</td>
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<td>Vetsulin</td>
<td>Intervet</td>
<td>Porcine</td>
<td>Intermediate acting</td>
<td>0.25–0.5 U/kg bid</td>
<td>40 IU/mL</td>
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overlap between the dosages that caused hypoglycemia, 
glycemic control, and lack of control after 45 days of 
treatment. Although variable, the blood glucose nadir 
occurred between 5 and 7 hours after administration in 
many cats; thus, twice-daily dosing is more appropriate 
to achieve glycemic control. Use of PZI Vet is limited to 
the existing supply; in April 2008, the manufacturer 
announced that following the sale of existing inventory, 
it will no longer manufacture or sell animal-based 
insulin. A bovine insulin product (BCP PZI, BCP Vet-
ernary Pharmacy, Houston) is still available.

**Vetsulin** 
Vetsulin (Intervet/Schering-Plough Animal Health) is a 
porcine zinc insulin suspension that is the only insulin for 
dogs and cats approved by the US Food and Drug 
Administration (FDA). It is identical to canine insulin 
but differs from feline insulin by three amino acids. Vet-
sulin is also formulated at a concentration of 40 U/mL. 
Its pharmacologic properties have been demonstrated to 
be suitable for twice-daily administration in cats,29 in 
which it appears to have a shorter peak onset and dura-
tion of action than PZI or glargine. The peak effect of 
Vetsulin in cats has been shown to be about 4 hours after 
administration.29

**Neutral Protamine Hagedorn** 
Neutral protamine Hagedorn (NPH) insulin is pro-
duced by recombinant DNA technology and is consid-
ered an intermediate-acting insulin. It is distributed by 
several manufacturers under names such as Humulin N 
(Eli Lilly) and Novolin N (Novo Nordisk). It is a crys-
talline suspension of human recombinant insulin with 
protamine and zinc added. The concentration of NPH 
is 100 U/mL. Short duration of action is a common 
problem with NPH, and thus cats can remain hyper-
glycemic for significant portions of the day.2

**MONITORING RESPONSE TO TREATMENT** 
For most newly diagnosed diabetic cats, treatment 
begins with the initiation of dietary modification along 
with conservative insulin therapy. If the cat is stable and 
has a blood glucose <350 mg/dL, therapy can be started 
with diet alone. Sometimes this can bring about remis-
sion without further medical treatment. Clients must be 
aware that this is the first step in diabetic management 
and that careful follow-up for life will be necessary. No 
consensus dictates the appropriate follow-up for diabetic 
cats. An ideal plan consists of a combination of in-hos-
ital monitoring, periodic measurement of fructosamine 
levels, owner awareness of clinical signs, and a degree of 
in-home monitoring.

**In-Hospital Monitoring** 
When initially reevaluating a newly treated diabetic cat, 
it is important to increase insulin dosages slowly. It can 
take several weeks on a particular insulin regimen for 
glycemic control to improve. Perhaps more importantly, 
initial rechecks help to identify hypoglycemia or the 
Somogyi phenomenon. Ideally, cats should be reevalu-
ated every 1 to 2 weeks for the first month or two of 
treatment. In reality, this can be difficult for owners in 
terms of expense or time involved. Therefore, it is 
important for the veterinarian and the owner to come 
up with a protocol that allows close monitoring but does 
not make owner compliance impossible.

Serial in-hospital blood glucose curves have been a 
mainstay of diabetic management. They are essential in 
identifying critical events such as the Somogyi phenom-
non and periods of hypoglycemia, and they aid in ident-
ifying the duration and efficacy of insulin action and 
glucose nadir. However, the accuracy of data generated 
from in-hospital curves is questionable in cats because 
stress hyperglycemia and in-hospital anorexia are com-
mon. Although stress hyperglycemia is sometimes diffi-
cult to identify, clearly stressed cats should be monitored 
by a combination of other methods, and data generated 
in “calm” cats must be evaluated with the awareness that 
stress may raise blood glucose levels.

Even if a serial blood glucose curve cannot be 
obtained, recheck examinations are imperative for 
obtaining owner reports of clinical signs, evaluating clin-
ical manifestations of disease (hydration status, weight 
gain or loss, evidence of diabetic neuropathy), and meas-
uring fructosamine levels. However, there are important 
limitations to fructosamine interpretation. First, high 
levels indicate that the mean blood glucose level over the 
past several weeks has been elevated but not why. One
possibility is that the insulin dosage may not be sufficient; others are extreme glucose fluctuations, as would be seen in the Somogyi phenomenon, and problems with owner insulin administration. If the Somogyi phenomenon is suspected or if there is a question about owner compliance, a blood glucose curve may be helpful to further assess the cat’s level of glycemic control. Second, while normal serum levels of fructosamine may indicate good glycemic control, they do not reflect episodes of hypoglycemia.

Home Monitoring
Home monitoring is imperative for all diabetic cats. The extent of home monitoring can range from owner observations of clinical signs to urine glucose and ketone monitoring to in-home blood glucose monitoring. In all cases, owners must be told that adjustments in insulin cannot be based on their judgments or perceptions alone, but only in consultation with their veterinarian. They should be encouraged to keep a log assessing water intake, frequency and quantity of urine output, appetite, and overall energy level. They should also be advised to watch for clinical signs of hypoglycemia such as lethargy, weakness, ataxia, and seizures. Urine glucose and ketone strips can be used once or twice weekly to check for uncontrolled hyperglycemia or negative urine glucose. Negative glucose dipstick findings may indicate diabetic remission or impending hypoglycemia and are a sign that reassessment via blood glucose curve is necessary. Likewise, elevated levels of glucosuria may indicate insulin resistance or the Somogyi phenomenon. Ideally, well-regulated, stable cats have urine glucose levels between a trace value and 1+. A series of values outside this range should prompt the owner to call the veterinarian and schedule further assessment after the initial insulin adjustment period.

Portable Blood Glucose Meters
Portable blood glucose meters (PBGMs) are now available. When used in the home setting, they are invaluable for reducing artifactual increases in blood glucose as a result of hospital-induced stress hyperglycemia. Results from several studies have demonstrated that blood glucose concentration measurements obtained from PBGMs are sufficiently accurate compared with results obtained from automated chemistry analyzers, although some meters tend to be more accurate than others. Owners interested in obtaining in-home blood glucose curves should be encouraged to receive training from the veterinary staff and try monitoring at home.

The success of home blood glucose monitoring appears to depend on the temperament of the cat and the skills of the owner. A recent retrospective study involving 26 cats over a 3-year period found that home monitoring appeared to be a feasible option and that most owners used home monitoring on a regular basis to generate blood glucose curves for their cat. In addition, owners who were successful at home monitoring felt they had become more confident in their ability to manage their pet’s disease. Therefore, it appears that for interested owners and compliant cats, home monitoring of diabetic cats can be an important adjunct to treatment. However, owners need clear and thorough instruction in the use of monitoring devices, and the veterinary staff must be committed to helping owners gain competence and confidence.

Blood for use in a PBGM is obtained from a capillary in the inner pinna using a lancing device. Different devices are available; some create negative pressure to facilitate blood collection. The user holds the cat’s ear in one hand, keeping the outer pinna flat. The user then places the lancet on the ear, being careful to not apply too much pressure to the device against the ear. After the device is depressed and blood is visible, the test strip is placed next to the ear to allow the blood to fill the strip. In several studies evaluating home blood glucose monitoring, owner and cat compliance appeared to be good, with one study reporting 17 of 26 cat owners using the procedure on a regular basis. Prospective studies are needed to determine if cats undergoing home blood glucose monitoring have better glycemic control than cats monitored with more conventional methods.
Continuous Glucose Monitoring Systems

Continuous glucose monitoring systems (CGMSs), which monitor interstitial glucose levels via a subcutaneously placed sensor, are the latest devices to help diabetic human patients improve glycemic control. This technology represents a significant advancement in the way veterinarians will be able to monitor their diabetic patients. Various models are available, but to date, the only FDA-approved devices are from Medtronic. Measurements of interstitial glucose concentrations avoid the need for repeated peripheral blood sampling either through numerous venipunctures or placement of an indwelling catheter. In addition, the technology may allow the patient to go home for the duration of the monitoring period. Several studies in humans and animals have demonstrated good correlation between interstitial glucose concentration and blood glucose concentration.

A first-generation CGMS called the MiniMed (Medtronic) consists of a subcutaneously placed sensor, transmitter, and pager-sized monitor. The sensor and transmitter are connected by a cable, which is secured to the patient’s back or side (Figures 1 and 2). The transmitter relays data to the monitor, which must be placed within several feet of the transmitter (e.g., hung on the patient’s cage). Glucose in interstitial fluid passes through a semipermeable membrane and interacts with glucose oxidase on the sensor electrode. This reaction generates an electrical current that is proportional to the glucose concentration. The current is sampled by the monitor every 10 seconds, and a mean reading is recorded every 5 minutes in milligrams per deciliter. Therefore, in a 24-hour period, 288 readings are recorded. The device can record for a total of 72 hours. For placement in dogs and cats, a small area on the thorax, either over the spine or the lateral thorax, is shaved and surgically prepared. The sensor is inserted and taped in place, and the transmitter is attached to a harness or wrapped in bandage material (Figure 3). After an hour, the monitoring device needs to be calibrated. A blood glucose reading is obtained and entered into the recording device for calibration. The manufacturer recommends three calibrations within a 24-hour period; however, after the initial calibration, one calibration every 12 hours is adequate. At the end of the monitoring period, data are downloaded and displayed on a spreadsheet.

The MiniMed CGMS has been demonstrated to be valid for cats, with good correlation between interstitial glucose concentration and blood glucose in the cats.
The device appears to be well tolerated by cats, and it did not appear to disrupt normal movement and feeding behavior in a study of hospitalized subjects. The advantages of this device are the ability to generate a continuous blood glucose curve without patient handling and the ability to adapt the system for at-home use. The sensor can record for up to 72 hours, which may be advantageous for some patients because glucose curves can vary from day to day and longer sampling periods give a more accurate indication of trends. The limitations of the CGMS include potential undetected interruptions in sensing. In addition, the need for calibration every 12 hours requires the owner to either use a PBGM at home or bring the patient back to the hospital. For cats, the stress involved in returning to the hospital may invalidate results, as for a traditional blood glucose curve. In one study of 14 cats, one cat removed the sensor, and two cats kinked it. Finally, the sensor records interstitial glucose readings only between 40 to 400 mg/dL. A flat line at the 400 level is displayed when values are above this level.

The latest generation of CGMS is Medtronic’s Guardian RT (Figure 4). This system displays an updated real-time interstitial glucose value every 5 minutes and has an alarm to monitor high or low glucose levels. The difference between the MiniMed and the Guardian RT is that the former was designed as a 72-hour diagnostic tool and the latter is designed to provide human patients with instant information about their own glycemic control. Similar to the MiniMed, the Guardian RT uses a subcutaneous sensor. However, it also includes a small radiotransmitter that is placed on the skin and communicates wirelessly with the monitoring device (Figures 5, 6, and 7). The patient and the monitor need to be within 6 ft for transmission. The
device is calibrated 2 hours after placement and 8 to 12 hours later. The results are downloaded into a software program, and a glucose curve is generated.

In humans, the technology has progressed to integrating insulin pumps with CGMSs to allow patients to program delivery of one to 12 different basal rates of insulin per 24 hours. One potential advantage of the Guardian RT system for use in feline patients is elimination of the need to wear the bulky cable-attached transmitter device. Although most cats evaluated appeared to accept wearing the radiotransmitter, it is unlikely to be as well tolerated by cats as it is by dogs. Cats in our hospital have tolerated the smaller Guardian RT well, with no adverse events to date. One disadvantage of the Guardian RT is the need to be within 6 ft of the monitor. Therefore, a cat at home would need to be placed in a crate or small room for the readings to be successfully transmitted.

At The University of Georgia, we have successfully used both the older MiniMed and the Guardian RT in cats; however, we currently use the Guardian RT. The major limitation of each device thus far has been brief periods in which the device did not record glucose readings. We are actively evaluating the Guardian RT to eliminate technical difficulties as well as to further assess the clinical utility of this type of monitoring. Overall, the many advantages of this type of glucose monitoring system will likely make CGMSs a standard of care for diabetic monitoring in the near future.

CONCLUSION
The treatment of diabetes mellitus in cats continues to be both rewarding and challenging. It is important for practitioners to be aware of species-specific differences when treating feline and canine patients. The availability of new insulin therapies and advancements in nutritional recommendations hold much promise for effective management of this disease. Client education and participation in treatment can greatly improve diabetic control in feline patients, as can advances in monitoring equipment. Great advances are being made in the understanding and treatment of diabetes in human medicine, and it is anticipated that these advances will aid in the treatment of feline patients.

REFERENCES
9. Rand JS, Kinnaird E, Baglioni A, et al. Acute stress hyperglycemia in cats is associated with struggling and increased concentrations of lactate and norepi-

**ARTICLE #1**

**CE TEST**

The Auburn University College of Veterinary Medicine approves this article for 3 contact hours of continuing education credit. Subscribers may take individual CE tests or sign up for our annual CE program. Those who wish to apply this credit to fulfill state relicensure requirements should consult their respective state authorities regarding the applicability of this program. CE subscribers can take CE tests online and get real-time scores at CompendiumVet.com.

1. **Diabetic neuropathy in cats**
   a. is rare, seen in less than 5% of feline diabetic patients.
   b. leads to an increase in motor and sensory nerve conduction velocities.
   c. appears to be due to alterations in the sorbitol metabolic pathway.
   d. is typically identified by forelimb weakness that progresses to the hindlimbs.

2. **Cats differ from dogs in glucose metabolism in that they**
   a. can handle a carbohydrate load better than dogs.
   b. can up-regulate disaccharidase activity when faced with increased intestinal glucose.
   c. do not need glucose as a substrate for metabolic activity.
   d. lack the hepatic enzyme glucokinase, which minimizes their ability to metabolize large glucose loads.

3. **When assessing a newly diagnosed diabetic cat, which of the following is true?**
   a. The complete blood count invariably demonstrates a decreased hematocrit as a reflection of anemia of chronic disease.
   b. Dilute urine is typically noted due to the polyuria experienced by most diabetic cats.
   c. Urinary tract infection is a common finding, despite the lack of clinical signs reported by owners.
   d. Fructosamine levels are not affected by the presence of other disease conditions.

4. **Which statement regarding the long-term effects of diabetes mellitus in cats is true?**
   a. Cataract formation is an important complication, as in dogs.
b. Control of glucose regulation will completely reverse signs of diabetic neuropathy in most cats.
c. Nephropathy and vasculopathy are common long-term complications, as they are in humans.
d. Diabetic neuropathy is the most common long-term complication of diabetes mellitus in cats.

5. Which statement is false regarding current research findings on the role of diet in the management of feline diabetes?
   a. Increased dietary fiber levels negatively affect glycemic control in cats.
   b. Moderate-carbohydrate, high-fiber diets and low-carbohydrate, low-fiber diets have both been shown to be of benefit in cats with diabetes mellitus.
   c. Low-carbohydrate, low-fiber diets appear to be superior to moderate-carbohydrate, high-fiber diets in helping cats achieve diabetic remission.
   d. Cats are less adapted than dogs to deal with high carbohydrate loads due to decreased glucokinase activity in the liver.

6. Which statement best characterizes the use of oral hypoglycemic agents in cats?
   a. Oral hypoglycemic agents have a greater role in the treatment of canine diabetes than in feline diabetes.
   b. They can be used alone to achieve diabetic control in most cats.
   c. Glipizide works best in patients that have lost insulin-secreting ability.
   d. The use of glipizide may lead to an increase in amyloid deposits.

7. Which statement best represents current information about the use of glargine in cats?
   a. Glargine is unique among insulins in that it is considered a peakless insulin in cats.
   b. The use of glargine has been shown to help induce diabetic remission earlier than PZI or lente insulin in some cats.
   c. Glargine is similar to Vetsulin in that it is formulated at a concentration of 40 U/mL.
   d. Due to its long duration of action, glargine should only be used once a day in cats.

8. Which statement regarding current insulin therapy for cats is true?
   a. No insulin currently on the market has been approved by the FDA for use in cats.
   b. Several available insulins have demonstrated a good response in cats.
   c. NPH has a long duration of action and, therefore, may be an excellent choice for use in cats.
   d. All available insulins are administered with the same syringe.

9. Owners of diabetic cats should not attempt to _______ by themselves at home.
   a. monitor blood glucose
   b. generate a blood glucose curve
   c. monitor urine glucose
   d. adjust the insulin dose

10. Continuous glucose monitoring systems
    a. have not been validated for use in small animals; therefore, results from these devices must be evaluated with caution.
    b. need to be calibrated every 6 hours; therefore, they are most useful in a hospital setting.
    c. are not tolerated by cats.
    d. record only interstitial glucose levels between 40 and 400 mg/dL.