The sudden onset of blindness in cats has been observed in association with systemic hypertension, similar to that in humans. Severe systemic hypertension (malignant or accelerated) is associated with an exudative retinopathy caused by disruption of the blood ocular barrier. Exudative retinopathy is no longer a common finding in humans with hypertension (malignant or accelerated) is associated with systolic blood pressures > 168 mm Hg. There was an increased risk for hypertensive retinopathy in female cats, > 10 years old, and neutered. The risk of chronic renal failure also increased as blood pressure, particularly systolic blood pressure, increased.

Direct invasive measurements are regarded as the gold standard for monitoring blood pressure; however, it is not possible to perform these techniques in a clinical environment. Use of the Doppler ultrasonic flow meter has been reported in healthy conscious cats. In those studies, systolic blood pressure (SBP) was measured because diastolic blood pressure (DBP) was difficult to assess with the Doppler ultrasonic flow meter. Hypertension in cats is defined as a blood pressure measurement > 160/100 mm Hg (SBP/DBP) when measured with the Doppler ultrasonic flow meter. Many cats with hypertension have SBPs > 200 mm Hg.

The oscillometric technique for indirectly measuring blood pressure has been validated in dogs, in which a range of blood pressures in relation to a large number of variables, particularly breed, has been determined. In contrast, there is a paucity of information on the use of the oscillometric technique in cats, perhaps because of the misconception that this technique is not useful in cats. Indirect blood pressure measurements obtained by use of the oscillometric monitors have been compared with direct arterial measurements obtained in healthy anesthetized cats. Of the oscillometric, Doppler, and photoplethysmographic techniques, the oscillometric technique was reported to be the least accurate and least efficient for measuring blood pressure indirectly in cats. The oscillometric technique underestimates direct blood pressure measurements by 10 to 20 mm Hg, and excessive time (greater than several minutes) is required to obtain the measurements. Results of a recent study in conscious cats indicated that the time required to obtain a repeatable measurement with the oscillometric monitor was an important factor, and in most cats, 15 to 20 minutes was determined to be acceptable. Results of another study that compared indirect blood pressure measurements obtained by oscillometric, Doppler, and photoplethysmographic techniques with direct arterial measurements in healthy anesthetized cats indicate that the oscillometric technique provided the most accurate prediction of direct SBP. There are few studies that support the use of the oscillometric technique for measuring blood pressure indirectly in cats. Data obtained from anesthetized cats may not be useful for evaluating data obtained from conscious cats.

The purpose of the study reported here was to determine whether there was an association between hypertensive retinopathy (HRet) and high SBP, DBP, and mean arterial pressure (MAP) in cats, which were measured by use of the oscillometric technique, and the strengths of the different associations were compared. The range of SBP, DBP, and MAP in healthy cats from various age groups was also determined. Because
many of the cats had chronic renal failure, hyperthyroidism, and left ventricular cardiac hypertrophy, we also determined associations between SBP, DBP, and MAP and these diseases, as well as abnormalities in serum biochemical analyses. The term HRet refers to hypertensive ocular disease.

Materials and Methods

Animals—Details of age, sex, breed, health status, temperament, SBP, DBP, and MAP were recorded in 181 cats. Cats were obtained from a colony used for nutrition studies, local breeders, and staff members or clients of the referral clinic at the Animal Health Trust. Data were collected during a 2-year period. Client consent was obtained for all procedures.

Blood pressure measurements—Systolic blood pressure, DBP, and MAP were recorded by use of a noninvasive oscillometric monitor. At least 6 measurements were obtained for each cat after the cat had become calm and a series of repeatable measurements could be obtained, and the mean of the series was calculated. Measurements were recorded with the owner present during the initial examination or during subsequent hospitalization required as part of the routine care of the cats. Cats were minimally restrained for the procedures. Systolic blood pressure, DBP, and MAP were measured with the cat in sternal recumbency to minimize the vertical distance between the cuff site (base of tail) and the heart, obviating the need to correct blood pressure values to account for this difference. The cuff was placed directly around the base of the tail. The hair was not clipped, and gel or alcohol was not used to wet the hair. Most measurements were recorded with a blood pressure cuff size 2 (circumference, 3 to 6 cm) because this was the optimum size for most adult cats.

Clinical investigations—The extent to which clinical investigations were performed was determined in each cat by clinical need and financial constraints of the owners. Thirty-six of 54 cats with HRet and 6 cats with hyperthyroidism were evaluated further by radiography and echocardiography by use of a diagnostic ultrasound machine with M-mode capabilities. Ultrasonography was also helpful in determining whether a retinal detachment was present if ophthalmoscopy could not be performed because of severe intraocular hemorrhage. Cats were manually restrained for all procedures.

Results of different diagnostic tests were required to allocate cats into disease status groups for statistical analyses. If a particular diagnostic test had not been performed for clinical or financial reasons, data from those cats were omitted for that part of the analysis. Cats were classified with hyperthyroidism if M-mode and 2-dimensional B-mode echocardiography revealed mild, moderate, or marked hypertrophy. Cats were classified with hyperthyroidism if serum thyroid hormone concentrations were > 160 µmol/L. Cats were classified with left ventricular cardiac hypertrophy if M-mode and 2-dimensional B-mode echocardiography revealed mild, moderate, or marked hypertrophy, which was defined by measuring 6 parameters (interventricular septum, left ventricular free wall, and left ventricular internal diameter each in systole and diastole) and comparing those measurements with published values. Cats were classified with hyperthyroidism if serum thyroid hormone concentrations were > 65 µmol/L. Left ventricular hypertrophy was also diagnosed in 1 cat at necropsy. Cats that were not classified into 1 of the 3 groups or did not have other recognized clinical signs of systemic diseases were classified as healthy.

Results of serum biochemical analyses obtained as part of the clinical investigations were used to determine associations between potassium and HRet, chronic renal failure, and increased blood pressure; and between cholesterol and HRet, chronic renal failure, and increased blood pressure.

Statistical analyses—Systolic blood pressure, DBP, and MAP for each cat were used in the statistical analyses. The association between disease (HRet, chronic renal failure, left ventricular hypertrophy, and hyperthyroidism) and each explanatory variable (SBP, DBP, MAP, age, sex, and neutered status) was initially determined by use of frequency tables, scatter plots, and descriptive statistics. The significance of univariable associations between disease and other explanatory variables was assessed by use of χ² tests (categorical variables included sex and neutered status) and Student t tests (continuous variables included blood pressure and age). Following univariable analyses, logistic regression models were used to describe the association between disease and explanatory variables. Variables were tested for inclusion in models if they were associated with disease in the univariate analysis (P < 0.3) or if there was a priori evidence of an association. Models were built by forward build-up techniques and confirmed by backward stepwise selection techniques. Variables were retained in models if they were significantly associated with disease (Wald statistic, P < 0.05) or they significantly improved the fit of the model (likelihood ratio statistic, P < 0.05). Biologically meaningful statistical interaction terms were tested between all variables retained in models. The stability of the models was evaluated through examination of fitted β values. Observations with high leverage were sequentially excluded from models, and conclusions were reevaluated. All statistical analyses were performed by use of a computer software program.

Results

Of the 181 cats initially studied, 94 were classified as healthy. Of the remaining 87 cats, 54 had HRet with or without concurrent disease and 33 had concurrent disease without evidence of HRet. Of the 54 cats with HRet, blood pressure measurements were available from 41 (blood pressure measurements could not be obtained from the tail in 8 cats, and measurements from 5 cats were erratic).

Of the 112 cats for which serum creatinine concentrations were available, 45 were classified with chronic renal failure. Of the 43 cats that underwent ultrasonographic examination, 32 were classified with Table 1—Blood pressure measurements (mm Hg) in healthy cats of various ages and cats with hypertensive retinopathy (HRet).

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Mean</th>
<th>Median</th>
<th>10%</th>
<th>25%</th>
<th>75%</th>
<th>90%</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 5</td>
<td>116.4</td>
<td>118</td>
<td>92</td>
<td>104</td>
<td>131</td>
<td>141</td>
</tr>
<tr>
<td>≥ 5, &lt; 10</td>
<td>128.3</td>
<td>128</td>
<td>110</td>
<td>118</td>
<td>138</td>
<td>152</td>
</tr>
<tr>
<td>≥ 10</td>
<td>146.8</td>
<td>150</td>
<td>123</td>
<td>135</td>
<td>158</td>
<td>168</td>
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<tr>
<td>HRet</td>
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<td>191</td>
<td>167</td>
<td>179</td>
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<td></td>
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</tr>
<tr>
<td>&lt; 5</td>
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<td>59</td>
<td>45</td>
<td>52</td>
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<td>84</td>
</tr>
<tr>
<td>≥ 5, &lt; 10</td>
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<td>82</td>
<td>51</td>
<td>60</td>
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<td>101</td>
</tr>
<tr>
<td>≥ 10</td>
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<td>92</td>
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<tr>
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<tr>
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<td>HRet</td>
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</table>
left ventricular hypertrophy. Fifteen of 181 cats were classified with hyperthyroidism. Other diseases, including diabetes mellitus (n = 2), liver disease (1), myopathy (1), inflammatory bowel disease (2), and primary hyperchylomicronemia (2), were diagnosed by use of standard clinical definitions.21

Ages in healthy cats ranged from 6 weeks to 17 years (median, 4 years). Ages of cats with evidence of HRet or other systemic disease ranged from 4.5 to 17 years (median, 13 years). Ages of cats with chronic renal disease, hyperthyroidism, and HRet ranged from 7 to 16 (median, 11 years), 11 to 17 (median, 15 years), and 9 to 17 years (median, 14 years), respectively. Ocular changes observed in this study included serous retinal detachment (53/54 cats) and intraocular hemorrhage (19/54) in the form of hyphema or vitreous hemorrhage.

The most common breeds of cats in this study included domestic shorthair (n = 155), Persian (7), and Abyssinian (5). Other breeds included Burmese, domestic longhair, British Silver, Himalayan, Russian Blue, and Siamese cross. There were 94 female cats (29 were sexually intact and 63 were neutered, and the neutering status of 2 were unknown) and 87 male cats (18 were sexually intact and 69 were neutered).

Mean SBP, DBP, and MAP increased with age in healthy cats, as did the range of the blood pressure values (Table 1). Data from healthy cats were used to estimate normal blood pressure variation for 3 different groups. Median SBP increased from 118 mm Hg (10th and 90th percentiles, 92 to 141 mm Hg) in cats < 5 years old to 128 mm Hg (10th and 90th percentiles, 110 to 152 mm Hg) in cats from 5 to 9 years old to 150 mm Hg (10th and 90th percentiles, 123 to 168 mm Hg) in cats ≥ 10 years old.

Mean SBP, DBP, and MAP were significantly higher in cats with HRet, compared with those without HRet. No significant association was found between sex and blood pressure. The low numbers of cats from breeds other than the domestic shorthair precluded evaluation of any association between blood pressure and breed.
In the univariable analysis, HRet was significantly associated with increased SBP, DBP, MAP, age, and chronic renal failure (Table 2). Cats > 10 years old were 7 times more likely to develop HRet. No cats < 9 years old had HRet; however, it was observed in cats that were 9 years (n = 1) and 10 years (8) old.

A logistic regression model of the association between HRet and explanatory variables was developed as described (Table 3). Systolic blood pressure was better than DBP and MAP in predicting the likelihood of HRet. There was no significant association between HRet and age or chronic renal failure when SBP was included in the model. Sex, neutering status, SBP, and hyperthyroidism were the significant variables retained in the model that were associated with the probability of a cat having HRet. Neutered cats (both males and females) were more likely to develop HRet than sexually intact cats. Female cats were more likely to develop HRet than males. Although the association between HRet and hyperthyroidism was not significant in the univariate analysis, when SBP was included in the multivariate analysis, there was a significant negative association between HRet and hyperthyroidism.

Univariable associations between HRet and serum biochemical analyses were determined (Table 4). Hypertensive retinopathy was associated with decreased serum potassium concentration (Fig 1) and increased serum concentrations of cholesterol (Fig 2), urea (Fig 3), and creatinine (Fig 4). The association between HRet and serum creatinine concentration was expected because of the association between HRet and chronic renal failure in the univariate analysis.
There was a significant univariable association between chronic renal failure and decreased serum potassium concentration when potassium was considered as a continuous variable (Table 5). There was a significant positive association between chronic renal failure and SBP in the multivariable analysis (Table 6). Similar to HRet, when SBP was included in the multivariable model, the odds of a cat having chronic renal failure decreased in cats with hyperthyroidism (and vice versa). The risk of developing
hyperthyroidism increased with age in cats of this study.

**Discussion**

There is a paucity of epidemiologic data on blood pressure values for cats. Only within the last 10 years has appropriate monitoring equipment become available for use in a clinical environment, in which blood pressure measurements can be obtained from conscious cats. Few studies have been published on use of the oscillometric technique for the measurement of blood pressure in cats. In the study reported here, reference ranges for blood pressure measurements in healthy cats of various ages were determined, and associations between blood pressure and various disease syndromes were identified.

In certain cats, a considerable amount of patience was required to obtain repeatable SBP, DBP, and MAP measurements, and the reason for this is unknown. Movement of the cuff frequently occurred during inflation and deflation of the cuff, and this may have been sufficient to cause blood pressure measurements to be inaccurate or unattainable. In particular, difficulties were encountered in obtaining blood pressure measurements from cats believed to have hypertension on the basis of ocular changes; measurements in several of these cats were unattainable. This may have been caused by changes in compliance of the blood vessel wall. Gel or alcohol to wet the hair was not used. Alcohol was used in our previous studies but was not found to be helpful in cats in which blood pressure measurements were difficult to obtain.

A series of blood pressure measurements can be obtained from conscious cats with the oscillometric technique, similar to those obtained from dogs in which the initial measurements are high; however, the values become stable and are repeatable as the cat becomes calm in a familiar environment. This suggests that blood pressure measurements obtained with the oscillometric technique are reliable in cats. Important issues in studies with noninvasive techniques used to measure blood pressure include precision, reproducibility, and consistency; accuracy is less important when blood pressure values that were consistently measured by use of the same method are compared in cats. The temperament of certain cats makes blood pressure monitoring difficult; however, in our study, this was an unusual finding. Most cats became calm quickly, particularly when owners were present.

Results of a study comparing blood pressure measurements obtained via the oscillometric technique, Doppler ultrasonic flow meter, and photoplethysmograph with direct arterial pressure measurements in healthy anesthetized cats reported good correlation of results from these 3 techniques and direct arterial measurements. All measurements were within ± 10 mm Hg of direct MAP, and the oscillometric technique provided the most accurate prediction of direct SBP. Mishina et al reported mean SBP and DBP values of 115 and 74 mm Hg, respectively, and MAP of 96 mm Hg in healthy conscious cats by use of the oscillometric technique. Ages in those cats ranged from 1 to 12 years, and the authors observed a significant correlation between age and MAP and DBP, but not SBP.

In our study, multivariate analyses were used to compare blood pressure measurements, age, sex, breed and neutered status in cats with and without HRet, chronic renal failure, and hyperthyroidism. Cats in our study were from local breeders, employees, a nutrition colony, and the referral clinic; therefore, they may not truly represent the general population. Sexually intact cats were more likely to have been from the healthy population or the nutrition colony because most cats obtained from the referral clinic were neutered.

Results of this study may be used as a reference range for indirect blood pressure measurements in cats. The results indicate a level of blood pressure that is capable of causing injury in target organs and suggests that the eye is the most vulnerable organ in cats. Ninety percent of healthy cats ≥ 10 years old had SBP values ≤ 168 mm Hg, whereas 90% of those with HRet had SBP values ≥ 168 mm Hg. There is a paucity of epidemiologic data available on use of the oscillometric technique for blood pressure measurements in cats; however, by use of techniques other than the oscillometric method, it has been suggested that SBP values ≥ 170 mm Hg indicate hypertension in cats, which is consistent with our findings. In contrast, Sparkes et al found that systolic blood pressures in healthy conscious adult cats ranged from 124 to 210 mm Hg (mean, 162 mm Hg) with the Doppler ultrasonic flow meter. Results of 1 study suggest that SBP values ≥ 140 mm Hg and DBP values ≥ 95 mm Hg should be considered as hypertensive. A greater understanding of the association between hypertension and retinopathy may be obtained by use of radiotomographic implants because they are likely to provide the most accurate and precise values of systemic arterial blood pressure in the future.

Results of our study indicate that an age-related increase in blood pressure occurs in healthy cats similar to that in humans and dogs. In humans, an age-related increase in blood pressure is associated with a high-salt diet and is not known to occur in the absence of excessive sodium intake. In the study reported here, the increase in blood pressure with age was continuous, in contrast to a previous study in which it increased at 11 years of age. However, this finding is not consistent among studies, and Sparkes et al and Lawler et al did not report that SBP increased continuously with age in cats. Results of a study in humans indicates that SBP and the incidence of hypertension increase with age and peak in the 55- to 64-year-old age group. However, hypertension is more common in males in the young (20 to 29 years) and middle-aged (30 to 39 years) groups and in the older age group (> 50 years) in females. In our study, similar to another study, no association was found between sex and SBP, DBP, or MAP in healthy cats.

Because cats with HRet referred for clinical examination were older than healthy cats, it was not surprising that neutering was associated with HRet. Similarly, Littman had a preponderance of male neutered cats (63%). In contrast, Kobayashi et al had 13 male and 15 female cats, all of which except 1 were sexually intact; however, neutering practices may vary between different populations, and this risk factor may thus be difficult to compare between studies.
In our study, we found female cats to be at markedly increased risk for developing HRet, compared with male cats. Others studies have also reported increased risk in females, with a female-to-male ratio in hypertensive cats of 2.6:1 in 1 study and 1.7:1 in another study. These results should be interpreted with caution before confirmation in other studies with entirely representative control populations.

The association between high blood pressure and HRet in dogs is not as obvious as in cats because of marked differences in blood pressures between breeds. Certain breeds of dogs such as sight hounds appear to have normally high blood pressures that are not associated with any specific pathologic changes. We were not able to identify whether any breed differences in blood pressure existed within our cat population.

In our study, diseases associated with hypertension included HRet and chronic renal failure, which have been previously reported. Systolic blood pressure appeared better at predicting the likelihood of HRet than other blood pressure measurements, and we would recommend use of SBP in future studies investigating the association between HRet and blood pressure.

Results of a previous study indicate an association between high blood pressure and progressive renal failure of a moderate nature in cats. However, those with severe renal failure had lower blood pressure measurements than those that were moderately compromised. In contrast, dogs with renal disease appear to be resistant to secondary hypertension. Causal associations among high blood pressure and cardiac and renal disease are not well understood and merit further investigation in dogs and cats.

Hypokalemia has been reported to be associated with renal failure in cats, and it was significantly associated with chronic renal failure in the study reported here. Results of epidemiologic studies in humans indicate that low potassium and high sodium intake is a risk factor for the development of high blood pressure. Increased blood pressure has been associated with reduced serum potassium concentration, and the results of another study suggest that potassium may have a protective effect against sodium-induced hypertension. Therefore, the sodium-to-potassium ratio may be more important than the concentrations of sodium or potassium alone.

Cholesterol concentrations were significantly increased (> 5.0 mmols/L) in cats with HRet. Hypercholesterolemia has been reported in cats with hypertension and chronic renal failure; however, the pathogenesis of hyperlipidemia in association with renal disease is not well understood. These lipid abnormalities are important risk factors for the development of atherosclerosis in humans.

In our study, increased blood pressure was not significantly associated with chronic renal failure. However, after adjustment for age, which was associated with blood pressure, increased blood pressure was significantly associated with increased risk of hyperthyroidism. The negative association between chronic renal failure and hyperthyroidism in the multivariable analysis does not indicate that the 2 diseases were less likely to occur together, but merely that the 2 diseases were less likely to be diagnosed together at given ages or blood pressure levels in cats in this study.

References


