Effect of age at gonadectomy on the probability of dogs becoming overweight

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Objective—To determine whether gonadectomy or age at gonadectomy was associated with the risk that dogs would subsequently become overweight.

Design—Retrospective cohort study.

Animals—1,930 dogs gonadectomized between 1998 and 2001 at ≤ 6 months of age (n = 782), > 6 months to ≤ 1 year of age (861), or > 1 to ≤ 5 years of age (287) and 1,669 sexually intact dogs.

Procedures—Dogs were followed-up through medical records for ≥ 10 years or until a diagnosis of overweight (defined as overweight, obese, or having a body condition score ≥ 4/5) was recorded. Information extracted included age at study entry, sex, breed, breed-size category, hospital visit frequency, and diagnosis (yes or no) of overweight or diseases that might affect body condition. Relative risk of a diagnosis of overweight was assessed among age groups of gonadectomized dogs and between gonadectomized and sexually intact dogs.

Results—No difference was detected among dogs grouped according to age at gonadectomy with respect to the risk of being overweight. This risk was significantly greater in gonadectomized dogs than in sexually intact dogs, but only during the first 2 years after gonadectomy. Sexually intact male dogs were approximately 40% less likely to have this diagnosis (hazard ratio, 0.61; 95% confidence interval, 0.52 to 0.72) than were sexually intact female dogs; no difference in risk between the sexes was evident for gonadectomized dogs.

Conclusions and Clinical Relevance—Gonadectomized dogs had a greater risk of being overweight than did sexually intact dogs, but this risk was not influenced by age at gonadectomy. Opportunities exist for veterinarians to provide counseling during the first years after gonadectomy to help dogs maintain a healthy weight. (*J Am Vet Med Assoc* 2013;243:236–243)

The prevalence of obesity in the general pet population is believed to mirror that in the human population.[1] However, accurate determination of the extent of and temporal trends in obesity among pets is hindered by the lack of large databases with historical veterinary health information and uniform objective measures to define the degree to which a pet is overweight. The percentage of overweight and obese adult dogs in the United States is high, with estimates in the past decade ranging from 34%[2] to 53%.[3] In pet dogs, factors reportedly associated with obesity include age, sex, reproductive status, breed, and diet type.[2,4,5] In addition, various diseases are overrepresented in overweight and obese dogs, such as hypothyroidism, diabetes mellitus, pancreatitis, cruciate ligament rupture, and neoplasia.[2,6]

Gonadectomy is common practice in the United States and is performed as a means of minimizing the number of unwanted pets.[7] However, evidence is mounting that along with population control and other beneficial effects, gonadectomy may also increase the risk of certain diseases in dogs.[8–10] Veterinary research is yielding evidence that gonadectomy increases a dog's risk of becoming overweight, compared with the risk in dogs that remain sexually intact, and this risk has been hypothesized to increase when pets are gonadectomized at an early age (ie, at ≤ 6 months of age).[11,12] However, review of published findings on the relationship between gonadectomy (at any age) and weight gain in dogs reveals gaps and, in the situation of early-age procedures, contradictions in our understanding of this relationship. Indeed, a retrospective cohort study[8] of dogs adopted from a shelter with a median follow-up time of 4.5 years found that dogs gonadectomized at an early age (ie, < 5.5 months) were less likely to become obese than were dogs gonadectomized after that age. However, the data used in that study[8] largely consisted of owner assessments and recollections regarding their dogs, and veterinarian assessments of body condition do not appear to have been included. Results of other studies[13,14] have shown that owner perceptions regard-

Abbreviations

CI	Confidence interval
HR	Hazard ratio
WP	Wellness plan

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ing weight status and body condition or shape can be unreliable. The purpose of the study reported here was to use data from a large pet dog population to determine whether dogs that underwent gonadectomy at an early age (ie, at ≤ 6 months) would be at greater risk of being diagnosed as overweight or obese during a 10-year follow-up period, compared with dogs that were gonadectomized later in life, and to compare this risk in gonadectomized versus sexually intact dogs.

Materials and Methods

Dogs—Banfield Pet Hospitals use proprietary practice management software to create electronic health records that are uploaded daily to a central database and stored in an object-relationship database system.[a] All medical records of dogs from January 1, 1998, through December 31, 2010, were considered for inclusion in the study.

For phase 1 of the study, the aim was to identify whether age at gonadectomy was a risk factor for a diagnosis of overweight (defined as overweight, obese, or having a body condition score ≥ 4/5) among gonadectomized dogs. For this purpose, 3 cohorts of dogs were created on the basis of age when spayed or neutered at a Banfield Pet Hospital between 1998 and 2001: early group (gonadectomized at ≤ 6 months of age), standard group (gonadectomized at > 6 months to ≤ 1 year of age), and late group (gonadectomized at > 1 to ≤ 5 years of age). Dogs that underwent gonadectomy at any other age or at other hospitals were excluded. Dogs were also excluded when they had < 10 years of regular hospital visits (ie, at least 1 visit every 3 years) on record after gonadectomy, they had > 1 gonadectomy procedure on record, they had a diagnosis of being overweight (as previously described) at or before the time of gonadectomy, or their data were missing or questionable.

A standardized body condition scoring system (5-point scale, with 1 = very thin, 2 = thin, 3 = ideal weight, 4 = overweight, and 5 = markedly obese) complete with diagrams was introduced to the Banfield staff and added to the electronic medical record system in 2010. Before that time, there was no standardized method of diagnosis for overweight dogs; assessments were made on a subjective basis. The reason for requiring a minimal visit frequency (once every 3 years) during the follow-up period was to exclude dogs with only 1 or 2 visits, thereby providing the possibility of detecting an overweight body condition ≥ 3 times during the 10-year period.

For phase 2 of the study, the aim was to identify whether undergoing gonadectomy (rather than age at gonadectomy) was a risk factor for dogs subsequently becoming overweight. Two cohorts were created for this evaluation: gonadectomized and sexually intact dogs. For the gonadectomized group, data from the 3 cohorts in phase 1 were combined. For the sexually intact group, dogs that had their first hospital visit between 1997 through 2000 and were on record as sexually intact through to 2010 were considered for inclusion. This extended period was required to include a sufficient number of dogs to approximate the number of gonadectomized dogs. Dogs in the sexually intact cohort were frequency matched to dogs in the gonadectomized cohort on the basis of age. To accomplish this, a random sample of sexually intact dogs was selected from each calendar year and from specific age groups (0 to < 6 months, 6 to < 12 months, 12 to < 24 months, 24 to < 36 months, 36 to < 48 months, and 48 to 60 months) to mimic the proportions of gonadectomized dogs in the same age groups. Sexually intact dogs matched in a previous year were ineligible to be reselected for another match. Dogs > 60 months of age at the first visit were excluded, as were those that met the same exclusion criteria as in phase 1.

Data collection—Information extracted from the records included age in months at study entry, sex, breed, breed size, state of home hospital, number of hospital visits during the study period, whether dogs were enrolled in a WP[b] (prepaid medical care plan) at any time during the study period (yes or no), and whether the dog was diagnosed as being overweight or having hypothyroidism, osteoarthritis, diabetes mellitus, or hyperadrenocorticism (yes or no) at any time during the study period. Dogs were assigned to breed-size categories on the basis of the typical adult weight achieved by various breeds as follows: small or toy breed (< 9.1 kg [20 lb]), medium breed (9.1 to 22.7 kg [20 to 50 lb]), or large breed (> 22.7 kg). No attempt was made to confirm the accuracy of diagnoses other than that of being overweight, such as evaluation of serum thyroxine concentration, blood glucose concentration, radiographic findings, or results of ACTH stimulation testing, because these were not the main variables of interest and were included solely for the purpose of controlling for potential confounders. Inclusion of data on diet or exercise patterns was considered, but review of the records revealed such data were not recorded for all dogs for all visits.

Statistical analysis—Data for each continuous variable (ie, age and number of visits/y) were tested for normality through examination of histograms. Because a pronounced left skew was evident for all distributions, these variables are reported as median (range).

The follow-up period began on the study entry date and ended on the last day of the following 10-year period. Dogs were censored from the study when a diagnosis of being overweight was recorded; when dogs did not have this diagnosis and the last hospital visit was within the 10-year follow-up period, the date of that visit was used as the censoring date. Statistical software[c] was used to evaluate unconditional associations between a diagnosis of being overweight and each of the following variables for each phase of the study (for the sole purpose of identifying associations): cohort assignment, breed size, sex, age in months, number of hospital visits per year within the follow-up period, WP status, hypothyroidism, osteoarthritis, diabetes mellitus, and hyperadrenocorticism. Logistic regression (multinomial or binomial) was used to identify differences among age groups (phase 1) and between gonadectomized and sexually intact groups (phase 2) for categorical variables. When values in the contingency table for phase 2 data were < 10, the Fisher exact test was used instead. For the 2 continuous variables, the Kruskall-Wallis test was used. Values of $P < 0.05$ were considered significant for all analyses.

To determine the incidence of dogs being overweight for each phase of the study, multivariate Cox proportional hazards regression models were constructed with the aid of statistical software.[d] The event modeled was the date a dog was first diagnosed as overweight within the follow-up period.

Selection models for each dependent variable for each phase of the study included cohort assignment, breed size, sex, age in months, number of hospital visits per year within the follow-up period, WP status, hypothyroidism, osteoarthritis, diabetes mellitus, and hyperadrenocorticism. First, all variables were entered into the Cox model to detect significant first-order (between 2 variables) and second-order (among 3 variables) interaction terms. Interaction terms identified as significant ($P < 0.05$) were entered into the model by forward selection, with individual variables entered as well. The variable of sex was also added to control for potential confounding, regardless of whether significance was attained. Nonsignificant variables were eliminated from the model if they were not included in a significant interaction term, had no confounding effect (ie, addition or removal from the model did not change the coefficients for the other variables by > 20%), and were not time dependent.

When the final model for phase 1 data was identified, an overall goodness-of-fit test was performed, revealing a poor fit ($P = 0.011$) of data to that model. Therefore, the data were examined for influential data points, and 3 dogs with an unusually high frequency of hospital visits (15 to 191 visits/y) were identified. After data for these dogs were removed from the analysis for phase 1, the goodness-of-fit test showed the fit had improved ($P = 0.16$).

A log-cumulative hazard plot of the final model for phase 2 data revealed nonparallel lines for gonadectomized versus sexually intact dogs, suggesting a violation of the assumption of proportional hazards.[15] To address this, a time-dependent variable for the diagnosis of being overweight was added to that model.

For all HRs, *P* values for 2-tailed tests and 95% CIs are reported. Product-limit survival estimates were also calculated and graphed to yield survival curves.[e] Hazard ratios and ORs were interpreted as an estimate of the relative risk of one group of dogs versus another group developing an outcome, with an HR or OR of 1 indicating no difference in risk.

Results

Dogs—Records of 27,627 spayed or neutered dogs in 1998 were evaluated; that year, Banfield operated 168 hospitals in 18 states. From these records, data pertaining to 782 dogs ≤ 6 months of age (early group), 861 dogs > 6 months to ≤ 1 year of age (standard group), and 287 dogs > 1 to ≤ 5 years of age (late group) at the time of gonadectomy were extracted for inclusion in phase 1 of the study. Median age at gonadectomy (ie, at study entry) was 5.48 months (range, 2.26 to 6.00 months) for the early group, 6.94 months (range, 6.03 to 12.00 months) for the standard group, and 21.42 months (range, 12.03 to 60.00 months) for the late group. The 5 breeds represented most among the 1,930 gonadectomized dogs were Labrador Retriever (333 [17.3%]), Golden Retriever (118 [6.1%]), German Shepherd Dog (106 [5.5%]), Shih Tzu (80 [4.2%]), and Beagle (64 [3.3%]). Although the intent was to include dogs with a minimum visit frequency of once every 3 years, the median visit frequency for each group was as follows: early group, 3.6 visits/y (range, 1 to 30.4 visits/y); standard group, 3.2 visits/y (0.8 to 34.8 visits/y); and late group, 2.8 visits/y (0.9 to 21.6 visits/y).

For phase 2, the gonadectomized group consisted of the same dogs included in phase 1. The sexually intact group consisted of all dogs that met the inclusion criteria (n = 1,669). There were 784 dogs ≤ 6 months of age (median age, 2.5 months [range, 0.2 to 6.0 months]), 597 dogs > 6 months to ≤ 1 year of age (median age, 8.6 months [range, 6.0 to 12.0 months]), and 288 dogs > 1 to ≤ 5 years of age (median age, 24.0 months [range, 12.1 to 60.0 months]) at the time of first visit (ie, study entry). The 5 breeds most represented were Labrador Retriever (191 [11.4%]), Chihuahua (99 [5.9%]), German Shepherd Dog (97 [5.8%]), Rottweiler (67 [4.0%]), and Pomeranian (48 [2.9%]). The median hospital visit frequency for the sexually intact group by age category was as follows: ≤ 6 months of age, 2.7 visits/y (range, 0.7 to 38.4 visits/y); 6 months to ≤ 1 year, 2.4 visits/y (range, 0.7 to 60.9 visits/y); and > 1 to ≤ 5 years of age, 2.4 visits/y (range, 0.7 to 10.6 visits/y).

Univariate analysis—Phase 1 univariate analyses revealed no difference in the proportion of dogs subsequently recorded as overweight (defined as overweight, obese, or having a body condition score ≥ 4/5) among the various gonadectomy groups ($P = 0.36$; **Table 1**). An additional analysis performed to address potential concerns about the cutoff age used to define early gonadectomy showed no difference in the risk of being identified as overweight between dogs gonadectomized at < 5 months of age (n = 85) and those that underwent gonadectomy at 5 through 6 months of age (597; $P = 0.66$).

Of dogs that underwent gonadectomy, males were no more likely to become overweight at any point during the study than were females (578/869 [66.5%] vs 704/1,061 [66.4%]; $P = 0.94$). No difference among groups was detected for proportions of dogs with a diagnosis of hypothyroidism ($P = 0.51$), osteoarthritis ($P = 0.28$), diabetes mellitus ($P = 0.62$), or hyperadrenocorticism ($P = 0.63$). Among gonadectomized dogs, the percentage enrolled in a WP in the early group was significantly ($P < 0.001$) greater than that in the standard or late groups. Nonparametric testing revealed that dogs in the early group had a significantly higher ($P < 0.001$) hospital visit frequency (3.6 visits/y) than did those in the standard (3.2 visits/y) or late (2.8 visits/y) groups.

Without controlling for other factors, results of phase 2 analyses showed that a significantly ($P < 0.001$) greater proportion of dogs that had been enrolled in a WP at some point during the study period were gonadectomized than were dogs never enrolled in a WP. In addition, the proportion of gonadectomized dogs identified as overweight was significantly ($P < 0.001$) greater than the proportion of sexually intact dogs with that diagnosis (Table 1). Of those that were sexually intact, the proportion of males that became overweight was significantly ($P < 0.001$) greater than the proportion of females that became overweight. Osteoarthritis was significantly ($P = 0.015$) more prevalent in sexually intact dogs than in gonadectomized dogs. Similar to the pattern for gonadectomized dogs, the median hospital visit frequency for sexually intact dogs was significantly ($P < 0.001$) greater for dogs that were ≤ 6 months of age at study entry than for dogs 6 months to ≤ 1 years of age or dogs > 1 to ≤ 5 years of age.

Hospital visit frequency differed significantly ($P < 0.001$) between sexually intact (median, 1.8 visits/y) and gonadectomized (3.0 visits/y) dogs. When data from both phases were combined, dogs enrolled in a WP had a significantly ($P < 0.001$) higher visit frequency (median, 3.0 visits/y) than did dogs not enrolled in a WP (median, 1.8 visits/y). However, enrollment in a

Table 1—Characteristics of pet dogs that were gonadectomized at ≤ 6 months of age (early group), > 6 months to ≤ 1 year (standard group), or > 1 to ≤ 5 years (late group) or remained sexually intact and were retrospectively evaluated over ≥ 10 years in a study to identify associations between gonadectomy and risk of becoming overweight.

	Phase 1				Phase 2		
Variable	**Early group (n = 782)**	**Standard group (n = 861)**	**Late group (n = 287)**	***P* value**	**Gonadectomized (n = 1,930)**	**Sexually intact (n = 1,669)**	***P* value**
Diagnosis of overweight	526 (77.1)	576 (66.9)	180 (62.7)	0.36	1,282 (66.4)	621 (37.2)	< 0.001
Male sex	328 (41.9)	392 (45.5)	149 (51.9)*	0.014	869 (45.0)	1,113 (66.7)	< 0.001
Enrolled in a WP	748 (95.7)	799 (92.8)*	254 (88.5)*	< 0.001	1,801 (93.3)	1,445 (86.6)	< 0.001
Breed size				< 0.001			
Small or toy	240 (30.7)	188 (27.6)	116 (40.4)	—	679	745	Referent
Medium	188 (24.0)	213 (24.7)	81 (28.2)*	—	482	372	< 0.001
Large	354 (45.2)	81 (9.4)*	90 (31.4)	—	769	552	< 0.001
Other diagnoses							
Hypothyroidism	7 (0.9)	11 (1.6)	5 (1.7)	0.51	23 (1.2)	25 (1.5)	0.43
Osteoarthritis	43 (5.5)	33 (3.8)	13 (4.5)	0.28	89 (4.6)	108 (6.5)	0.02
Diabetes mellitus	1 (0.1)	3 (0.4)	1 (0.3)	0.62	5 (0.3)	2 (0.1)	0.34
Hyperadrenocorticism	1 (0.1)	3 (0.4)	1 (0.3)	0.63	5 (0.3)	5 (0.3)	0.82

Data are No. (% of group).
*Indicated percentage differs significantly ($P < 0.05$) from the percentage for the early group.
— = Not calculated.
In phase 1, the aim was to identify whether age at gonadectomy was a risk factor for a diagnosis of overweight (defined as overweight, obese, or having a body condition score ≥ 4/5) in gonadectomized dogs. In phase 2, the aim was to identify whether undergoing gonadectomy (rather than age at gonadectomy) was a risk factor for dogs subsequently becoming overweight. The purpose of the unconditional (univariate) comparisons shown in the table was to identify potential confounding factors that might need to be controlled for in the final conditional (multivariate) analysis.

Table 2—Results of multivariate modeling of the hazard of becoming overweight after gonadectomy at ≤ 6 months of age (early group; n = 782), > 6 months to ≤ 1 year (standard group; 861), or > 1 to ≤ 5 years (late group; 287).

Variable or interaction term	HR	95% CI	*P* value
Sex (male vs female)	0.95	0.85–1.06	0.36
WP enrollment (yes vs no)	0.95	—	0.79
No. of visits/y	1.35	—	< 0.001
Breed size of dog with early gonadectomy and the mean No. of visits/y			
Small or toy vs medium	0.67	0.52–0.85	0.001
Small or toy vs large	0.61	0.49–0.75	< 0.001
Medium vs large	0.91	0.74–1.13	0.39
Breed size of dog with standard gonadectomy and the mean No. of visits/y			
Small or toy vs medium	0.79	0.64–0.98	0.034
Small or toy vs large	0.62	0.51–0.75	< 0.001
Medium vs large	0.79	0.64–0.97	0.022
Breed size of dog with late gonadectomy and the mean No. of visits/y			
Small or toy vs medium	0.67	0.47–0.96	0.030
Small or toy vs large	0.76	0.53–1.08	0.12
Medium vs large	1.13	0.78–1.64	0.53
Visit frequency			
Dogs not enrolled in a WP			
Small or toy breed	1.67	1.48–1.88	< 0.001
Medium breed	1.69	1.50–1.90	< 0.001
Large breed	1.69	1.50–1.90	< 0.001
Dogs enrolled in a WP			
Small or toy breed	1.33	1.29–1.41	< 0.001
Medium breed	1.35	1.29–1.41	< 0.001
Large breed	1.35	1.31–1.39	< 0.001

— = Not calculated separately.
Hazard ratios represent an estimate of the relative risk of dogs in 1 group versus the referent group for a diagnosis of overweight. When the HR is reported for a continuous variable such as time, the value represents an estimate of the increase in relative risk for each 1-unit increase in the variable. An HR of 1 indicates no significant ($P > 0.05$) difference in risk.

Table 3—Results of multivariate modeling of the hazard of becoming overweight among dogs that did (n = 1,930) or did not (1,669) undergo gonadectomy.

Variable or interaction term	HR	95% CI	*P* value
Gonadectomy (yes vs no) by period after gonadectomy (y)*			
0 to 1	2.22	1.33–3.71	0.002
1 to 2	1.84	1.14–2.98	0.013
2 to 3	1.44	0.90–2.31	0.13
3 to 4	1.36	0.83–2.22	0.23
4 to 5	1.16	0.71–1.92	0.55
5 to 6	0.91	0.55–1.51	0.72
6 to 7	0.87	0.52–1.47	0.60
7 to 8	0.82	0.48–1.39	0.46
8 to 9	1.18	0.66–2.08	0.58
Sex			
Sexually intact male vs female	0.61	0.52–0.72	< 0.001
Gonadectomized male vs female	1.08	0.97–1.21	0.39
WP (yes vs no)	0.89	—	0.28
No. of visits/y	1.58	—	< 0.001
Age at study entry			
≤ 6 mo	1.00	Referent	Referent
6 mo to ≤ 1 y	1.07	0.97–1.18	0.18
> 1 y to ≤ 5 y	1.21	1.06–1.38	0.006
Breed size			
Small or toy	1.00	Referent	Referent
Medium	1.50	1.33–1.69	< 0.001
Large	1.82	1.63–2.02	< 0.001
WP (yes vs no), by No. of visits/y†			< 0.001
1 visit	0.78	0.65–0.94	—
2 visits	0.68	0.58–0.81	—
3 visits	0.60	0.51–0.71	—
4 visits	0.53	0.44–0.63	—
5 visits	0.46	0.38–0.57	—
6 visits	0.41	0.32–0.52	—
No. of visits/y, by WP status			< 0.001
Not enrolled in WP	1.58	1.50–1.67	—
Enrolled in WP	1.39	1.36–1.41	—
Other diagnoses			
Hypothyroidism (yes vs no)	0.62	0.40–0.96	0.031
Hyperadrenocorticism (yes vs no)	0.12	0.02–0.82	0.031
Osteoarthritis (yes vs no)	0.34	0.26–0.44	< 0.001

*A time-dependent variable was included in the model to account for the lack of a constant hazard over the study period (from time of gonadectomy or study entry to last visit on record). †Significant ($P < 0.001$) interactions between the 2 variables were detected.
— = Not calculated separately.

WP was not significantly ($P = 0.06$) associated with a dog's risk of becoming overweight (OR, 1.23; 95% CI, 0.99 to 1.54). In neither phase was state of home hospital significantly ($P > 0.10$ for all) associated with becoming overweight.

Multivariate hazard analysis—The final model for phase 1 data included the variables age at gonadectomy, sex, breed size, WP status, and visit frequency. Visit frequency was the only single variable in the model that significantly ($P < 0.001$) predicted dogs becoming overweight after gonadectomy. The variables age at gonadectomy ($P = 0.76$ for standard vs early; $P = 0.32$ for late vs early), sex ($P = 0.36$), breed size ($P > 0.26$ for all comparisons), and WP status ($P = 0.79$) had no individual effect on the risk of becoming overweight in this model.

Significant interaction terms identified included various combinations of breed size, age at gonadectomy, and visit frequency and the combination of visit frequency, breed size, and WP status **(Table 2)**. Again, male dogs were no more likely to be identified as overweight than were female dogs ($P = 0.36$). Among dogs that underwent gonadectomy, assuming the mean visit frequency (3.93 visits/y), small- or toy-breed dogs in the early group were approximately two-thirds as likely to become overweight as were medium- or large-breed dogs. In the standard group, small- or toy-breed and medium-breed dogs were approximately two-thirds to three-quarters as likely to become overweight as were large-breed dogs. In the late gonadectomy group, small- or toy-breed dogs were less likely to become overweight than were medium-breed dogs. For every 1-unit increase in the number of visits per year, the risk of becoming overweight also increased significantly ($P < 0.05$) by 33% to 69%, regardless of breed size or WP status.

The final multivariate model for phase 2 data included a term representing reproductive status that accounted for the nonconstancy of the hazard of becoming overweight over time as well as the variables age at study entry, sex, breed size, WP status, visit frequency, and interactions between sex and reproductive status (gonadectomized vs sexually intact) and between visit frequency and WP status. Unlike the model for phase 1, the variables hypothyroidism, osteoarthritis, and hyperadrenocorticism (yes or no for all) were also significant and included. The variable representing HR over time for gonadectomized versus sexually intact dogs revealed that gonadectomized dogs were at significantly greater risk of becoming overweight than were sexually intact dogs during the first 2 years after gonadectomy or study entry but not afterward **(Table 3)**. The model also showed sexually intact male dogs were at a significantly lower risk of becoming overweight, compared with the risk for sexually intact female dogs (HR, 0.61). In addition, dogs with hypothyroidism, osteoarthritis, or hyperadrenocorticism were less likely to become overweight than were dogs without these conditions.

Discussion

Results of the present study involving pet dogs evaluated at veterinary practices throughout the United States indicated that gonadectomized dogs had a higher risk of being identified as overweight (defined as overweight, obese, or having a body condition score ≥ 4/5) than did sexually intact dogs at several time points, but that this increased risk was significant during the first 2 years after surgery only. However, age at the time of gonadectomy appeared to have no effect on the risk of becoming overweight. The findings reported here are more representative (in sample size and in characteristics) of the general US pet dog population than have been reported elsewhere, and they raise some important concerns. The authors' intent in performing this study was not to encourage debate on the practice of neutering dogs, but rather to explore the impact of gonadectomy on weight gain as a first step in determining how to prevent dogs from becoming overweight. Although a high proportion (1,282/1,930 [66.4%]) of all gonadectomized dogs became overweight during the study period, a lower but not unimportant proportion (621/1,669 [37.2%]) of sexually intact dogs also became overweight, which suggests that overweight body condition is common in pet dogs (proportion of all study dogs affected, 1,903/3,599 [52.9%]).

One strategy for avoiding an overweight body condition in gonadectomized (as well as sexually intact) dogs may be as simple as controlling energy intake. It is the mismatch of energy intake and energy expenditure in animals, including humans, that creates a positive energy balance and subsequent weight gain. Energy requirements of pets are dependent on their species, size, life stage, and energy expenditure.[16] Findings of experimental studies[17,18] involving small numbers of young adult Beagles (n = 4/study) suggest spayed dogs have a decrease in energy requirements after ovariectomy. Many effective dietary strategies are available for reducing body weight in dogs[19–22]; however, our findings suggested an opportunity to prevent dogs from becoming overweight. Dietary goals for pets should be proactively implemented to match individual energy and nutrient requirements at each particular life stage to maintain a lean or ideal body condition score, and this includes the time after gonadectomy. In dogs that undergo gonadectomy while still growing, the challenge becomes meeting energy requirements for proper development and providing the correct amount of nutrients. Veterinarians have the opportunity to educate clients in this respect, not only at gonadectomy but also in the years following the procedure. This is one of the reasons that annual or semiannual veterinary visits are important for healthy young adult dogs; they offer the chance to monitor a pet's body condition, assess and modify the diet as needed, and help owners to understand the importance of good feeding habits. By supporting dog owners in the appropriate management of their pets' weight during early life stages and after gonadectomy, veterinarians can help reduce the potential for excessive weight gain as pets reach adulthood.

Although it is widely believed that gonadectomized dogs have a higher risk of becoming overweight or obese than do sexually intact dogs, a dearth of strong scientific evidence was available to support this premise before the present study was conducted. In a small (n = 32) randomized controlled trial,[9] weight gain over a 15-month period did not differ significantly between sexually intact and gonadectomized dogs, regardless of age at gonadectomy (7 weeks or 7 months). A cross-sectional study[2] yielded evidence that the prevalence of overweight and obese body condition is higher in gonadectomized than in sexually intact dogs, but such study designs provide no evidence as to whether a given factor precedes another. The few experimental studies[17,18] that identified associations between ovariectomy and overweight status did not include control dogs and involved ad libitum feeding, which limit generalization of the findings.

The hypothesis that age at gonadectomy influences weight gain in dogs has also been evaluated in the past, but with equivocal results. Results of the present study suggested that age at gonadectomy is not a risk factor for dogs becoming overweight or obese after surgery. This conflicts with the findings of Spain et al,[8] who reported that dogs that underwent gonadectomy before 5.5 months of age were less likely to be overweight later in life, compared with dogs gonadectomized at ≥ 5.5 months of age. However, our findings are in agreement with those of Howe et al,[11] who reported no difference in the risk of becoming overweight between dogs that underwent gonadectomy at ≤ 24 weeks (6 months) versus > 24 weeks of age. Although it may be argued that many dogs included in the early gonadectomy group of the present study were sexually altered at an age that might not be considered early (ie, 6 months), the median age of dogs in that group was 5.5 months, and dogs as young as 2.3 months were included. In selecting ages for defining the early group, we decided to use 6 months as the cutoff because this is the age at which gonadectomy is commonly recommended at Banfield Pet Hospitals. If the cutoff used to define early gonadectomy had been earlier (eg, < 5 months of age), it is possible that results would have been different. However, no difference was identified between dogs gonadectomized at < 5 months of age and those gonadectomized between 5 and 6 months of age.

A limitation of the present study was that obese and overweight conditions were considered the same outcome. Indeed, it is possible that if obesity alone had been the outcome investigated, an effect of age at gonadectomy would have been detected. However, we chose to combine the 2 diagnoses because we believe that an overweight body condition has the potential to lead to obesity and because the ability to distinguish notations in the medical records regarding overweight versus obese dogs was not consistent across the entire study period. Judgment of these variables was highly subjective for most of the study period, and given that multiple sites each with multiple assessors were involved, inter-rater reliability was likely imperfect and misclassification of dogs in regard to the study outcome was possible. It was not until 2010 that a standardized 5-point body condition scoring system was introduced with the intent of improving the accuracy and consistency of these assessments. The possibility of misclassification is particularly important because it concerned the outcome of interest. However, there is no reason to believe that sexually intact dogs or gonadectomized dogs of various age groups would have been misclassified to different extents because of this potential bias.

Interestingly, results suggested that sexually intact male dogs were less likely to become overweight than were sexually intact female dogs. To our knowledge, this finding has not been reported previously. This is particularly noteworthy given that there was no sex difference among gonadectomized dogs with respect to the probability of being diagnosed as overweight. This may possibly be explained by differences in concentrations and types of circulating hormones between sexually intact male and female dogs and the influence of those hormones on body condition. Another interesting finding was that regardless of neuter status, large-breed dogs were generally at greater risk of becoming overweight or obese when controlling for other factors than were medium- and small- or toy-breed dogs, with a few exceptions (Tables 2 and 3). Thus, possible opportunities for veterinary intervention were identified for 2 groups: sexually intact female dogs and large-breed dogs of any reproductive status.

The observation that an increase in visit frequency appeared to increase the risk of being identified as overweight might be explained by the fact that the more often a dog visits a veterinary hospital, the more likely any excess body weight will be detected and recorded in the medical record. One could also argue that because dogs in the gonadectomized group had a higher visit frequency (3.0 visits/y) than did sexually intact dogs (1.8 visits/y), the opportunity to detect excess weight in gonadectomized dogs was greater or may have occurred sooner. The available information did not allow investigation of these hypotheses. It is also possible that the higher visit frequency among dogs eventually identified as overweight in the gonadectomized versus sexually intact groups in the present study reflects a different type of human-animal bond, given that owners who view their dogs from a highly anthropomorphic perspective are reportedly more likely to have obese dogs than owners who perceive them more as pets.[23]

Ideally, veterinary visits would provide a forum for discussing with owners the importance of appropriate nutrition and exercise for maintaining a healthy weight in dogs, and a high visit frequency would increase the opportunity to impress this importance upon owners. However, it cannot be determined from the study design whether opportunities for owner education or other interventions were missed. It is possible that nonoverweight dogs with less frequent visits were overweight at some point, but this weight gain was not evident at the time they visited the veterinarian. The visit frequency reported here should not be interpreted as being typical of veterinary practice because inclusion criteria required that dogs have at least 1 visit every 3 years and had ≥ 10 years of regular hospital visits on record from the time of study entry.

Although sexually intact dogs had a lower risk of becoming overweight or obese than did gonadectomized dogs during the 2 years after gonadectomy or study entry in the present study, they had a higher risk of developing osteoarthritis during the study period (as defined solely by a record entry of this diagnosis). One possible explanation is that sexually intact dogs participated in different activities or were managed differently, compared with gonadectomized dogs. Another reason might be that the percentage of dogs with a breed predisposition for osteoarthritis was higher in the sexually intact group. However, the observed distribution of breeds at high risk for osteoarthritis such as Labrador Retriever, Golden Retriever, German Shepherd Dog, and Rottweiler[24] in the 2 study groups does not appear to support that possibility.

When interpreting data on osteoarthritis and other diagnoses and their associations with a diagnosis of being overweight, it is important to consider inter-rater variability, which is a major limitation of retrospective studies, particularly those involving medical records compiled at several sites by multiple veterinarians with various degrees of experience. Inter-rater variability in the present study could have been controlled for by requiring that any dogs with these diagnoses have confirmatory tests on record; however, because such a criterion would have severely restricted the number of dogs with each diagnosis available for inclusion and because these variables were included solely to control for any confounding they might have introduced, only the recorded diagnosis was used to define whether the disease was present. The degree of inter-rater variability in making the described diagnoses could not be assessed; however, as with the outcome diagnosis in this study, the degree of misclassification resulting from differences in clinicians' criteria for diagnoses was unlikely to be substantially different among study groups. Indeed, when nondifferential misclassification of predictor variables (or putative risk factors) exists, the effect on study results is typically to bias findings toward the null hypothesis,[15] making it more difficult to find associations when they do exist.

Two findings in the study reported here were unexpected. Because excess body weight is a common clinical finding in dogs with hypothyroidism,[25,26] it was presumed that an overweight or obese body condition would be overrepresented in these dogs. This was not the situation. Also surprisingly, dogs that had a diagnosis of osteoarthritis at some point during the study were less likely to be identified as overweight than were dogs without the disease, even when other factors were controlled. Although a definitive association between osteoarthritis and obesity has not been established,[27] we had presumed that dogs with osteoarthritis would be less likely to exercise and hence at risk for gaining weight and that weight gain would contribute to the progression of osteoarthritis by increasing the load on affected joints. Because dogs were censored from the study when a diagnosis of being overweight was recorded, it is reasonable to assume that these diagnoses did not follow a diagnosis of hypothyroidism or osteoarthritis. However, whether the diagnosis of hypothyroidism or osteoarthritis preceded or was made concurrently with that of overweight or obesity was not determined. Additional research is required to further define the relationship between these 2 diseases and body weight in dogs.

The present study showed that dogs enrolled in a WP at any point during the study period were significantly more likely to undergo gonadectomy than were dogs that were never enrolled in a WP, but this should not be interpreted as suggesting that owners who enrolled their dogs in WPs had characteristics different from other owners that might protect a dog from becoming overweight. Although owner characteristics were not investigated, the intent of the described WPs is to bundle the cost of gonadectomy and other preventive services to help make pet health care affordable and accessible to owners. Therefore, gonadectomy was more common in dogs enrolled in WPs than in dogs not enrolled in WPs because the WP was likely purchased by owners already intending to pursue gonadectomy. On the other hand, WP status alone had no significant effect on the likelihood of dogs becoming overweight.

The findings reported here confirmed that spaying and neutering increase the risk of dogs becoming overweight during the first 2 years after the procedure, which is a period when the frequency of veterinary visits can decline, perhaps because some owners of healthy dogs do not believe it important that their pets receive regular veterinary care in the young adult period. Our results indicated that this period is indeed important. Veterinarians have the opportunity during that time to shape a dog's future health by guiding and supporting clients in maintaining their pet's optimum body condition, with the aim of mitigating the development of obesity and its unhealthy sequelae.

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b. Optimum Wellness Plan, Banfield Pet Hospital, Portland, Ore.
c. Stata/IC, version 11.1 for Windows, StataCorp LP, College Station, Tex.
d. PHREG, SAS, version 9.2, SAS Institute Inc, Cary, NC.
e. LIFETEST, SAS, version 9.2, SAS Institute Inc, Cary, NC.

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