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Age at gonadectomy, sex, and breed size affect risk of canine overweight and obese outcomes: a retrospective cohort study using data from United States primary care veterinary clinics

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OBJECTIVE
To examine the risk of developing an overweight or obese (O/O) body condition score (BCS) in gonadectomized versus intact dogs and, separately, the impact of age at gonadectomy on O/O outcomes among sterilized dogs.

ANIMALS
Dogs were patients of Banfield Pet Hospital in the US from 2013 to 2019. After exclusion criteria were applied, the final sample consisted of 155,199 dogs.

PROCEDURES
In this retrospective cohort study, Cox proportional hazards models evaluated associations between O/O and gonadectomy status, sex, age at gonadectomy, and breed size. Models were used to estimate the risk of becoming O/O in gonadectomized versus intact dogs and, separately, to estimate risk of O/O BCS according to age at surgery among gonadectomized dogs.

RESULTS
Gonadectomy increased O/O risk for most dogs compared to intact dogs. Unlike most prior findings, O/O hazard ratios among gonadectomized versus intact dogs were larger for males than females. O/O risk varied according to breed size but not linearly. Sterilizing at 1 year old tended to yield a lower O/O risk compared to doing so later. Comparative O/O risk among dogs gonadectomized at 6 months versus 1 year varied by breed size. Overall patterns for obesity related to size were similar to patterns in the O/O analysis.

CLINICAL RELEVANCE
Veterinarians are uniquely positioned to help prevent O/O in their patients. Results extend understanding of risk factors for O/O development in dogs. In combination with information about other benefits and risks associated with gonadectomy, these data can help tailor recommendations regarding gonadectomy in individual dogs.

Gonadectomy (sterilization and spay/neuter [S/N]) is a widely accepted procedure in the US that contributes to management of dog population numbers and is associated with positive outcomes for individual dogs.[1–5] In females, these benefits include eliminating risk of unwanted pregnancies, pyometra, and ovarian or uterine tumors.[2,6,7] Some studies have found that spaying can potentially reduce incidence of mammary gland neoplasms, albeit with some evidence of varied risk related to dog breed and age at surgery.[2,3,7–12] In males, gonadectomy has been found to decrease risk of perianal adenomas,[13] eliminate risk of benign

prostatic hyperplasia,[14] and reduce some sexually dimorphic behaviors.[15–17] Data are equivocal regarding castration's effect on prostatic neoplasia.[18,19]

Gonadectomy has also been associated with negative canine health outcomes, including increased risk of overweight or obese (O/O) body condition.[1,5,20–24] O/O has been identified as a serious problem in the US[20,21,25,26] and multiple other countries.[22,24,27–30] In a recent analysis, 51% of the > 1.9 million adult dogs seen at Banfield Pet Hospital clinics (located in North America) were classified as overweight,[26] and research has found the prevalence of canine O/O in industrialized countries to approach 60%.[31,32] Beyond being a welfare concern, canine O/O may be a risk factor for the development of some joint disorders (eg, cranial cruciate ligament tears) and exacerbate the severity of others (eg, hip dysplasia); it has also been associated with other long-term ancillary health consequences (eg, diabetes), behavioral issues, and reduced longevity and quality of life.[20,33–35]

Many studies on the association between gonadectomy and O/O have evaluated risk among dog breeds or breed groups[20,23,24,27,32,36] and/or classified mixed breeds as a single category.[20,24,32,36] There are unresolved questions about the relationship between gonadectomy and risk of subsequent O/O in different dog populations (as is true for gonadectomy and other health and behavior outcomes). Specifically, while most published work reports similar incidence of O/O in sterilized dogs of both sexes,[5,20,21,24,27] 1 study[22] found males to be at higher risk than females. There are also inconsistencies regarding risk of O/O among sterilized dogs relative to age at surgery. For example, studies have identified similar increased O/O risk regardless of age,[21] decreased incidence in dogs sterilized before 5.5 months old,[37] and increased risk among dogs sterilized at 6 to 12 months compared to those sterilized after 1 year.[23]

Several studies have evaluated age as a risk factor for O/O.[20,22,24,27,28] Data on risk relative to time following gonadectomy are limited; however, Lefebvre et al[21] found that increased O/O risk in gonadectomized versus intact dogs diminished starting 2 years after surgery.

There have been calls for veterinarians to play a greater role in managing the obesity epidemic among companion animals.[24,26,38,39] While that requires addressing a host of variables contributing to unhealthy weight gain, sterilization is 1 factor. More precise and comprehensive information on risk profiles for weight gain following gonadectomy can help veterinarians and owners make more informed decisions around surgery timing and husbandry measures to minimize O/O risk. Additional information will help clarify the role of O/O in mediating the development of other possible effects of gonadectomy. Moreover, establishing a baseline risk of sterilization surgery on weight gain will aid in evaluating the comparative effect of future nonsurgical sterilization and contraception alternatives.

The current study examined the relationship between sterilization and O/O in a sample of companion dogs seen in US primary care hospitals. The aims were to assess the following: (1) whether sterilization is associated with development of O/O compared to intact dogs, (2) whether age at the time of sterilization is associated with development of O/O compared to intact dogs, and (3) whether risk of O/O varies depending on age at time of surgery among sterilized dogs. Additional variables were dog sex and breed size category, controlling for numbers of preindex veterinary visits, purebred/mixed-breed status, and enrollment in a preventive veterinary care package.

Materials and Methods

Data were obtained from Banfield Pet Hospital's medical records software (PetWare[40]). Data were collected from 2013 to 2019, during which all practices used 5-point body condition score (BCS) guidelines: very thin (BCS = 1), thin (BCS = 2), ideal (BCS = 3), overweight (BCS = 4), or obese (BCS = 5). For this retrospective cohort study, outcomes of interest were overweight (BCS = 4) and obese (BCS = 5) categorizations.

Anonymized aggregate data for each dog were supplied for the following variables: date of each visit; BCS and weight (kg) at each visit; unique identification number; sex; primary breed; purebred/mixed-breed status; date of gonadectomy in the affiliated practices, if applicable; date of first O/O BCS; US state where patient was seen; date of hypo- or hyperthyroidism diagnosis, if present; and enrollment status in a Banfield Optimum Wellness Plan, an optional prepaid preventive veterinary care package.[41]

Dogs seen at one of the clinics in 2014 that had at least 1 visit in 2013 were divided into 2 groups. Dogs gonadectomized at Banfield in 2014 were placed in the S/N cohort, and those intact in 2014 were placed in the intact cohort. Dogs were followed from 2014 through December 31, 2019, or until (1) O/O BCS was recorded in their medical record, (2) their last recorded visit before 2020, (3) they were diagnosed with hyperthyroidism or hypothyroidism within the study period, or (4) they were sterilized, if initially assigned to the intact group. The index visit (enrollment date) was the date of sterilization surgery at a Banfield Pet Hospital for dogs in the S/N group and date of first visit in 2014 for the intact group. Follow-up time was limited to 5 years after index visit. Banfield typically recommends neutering males at 5 to 6 months and spaying females soon before their first heat cycle (approx 6 months old).[42] However, because pediatric gonadectomy is common in the US,[1,43] this study reports data at 3 months through 6 years of age.

Dogs with an O/O BCS prior to and/or at index were excluded. Among dogs remaining after exclusions, age at index was calculated by subtracting date of birth from date of enrollment in the study. Breed was based on data input to PetWare and included 505 breed options. The system required a breed designation, and each dog could be assigned only 1 breed. The system included a checkbox to identify mixed-breed dogs.

Each dog was assigned to 1 of 5 categories using the assigned breed: toy/small (< 10 kg), medium (10 to 19.9 kg), standard (20 to 29.9 kg), large (30 to 39.9 kg), and giant (≥ 40 kg). These are the same categories used by the Dog Aging Project, a large multiyear epidemiologic study of aging in dogs that

includes both purebred and mixed breeds.[44] The process by which dogs were assigned to a size category is detailed elsewhere **(Supplementary Appendix)**.

Statistical analysis

Time-to-event analyses were conducted, with the study period concluding on December 31, 2019. Follow-up time was expressed as "dog years." For example, a dog first seen in February 2014 and last seen in February 2016 would have 2 dog years of follow-up. Each dog's follow-up was truncated (censored) at the end of the time period they were observed.

Preliminary univariable analyses evaluated associations between O/O and sterilization status, sex, age at gonadectomy, and breed size. Cox proportional hazards models were used to estimate risk of O/O in gonadectomized dogs versus intact and, separately, estimate risk of O/O in sterilized dogs by age at gonadectomy. Models included the following covariates: main exposure (S/N or intact), sex, age, breed size, weight at index visit, purebred or mixed breed, wellness plan enrollment, and number of preindex veterinary care visits. Hazard ratio (HR) estimates and 95% CIs associated with risk of O/O by age at index visit across breed sizes stratified by sex were calculated, controlling for number of preindex visits, wellness plan enrollment, and mixed versus purebred status.

Age was treated as a continuous variable in the models; no categorization was done. Consequently, HRs pertain to dogs at a particular age, not within an age range. Specific ages were chosen to evaluate the effect of age for ease of exposition. The results therefore effectively describe hypothetical dogs rather than dogs in this sample. The models did not capture age as an isolated variable because they simultaneously accounted for the multiple aforementioned covariates.

Since enrollment in a wellness plan encourages more frequent office visits due to unlimited appointments at no charge, this variable was included because enrolled dogs might have had more opportunities to be identified as O/O than those not enrolled. By extension, they might have been identified as O/O at an earlier age than their nonenrolled counterparts. Including this variable minimized bias resulting from differences between cohorts. For similar reasons, a variable representing frequency of visits was included to minimize ascertainment bias. It is best practice in survival analysis to use only data preceding the beginning of follow-up, so preindex visits were used in lieu of number of visits during follow-up.

HRs derived from the models, although not technically identical to relative risks, are interpreted similarly in this manuscript. Restricted cubic splines were used for continuous variables included in the models, namely age, index weight, and number of visits. Restricted cubic splines use flexible curves to estimate nonlinear effects and thus avoid the assumption of linearity.[45] Additional model assumptions were checked by inspecting plots of residuals.[46] Relevant interaction terms were also included in the models. All analyses were performed using R (version 4.1.3; R Foundation for Statistical Computing).

Body condition scoring is subjective. Since misclassification as 1 score higher (eg, BCS = 4 vs BCS = 3) is more likely than misclassification as 2 scores higher (eg, BCS = 5 vs BCS = 3), multivariable models with an obese only outcome were evaluated in sensitivity analyses. The magnitude of HRs and patterns by age, sex, and breed size were then compared for those dogs classified as obese to those classified as overweight or obese.

Results

Records of 200,657 dogs that were examined at a Banfield Pet Hospital in 2014 and had at least 1 prior visit in 2013 were reviewed for inclusion. After applying exclusion criteria, the final sample consisted of 155,199 dogs, of which 45,732 were gonadectomized in 2014 and 109,467 remained intact throughout 2014 **(Figure 1; Table 1)**. It included 347 recorded breeds and associated breed mixes.

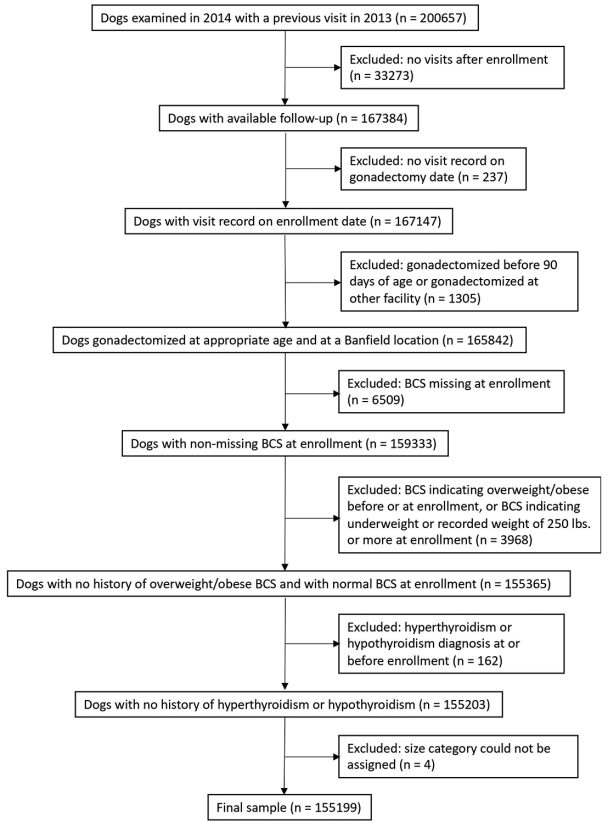

Figure 1—Cohort flow diagram for Banfield cohort.

The unadjusted incidence of O/O was 1.91 (95% CI, 1.87 to 1.95) times higher in gonadectomized dogs compared to intact **(Supplementary Table S1)**. Interpretation of the effect of gonadectomy on relative risks of O/O was contingent on multiple factors due to numerous interaction terms in the multivariable Cox model **(Supplementary Table S2)**. HR estimates and 95% CIs associated with risk of O/O by age (treated as a continuous variable) at index across breed sizes stratified by sex are delineated **(Figure 2; Supplementary Table S3)**. As examples, based on median weight at index within each age, sex, and breed size class, toy/small female dogs spayed at 3 years were 2.1 (95% CI, 1.97 to 2.27) times

Table 1—Characteristics of Banfield cohort stratified by spay/neuter status at index.

Variable	Intact (n = 109,467)	Spayed/neutered (n = 45,732)
Sex		
Male	70,331 (64)	23,991 (52)
Female	39,136 (36)	21,741 (48)
Pure breed		
Yes	88,419 (81)	31,426 (69)
No	21,048 (19)	14,306 (31)
Age in years (median, IQR)	3 (1, 6)	1 (0, 1)
Age		
3 mo to < 6 mo	7,939 (7)	16,809 (37)
6 mo to < 1 y	10,290 (9)	18,894 (41)
1 y to < 2 y	21,519 (20)	5,421 (12)
≥ 2 y	69,719 (64)	4,608 (10)
Breed size		
Toy and small	66,288 (61)	23,714 (52)
Medium	4,723 (4)	2,940 (6)
Standard	17,174 (16)	7,241 (16)
Large	16,551 (15)	9,818 (21)
Giant	4,731 (4)	2,019 (4)
Enrolled in wellness plan		
Yes	95,054 (87)	45,108 (99)
No	14,413 (13)	624 (1)
Follow-up in days for overweight/obese (median, IQR)	664 (282, 1,399)	549 (220, 1,265)
Follow-up in days for obese (median, IQR)	889 (341, 1,780)	1,115 (307, 1,825)
Visits per year during follow-up (median, IQR)	3 (2, 5)	4 (3, 7)

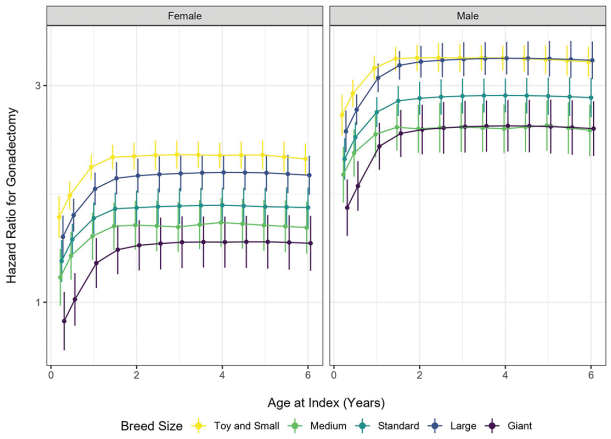

Figure 2—Hazard ratios and 95% CIs for effect of gonadectomy on risk of overweight/obese outcome compared to intact status by age at index stratified by breed size category and sex. Estimates are for dogs at median weight at index within age, sex, and breed size class. Effects are adjusted for age, sex, breed size, weight, mixed-breed status, enrollment in a Banfield Optimum Wellness Plan, and number of visits per year.

more likely to receive an O/O BCS compared to intact counterparts. Giant female dogs spayed at 3 years were 1.36 (95% CI, 1.19 to 1.55) times more likely to become O/O compared to intact counterparts. The smallest HR was seen in giant females spayed at 3 months (HR, 0.91; 95% CI, 0.78 to 1.05), followed by giant females spayed at 6 months (HR, 1.01; 95% CI, 0.89 to 1.16). The largest HR was observed in toy/small males neutered at 2.5 years (HR, 3.46; 95% CI, 3.21 to 3.72).

Risk of O/O associated with gonadectomy compared to intact dogs

The effects of dog sex, age at gonadectomy, and breed size on HRs for O/O based on multivariable modeling are described below.

Effect of dog sex—HRs of gonadectomized versus intact dogs were larger for males than females in the same age and breed size categories (Figure 2). For example, standard males sterilized at 1 year had an HR of 2.62 (95% CI, 2.43 to 2.83) compared to intact counterparts. This was higher than for standard females gonadectomized at this age, whose HR was 1.53 (95% CI, 1.41 to 1.66) compared to intact counterparts.

Effect of dog age at gonadectomy—Compared to intact counterparts of the same age, O/O risk was greater for gonadectomized dogs regardless of age at sterilization. Among both sexes and all breed size categories, HRs for O/O associated with gonadectomy tended to increase with age at sterilization until approximately 1.5 to 3 years, when they leveled off (Figure 2).

Effect of dog breed size—Risk of O/O varied according to size group but not linearly. Across all ages, toy/small dogs saw the largest HRs associated with gonadectomy and giant dogs the smallest. Large dogs exhibited HRs more similar to toy/small dogs, however, and medium dogs were more similar to giant.

Risk of O/O among dogs gonadectomized at 1 year compared to dogs gonadectomized at other ages

The risk of O/O among dogs gonadectomized at 1 year was compared to the risk among those that underwent the procedure at other ages across sex and size categories and controlling for the same covariates **(Figure 3)**. The relative risk of O/O at different ages varied on the basis of breed size and sex. HRs for comparisons using a reference age other than 1 year were also calculated **(Supplementary Figure S1; Supplementary Table S4)**.

Among males of all sizes, dogs neutered after 1 year faced a higher risk of O/O than those neutered at 1 year (Figure 3; Supplementary Table S4). The

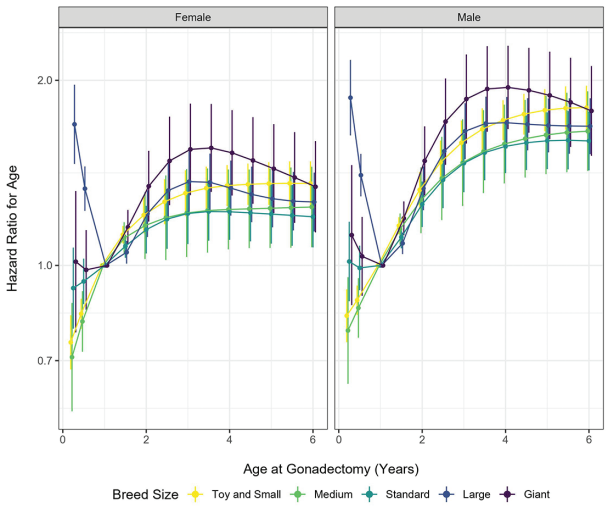

Figure 3—Hazard ratios and 95% CIs for effect of age at gonadectomy on risk of overweight/obese outcome at various ages compared to gonadectomy at 1 year of age stratified by breed size category and sex. Effects are adjusted for age, sex, breed size, weight, mixed-breed status, enrollment in a Banfield Optimum Wellness Plan, and number of visits per year.

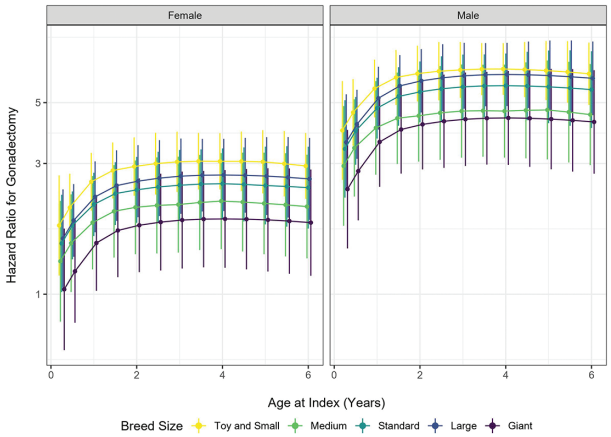

Figure 4—Hazard ratios and 95% CIs for effect of gonadectomy on risk of obese only outcome compared to intact status by age at index stratified by breed size category and sex. Estimates are for dogs at median weight at index within age, sex, and breed size class. Effects are adjusted for age, sex, breed size, weight, mixed-breed status, enrollment in a Banfield Optimum Wellness Plan, and number of visits per year.

comparative risk of O/O among those neutered at 6 months versus 1 year varied by size. Among standard and giant dogs, the relative risk was not statistically significant. Toy/small (HR, 0.88; 95% CI, 0.83 to 0.93) and medium (HR, 0.85; 95% CI, 0.76 to 0.95) dogs were significantly less likely to become O/O when sterilized as 6-month puppies. The difference in risk was most pronounced in large males, which showed a 40% increase in O/O risk (HR, 1.40; 95% CI, 1.30 to 1.52) when neutered at 6 months versus 1 year. Risk of O/O in dogs gonadectomized at 3 months generally followed the same trajectory as dogs gonadectomized at 6 months, albeit in a more pronounced capacity, for all breed size groups.

As with males, the risk of O/O among females sterilized after 1 year was elevated across size categories when compared to females sterilized at 1 year (Figure 3). Spaying at 6 months was generally associated with lower risk of O/O than spaying at 1 year (HR, 0.81 to 0.98), and there was a statistically significant difference for toy/small and medium dogs. Like males, large females spayed at 6 months were approximately one-third more likely to develop O/O than those spayed at 1 year (HR, 1.33; 95% CI, 1.23 to 1.45). As with males, risk of O/O in females spayed at 3 months generally followed the same trajectory as those spayed at 6 months for all breed sizes, with results that were more pronounced.

Sensitivity analyses

The unadjusted incidence of obesity was approximately 3.5 (95% CI, 3.25 to 3.75) times higher among gonadectomized compared to intact dogs (Supplementary Table S1). The multivariable model for obesity in gonadectomized versus intact dogs (Supplementary Table S2) yielded similar results as O/O (**Figure 4**; Supplementary Table S3). However, HRs observed for obesity comparing gonadectomized to intact dogs were higher than those for O/O among dogs of the same age, sex, and size. HRs for obesity peaked at approximately 2.5 to 3.5 years of age at gonadectomy, which is slightly later than the peak for O/O combined (1.5 to 3 years). After this peak, elevated relative risks stabilized or slightly declined (Figure 4 vs Figure 2).

Overall HR patterns for obesity related to dog size were similar to patterns in the O/O analysis. For example, toy/small gonadectomized dogs of both sexes had the highest HRs for an obese outcome compared to toy/small intact dogs and giant dogs had the lowest. Like the O/O model, HRs for obesity in gonadectomized versus intact dogs were higher in males than females (Figure 4). For example, toy/small male dogs castrated at 2 years had an HR of 5.76 (95% CI, 4.58 to 7.25) for an obese BCS; comparable spayed females had an HR of 3.28 (95% CI, 2.59 to 4.15).

When comparing dogs gonadectomized before 1 year to those sterilized at 1 year across sex and breed size categories, HR patterns were similar for O/O and obesity, except that they were generally higher for obesity. As was true in the O/O risk analysis, large male and female dogs sterilized at 6 months were at significantly higher risk of becoming obese compared to dogs sterilized at 1 year; there was not a statistically significant difference in risk between 6 months and 1 year for other sizes (**Figure 5** vs Figure 3). As with the O/O analysis, dogs gonadectomized at 3 months generally followed the same trajectory as those gonadectomized at 6 months for all size groups of both sexes.

When comparing male dogs gonadectomized after 1 year to those gonadectomized at 1 year across sex and breed size categories, HRs for obesity increased up to 3 to 4 years old at castration (similar

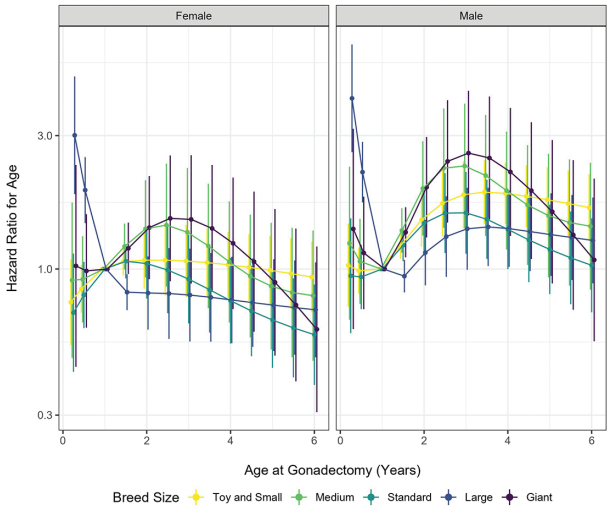

Figure 5—Hazard ratios and 95% CIs for effect of age at gonadectomy on risk of obese only outcome at various ages compared to gonadectomy at 1 year of age stratified by breed size category and sex. Effects are adjusted for age, sex, breed size, weight, mixed-breed status, enrollment in a Banfield Optimum Wellness Plan, and number of visits per year.

to O/O) but then declined sharply for some breed size categories (unlike for O/O). Among females, HR patterns for obesity were more disparate from those for O/O. Most HR estimates for obesity were nonsignificant for dogs spayed after 1 year, in contrast to the statistically elevated HRs for O/O (Figure 4 vs Figure 2). HRs for comparisons using a reference age other than 1 year were also calculated (Supplementary Table S4; **Supplementary Figure S2**).

Discussion

This study used Cox proportional hazards models to evaluate relative rates of O/O in a large sample of sterilized versus intact dogs in the US and in gonadectomized dogs sterilized at different ages, while accounting for multiple key interaction terms. The analysis treated mixed-breed dogs comparably to purebred, specifically evaluating relative rates of O/O according to the dog's expected size category rather than either excluding mixed breeds or analyzing mixed-breed dogs as a single group. Unlike much of the previous literature that used a cross-sectional approach (evaluating factors associated with having O/O),[20,24,32] this study followed dogs over time to assess their risk of developing O/O. Cross-sectional studies can misclassify dogs that have returned to normal weight and exclude those that died, leading to biased estimates of risk factors.

Consistent with prior research,[1,5,20–24] this analysis found that, compared to intact dogs, gonadectomy increased O/O risk for most dogs, with the possible exception of giant females spayed before 6 months (whose risk was comparable to intact counterparts). The degree to which gonadectomy increased risk of O/O differed according to sex, age when sterilized, and size, controlling for number of preindex visits, purebred or mixed-breed status, and wellness program enrollment. Biologically, it is not surprising that effects of gonadectomy on O/O vary on the basis of other factors, and this analysis mirrors 2 other studies[21,23] that used large data sets and reported joint effects. This underscores the importance of evaluating factors that may modify the effect of gonadectomy.

Compared to intact counterparts of the same sex, age, and size, the relative risk of O/O was larger for neutered males than spayed females across all ages and size categories. This higher relative risk of O/O in males is consistent with a study[22] of Danish dogs aged 2 years and older but distinct from others.[24,27,29] These discrepancies may be related to study design (eg, cross-sectional), definitions (eg, breed size), or other features.

The analysis suggested an apparent effect of gonadectomy timing on O/O risk, which could have clinical implications for recommended age of gonadectomy among different dog sexes and sizes if a primary objective is to reduce risk of O/O. The elevated risk of O/O appeared to peak among dogs sterilized at 1.5 to 3 years and then plateaued across size and sex categories.

Breed size also influenced relative risk of O/O following sterilization. Breed is a fraught variable in determining risk of O/O outcomes in dogs, due in part to challenges with accurate phenotypic breed identification and limited genotyping. To date, researchers have responded by limiting evaluation of O/O risk to purebreds or combining all mixed-breed dogs in a sample into a single category.[20,23,24,27,32,36] Prior studies have also used a range of approaches to categorize dog breeds or breed sizes. Varied methodologies make it impossible to directly compare breed findings in prior analyses to this one. The current study was the only one of which the authors are aware to assign dogs to these 5 particular size categories to evaluate relative risk of O/O. Doing so permitted inclusion and assignment of mixed breeds to an appropriate size category.

In this study, toy/small dogs had the largest HRs for O/O and giant dogs had the lowest. However, increased relative risk of O/O did not linearly track with size category. Some differences in O/O incidence among gonadectomized versus intact dogs in the different size categories could potentially be attributed, at least in part, to lifestyle factors of dogs in different AKC breed groups (toy, sporting, working, herding, etc). Future work should consider the most prevalent breed designations within breed size and identify whether specific breeds or mixes appear to be driving results of the size category.

The study's third objective evaluated the effect of age at gonadectomy on O/O among gonadectomized dogs. Although risk comparisons are available at 3 months and then 6-month intervals for dogs sterilized at 6 months to 6 years old, this manuscript focused on comparative risks of O/O among dogs gonadectomized at 1 year compared to those sterilized at other ages.

The analysis found that dogs of both sexes gonadectomized at 6 months or younger generally had

a similar or lower risk of becoming O/O compared to counterparts gonadectomized at 1 year. Among toy/small and medium dogs, the reduction in risk was statistically significant. The one pronounced exception was large dogs, for which gonadectomy at 6 months carried a significant increased risk of subsequent O/O among both sexes. These findings have not been reported thus far and generate interesting and as-yet-unanswered questions, including whether this is a reliable result or there remain unobserved confounding factors, what is the mechanism behind these findings, and how this result can or should be transformed into practical advice to veterinarians and dog owners.

The only other published cohort study[21] of Banfield Pet Hospital patients also revealed varying HRs by breed size and age at gonadectomy. The study used older data, with dogs enrolled between 1998 and 2001; given the studies' different definitions of breed size and age at gonadectomy, results cannot be fairly compared.

Multivariable Cox modeling of an obesity-only outcome produced results generally aligned with those of O/O, helping to validate O/O results. By minimizing error associated with assigning BCS across sex and breed size categories, the elevation in obesity risk associated with gonadectomy (compared to being intact) was more dramatic and peaked at later ages compared to the O/O outcome (Figure 4 vs Figure 2).

HR patterns for O/O and obesity outcomes (comparing rates of dogs gonadectomized at < 1 year to those gonadectomized at 1 year) were also similar for males and females (Figure 5 vs Figure 3). Among male dogs gonadectomized after 1 year old, obesity HRs were generally higher than for O/O. However, unlike O/O patterns, obesity HRs dropped dramatically for some dogs with advancing age at time of castration. For females, HRs were elevated for an O/O outcome but not statistically significant for dogs spayed after 1 year compared to those spayed at 1 year. These differences in HR patterns might reflect different reasons for sterilizing older dogs (eg, medical conditions, end of breeding, or pyometra) or that older dogs that are in good body condition up to the age of gonadectomy are less likely to become obese after surgery (eg, they get more exercise and have a proper diet). These differences might also reflect unstable rates due to small numbers, particularly among those dogs gonadectomized at 4 years or older.

Research suggests that owner behaviors and perceptions can influence pet weight through feeding patterns, such as quantities of food or frequency of treats, and physical activity levels and intensities.[47,48] Factors such as urban versus rural residence as well as food type have also been identified as O/O risk factors.[27,47] This study could not account for these factors. Similarly, it was not possible to exclude dogs with many of the diseases or treatments that could affect risk of becoming O/O; a randomized controlled trial or prospective cohort study would be necessary to address these limitations.

Large data sets permit exploring possible interactions, looking for factors that might modify or confound effects of exposures on the risk of outcomes. In this study, this entailed examining how a dog's size and sex might modify or confound the effect of gonadectomy on O/O outcomes. Large data sets can also have the disadvantage of identifying relationships of questionable clinical relevance. Caution should be exercised when evaluating results in this study, particularly where point estimates or CIs hover close to 1.

Toy/small dogs constituted 58% of the sample population, which is higher than a recent estimate of the percentage of small dogs in US homes.[49] This was potentially due to the concentration of Banfield hospitals in urban and suburban areas. Even so, sufficient statistical power was present in the multivariable models to evaluate effects of other breed sizes. Additionally, Banfield's client demographic is higher in age, income, and college education rates and more racially diverse than national samples of dog owners.[49,50] These distinctions are worth noting for extrapolating findings to the broader US dog population.

It is difficult to discern the impact of wellness plan enrollment on study results. The vast majority (85%) of patients in Banfield hospitals participate in a wellness plan, potentially contributing to detection bias if these patients are seen more frequently and more thoroughly evaluated via physical exams (twice-yearly comprehensive) and routine diagnostics.

BCS as a measure of O/O status is imperfect, and its use was a limitation of this and any study relying on BCS scoring versus dual-energy x-ray absorptiometry scans to evaluate O/O. "Normal" body composition can vary somewhat by breed, and BCS scores are subjective and only semiquantitative.[51] This noted, BCS scores in this data set were entered by veterinarians who are responsible for the medical accuracy of their records, and records must be finalized by the veterinarian of record. Teams are experienced with evaluating BCS because it is a required input into every hospital visit. Moreover, this study took measures to enhance the meaningfulness of the analysis. The sample relied on a period when Banfield consistently used a 5-point scoring scale, and a sensitivity analysis was conducted analyzing risk of obese BCS and comparing results to those of O/O dogs. Trends in the 2 analyses were generally comparable.

In a recent analysis, 39% of dogs seen at Banfield had a recorded O/O BCS, yet unstructured fields in the records reported 51% of these dogs to be overweight.[26] This suggests that estimates of O/O as defined by BCS might be conservative and could reflect potential reluctance of hospital teams to broach the subject with owners. This would be particularly important if, for example, gonadectomized dogs were more likely than intact to receive an O/O BCS, because it would inflate the relative risks associated with gonadectomy. Nonetheless, BCS remains the standardized measure of body condition recommended by US and global veterinary associations[51,52] and is widely used by American veterinarians as well as in previous research.

DNA analysis has cast doubt on the accuracy of breed labels by owners and shelters, especially for mixed breeds.[53] Particular disparities have been found

regarding dogs labeled as "pit bulls."[54] Pertinent to this study, Banfield's computer system requires that a primary breed be assigned using a drop-down menu. This breed was input by the hospital team but owner reported. It is therefore likely that some dogs, particularly mixes, were misidentified. In turn, this could affect a dog's assignment to a size category.

It is also likely that some individual mixed-breed dogs were not identified as such in the system because doing so required checking a box. Additionally, with very limited exceptions, the system did not account for intentional crossbreeds (eg, Labradoodle or Maltipoo). This means, for example, that a Goldendoodle would likely be categorized as a Golden Retriever mix. In this study, the percentage of dogs recorded as purebred was 77.2%, whereas national estimates from recent years range from 49% to 55%.[50,55] The overrepresentation of purebred dogs in this data set could be attributable in part to the method of recording breed, although client demographics and exclusion methodology could also be factors.

The approach of assigning individual dogs of each recorded primary breed to a size category rather than analyzing risk among particular breeds mediated some challenges that incomplete breed identification posed. It also obviated issues that would arise if dogs had been assigned to a size category based on index weight, given that many entered the study as growing puppies.

This analysis found that, except for large dogs, sterilizing at 3 or 6 months of age was associated with a lower or equal risk of subsequent O/O than sterilizing at 1 year old. Among large dogs, sterilizing at 1 year of age was associated with the lowest risk. This was true for both males and females. Among both sexes and all sizes, O/O risk was elevated for dogs sterilized after 1 year of age compared to dogs sterilized at 1 year old.

These findings suggest that with regard to O/O, sterilizing a dog earlier is generally better than postponing surgery. However, studies have also evaluated other important outcomes associated with age at gonadectomy, including orthopedic injury and joint disorders,[37,56–61] cancers,[56–58,60,62] urinary incontinence,[37,59] and undesirable behaviors.[16,37,63] Several of these studies have found that the incidence of a particular adverse outcome is higher among dogs sterilized before 1 year of age, or before puberty, compared to those sterilized after.[56–63] Much of the research was limited in scope to purebred dogs[56–59,62] or dogs seen at a tertiary veterinary hospital,[56–60] and owner-reported data[61] carries the potential for selection, recall, and other measurement biases, all of which potentially limit generalizability. Other studies have found associations between gonadectomy and positive outcomes, leaving open the question of when gonadectomy should be performed. It is therefore important to emphasize that obesity is but one of several outcomes to consider relative to timing of gonadectomy. Any decision regarding the procedure should be made on a case-by-case basis based on all potential risks and benefits for the individual animal.[7]

Veterinarians are uniquely positioned to help prevent O/O in dogs through educating and supporting clients regarding an appropriate weight for their pets, metabolic changes, and caloric requirements and advising on unhealthy weight gain. More precise and comprehensive information about which dogs have higher risk profiles for O/O following sterilization, as provided by these data, can help veterinarians counsel clients in a manner that is more personalized to individual animals. Of course, recommendations must also consider other potential risks and benefits associated with gonadectomy and with the age at which surgery is performed. Future nonsurgical fertility control options might also be evaluated as ways to protect against unhealthy weight gain following sterilization.

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Supplementary Materials

Supplementary materials are posted online at the journal website: avmajournals.avma.org

Correction: Current per- and polyfluoroalkyl substance (PFAS) research points to a growing threat in animals

In the Currents in One Health article "Current per- and polyfluoroalkyl substance (PFAS) research points to a growing threat in animals" (*J Am Vet Med Assoc.* 2023;261[7]:952–958. doi.org/10.2460/javma.22.12.0582), the image for Figure 1 is incorrect. The molecular structure drawing shows 9 carbon atoms instead of the correct number of 8. The correct image appears below.