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Gonadectomy status and age are associated with variable risk of overweight or obese outcomes in 15 dog breeds: a retrospective cohort study using data from primary care veterinary clinics

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Objective
To examine rates of overweight or obese (OvOb) body condition score, including the association between OvOb and gonadectomy, in 15 dog breeds.

Methods
The analysis considered the 5 most recorded large breeds (26,369 dogs) and 10 most recorded toy/small breeds (90,002 dogs) in Banfield Pet Hospital's database from 2013 to 2019. Cox proportional hazards models evaluated associations between OvOb and gonadectomy status, gonadectomy age, sex, and primary breed. Models estimated OvOb rates in gonadectomized versus intact dogs of each breed and, separately, OvOb rates according to gonadectomy age.

Results
There was substantial breed variation in underlying (intact dog) OvOb rates among the 15 breeds. Pugs, Golden Retrievers, and Labrador Retrievers had highest underlying susceptibility to OvOb outcomes. There was some variation in relative OvOb rates among breeds, but breeds differing substantially from size group peers were limited. Among all toy/small breeds, gonadectomy at 3 or 6 months had hazard ratios (relative risks) lower than, or not statistically different from, gonadectomy at 1 year or older. For large dogs, OvOb outcomes associated with prepubertal gonadectomy varied by breed.

Conclusions
Underlying susceptibility to OvOb varies by breed. Gonadectomy offers significant benefits at individual and population levels. As with many veterinary care decisions, however, there is complexity, and associated OvOb risks are not uniform across breeds.

Clinical Relevance
Results may facilitate more individualized recommendations for gonadectomy timing and proactive strategies (specifically diet and exercise) to mitigate risk of OvOb outcomes, while accounting for the broader context of individual dog and population-level benefits of gonadectomy.

Keywords: gonadectomy, dog, obesity, dog breeds, sterilization

Gonadectomy (spay/neuter) is a widely accepted and performed surgical procedure in the US.[1] Besides preventing births of unwanted puppies, gonadectomy has been found to reduce or eliminate the risk of multiple adverse health outcomes in individual dogs, including pyometra and mammary neoplasia in females and benign prostatic hyperplasia and perianal adenomas in males.[1–4]

Research has also identified some adverse health outcomes associated with gonadectomy and with gonadectomy performed at specific ages.[1,2,4] One of these is canine obesity, a significant problem in the US and multiple other countries, which is associated with a range of detrimental physical, behavioral, and quality-of-life outcomes.[5–9] Several studies[6,7,10,11] have

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identified gonadectomy as 1 risk factor for overweight and obese (OvOb) outcomes in dogs, but details vary. Most studies[6,7,11–13] report similar population prevalence of OvOb in gonadectomized dogs of both sexes, although 2 European studies[14,15] found males at higher risk than females, and 1 US study[16] found the opposite. Studies[7,10,17] have also identified varied relative risks associated with age at gonadectomy.

A foundational study[18] for the present analysis evaluated the relationship between gonadectomy and subsequent OvOb in patients of Banfield Pet Hospital, which has primary care clinics across the US. Breeds (and mixes thereof) recorded in the electronic medical record were assigned to 1 of 5 size groups matching those of the Dog Aging Project, an epidemiologic study[19] with purebred and mixed-breed dogs: 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). Assigning the breeds in this way addressed limitations of some prior analyses, including those that investigated individual dog breeds or breed groups[6,10–12,16,20] or combined mixed breeds into a single category.[6,11,16,20] Categorizing by breed size in the foundational analysis[18] enabled purebred and mixed-breed dogs to be analyzed comparably to determine risk. From a clinical perspective, breed size influences maturation rate, providing a rationale to consider health outcomes as they relate to adult size.

This prior study[18] produced some findings consistent with previous literature, including a higher hazard ratio (or relative risk) for developing OvOb among gonadectomized dogs compared to intact. It also generated novel findings. Across all ages, toy/small dogs had the highest OvOb rates, followed by large breeds. Hazard ratios were particularly high among males. Medium, standard, and giant breeds all had lower OvOb hazard ratios following gonadectomy compared to their toy/small and large counterparts.

There was an unexpected outcome regarding OvOb rates associated with age at gonadectomy. Among toy/small, medium, standard, and giant groups, gonadectomy at 3 or 6 months was associated with either lower or equal rates of subsequent OvOb compared to surgery at 1 year old. Among large dogs of both sexes, gonadectomy at 3 or 6 months was associated with significantly *higher* rates of OvOb than at 1 year old.

Toy/small and large group results raised questions about the influence of individual breeds within these 2 popular size categories. The present analysis therefore evaluated OvOb outcomes of the 10 most recorded toy/small breeds and 5 most recorded large breeds (including mixes) in the data set. It explored whether there was consistency in OvOb trajectories among individual breeds within a size category or whether a specific breed, or breeds, had a disproportionate impact on group-level results, thus potentially disguising variability among dog breeds within the size category.

It must be emphasized that increased OvOb risk following spay/neuter is not on its own a reason to postpone or avoid surgery. The risk of unwanted litters, plus other health and behavioral risks and benefits of both gonadectomy and remaining intact, should be considered in decision-making. There are also practical considerations, particularly for shelters and rescue organizations with limited time to spay or neuter animals before adoption. Moreover, human behaviors influence pet OvOb outcomes through feeding practices and physical activity,[21–25] making OvOb an outcome largely under owner control. What these data *can* do is detail breed-related risk of developing OvOb and ages of gonadectomy that appear to increase or decrease this likelihood, thereby enabling veterinarians and guardians to be more attuned to and proactive about managing dog weight.

Methods

This analysis expands upon Benka et al[18] to review OvOb outcomes among the 10 toy/small breeds and 5 large breeds recorded in greatest numbers (ie, *focus breeds*) at Banfield during the study period, after applying exclusion criteria. Detailed methods were previously described.[18] Briefly, data were collected from 2013 to 2019, when clinics used 5-point body condition score (BCS) guidelines.[26] For this retrospective cohort study, outcomes of interest were overweight (BCS = 4) and obese (BCS = 5) categorizations. Dogs seen in 2014 with at least 1 Banfield visit in 2013 were divided into 2 groups. Dogs gonadectomized at Banfield in 2014 were assigned to the gonadectomized cohort, and those intact in 2014 to the intact cohort. They were followed through December 31, 2019, or until they received an OvOb diagnosis, stopped being seen at Banfield, received a hyperthyroidism or hypothyroidism diagnosis, or were gonadectomized (for those who entered the study intact). Index visit was defined as date of surgery for the gonadectomized group and date of first visit to Banfield in 2014 for the intact group.

Records of 200,657 dogs were reviewed for inclusion. Dogs were excluded for the following reasons: they had no visits following enrollment, their gonadectomy was not at Banfield, they had a gonadectomy before they were 90 days old, they were missing a BCS or assigned a BCS other than 3 (ideal body weight) before or at enrollment, they had an unrealistic weight (over 250 lb) recorded at enrollment, they had a diagnosis of hyperthyroidism or hypothyroidism prior to enrollment, or they were lacking data to assign to a size group category.[18] After exclusion criteria were applied, the sample consisted of 155,199 dogs, including 347 recorded breeds and associated mixes. Within this sample, the gonadectomized cohort was a median of 1 year old at enrollment (IQR, 0 to 1) and had a median of 4 visits annually (IQR, 3 to 7). Intact dogs were older (median age of 3 years; IQR, 1 to 6) and had a median of 3 yearly visits during the follow-up period (IQR, 2 to 5).

Breed designation was based on owner-reported breed or veterinary team assessment and entered into Banfield's medical records software (PetWare) using its dropdown menu. The system requires a breed designation to finalize a record, and each dog can be assigned only 1 breed. A checkbox is used to identify mixed-breed dogs. Prevalence ranking for this analysis was

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based on total numbers of dogs of a given breed in the data set, combining purebreds and mixes.

Restricting to toy/small and large breeds for the present analysis meant that some popular breeds within the Banfield data set and US dog population in 2013 to 2019 were not included (eg, Pit Bull, Husky, English Bulldog, Rottweiler, Beagle). These breeds were assigned to different size categories than the 2 reviewed here, using methods described previously.[18]

Statistical analysis

Time-to-event analyses were conducted, with the study period concluding on December 31, 2019. Detailed methods are previously described.[18] Briefly, preliminary univariable analyses compared incidence of OvOb by gonadectomy status and breed. Cox proportional hazards models were used to estimate OvOb rates in gonadectomized versus intact dogs within each focus breed and at different enrollment ages. Separately, hazards models were used to estimate relative risk of OvOb in gonadectomized dogs by spay/neuter age, specifically among dogs gonadectomized at 1 year versus other ages. These models included the following covariates: main exposure (gonadectomy or intact), sex, age, breed, weight at index visit, purebred or mixed breed, enrollment in a preventive care package, and number of preindex veterinary visits. Hazard ratio estimates and 95% CIs associated with OvOb by age at index across breed stratified by sex were calculated, controlling for covariates. Age was treated as a continuous variable in the models. Consequently, hazard ratios pertain to dogs at a particular age, not within an age range. The proportional hazards assumption was evaluated by plotting Schoenfeld residuals.

Hazards models were created for the 15 focus breeds, combining pure and mixed breeds. For each breed, hazard ratio estimates were calculated through age 6 for the size group and focus breed. They were also calculated for the size group *excluding* the focus breed to assess the impact of removing the focus breed from the size group. Significance was determined based on whether 95% CIs included 1.0, the null value for hazard ratios.

Although not technically identical, hazard ratios derived from the current models are interpreted similarly to relative risks. Restricted cubic splines were used for continuous variables (age, index weight, number of visits) in the models. Restricted cubic splines use flexible curves to estimate nonlinear effects and thus avoid the assumption of linearity.[27] Additional model assumptions were checked by inspecting plots of residuals.[28] Relevant interaction terms were also included in the models.

Forest plots were created to summarize data from the 2 proportional hazards models. The first plot reports OvOb rates in gonadectomized dogs versus intact at enrollment ages of 3 months, 6 months, 1 year, and 2.5 years. The second summarizes OvOb rates within the gonadectomized cohort according to age at gonadectomy, comparing 3 months, 6 months, and 2.5 years to 1 year. Three and 6 months were chosen because they represent typical ages for prepubertal gonadectomy; 2.5 years was chosen because by this age large and giant breeds have reached their adult size.[29,30]

A subgroup analysis was performed by running the same models as in the main analysis but restricting to dogs that were recorded as a purebred member of a breed heavily represented in both Banfield patient and US shelter populations.[31]

All analyses were performed with R 4.1.3 (R Foundation for Statistical Computing).

Results

Toy/small breeds

In the original cohort, 90,002 dogs were assigned to the toy/small category, constituting 58% of the total study population. The 10 most recorded toy/small breeds were Yorkshire Terrier (17.5%), Chihuahua (17.3%), Shih Tzu (14.2%), Maltese (8.7%), Poodle (8.3%), Pomeranian (5.1%), Dachshund (4.7%), Miniature Schnauzer (2.5%), Pug (1.9%), and Bichon Frise (1.8%) **(Table 1)**.

Table 1—The study population: breeds, numbers, percentages, purebreds and mixed breeds, and intact and gonadectomized (spayed/neutered) dogs.

		Intact[a]				Gonadectomized (spayed/neutered)[b]			
Breed	Total Nos. (%)[c]	Male (n [%])	Female (n [%])	Purebred (n [%])	Age (median [IQR])	Male (n [%])	Female (n [%])	Purebred (n [%])	Age (median [IQR])
Toy/small breed	90,002 (100)	40,413 (61)	25,875 (39)	52,185 (79)	3.6 (1.7–6.3)	12,265 (52)	11,449 (48)	15,571 (66)	0.6 (0.5–1.0)
Yorkshire Terrier	15,748 (17)	7,404 (61)	4,766 (39)	10,400 (85)	3.2 (1.6–5.5)	1,901 (53)	1,677 (47)	2,543 (71)	0.6 (0.5–1.1)
Chihuahua	15,586 (17)	6,411 (56)	5,134 (44)	9,062 (78)	3.4 (1.6–6.0)	1,938 (48)	2,103 (52)	2,634 (65)	0.6 (0.5–1.0)
Shih Tzu	12,797 (14)	5,947 (62)	3,631 (38)	7,702 (80)	3.5 (1.7–6.1)	1,693 (53)	1,526 (47)	2,201 (68)	0.6 (0.5–1.0)
Maltese	7,806 (9)	3,346 (59)	2,317 (41)	3,665 (65)	3.4 (1.6–6.0)	1,077 (50)	1,066 (50)	960 (45)	0.6 (0.5–1.0)
Poodle	7,454 (8)	3,386 (59)	2,358 (41)	4,013 (70)	4.1 (1.9–6.9)	864 (51)	846 (49)	838 (49)	0.6 (0.5–1.0)
Pomeranian	4,550 (5)	2,061 (59)	1,440 (41)	2,942 (84)	3.9 (1.7–6.7)	586 (56)	463 (44)	735 (70)	0.6 (0.5–1.2)
Dachshund	4,215 (5)	1,872 (66)	967 (34)	2,426 (85)	4.3 (2.0–7.1)	693 (50)	683 (50)	1,052 (76)	0.6 (0.5–0.9)
Miniature Schnauzer	2,279 (3)	1,162 (69)	524 (31)	1,586 (94)	3.9 (1.8–6.6)	324 (55)	269 (45)	546 (92)	0.5 (0.5–0.7)
Pug	1,674 (2)	691 (68)	321 (32)	813 (80)	2.9 (1.3–5.9)	380 (57)	282 (43)	440 (66)	0.5 (0.5–0.8)
Bichon Frise	1,659 (2)	771 (64)	442 (36)	871 (72)	4.8 (2.3–7.2)	264 (59)	182 (41)	269 (60)	0.6 (0.5–1.1)
Large breed	26,369 (100)	11,703 (71)	4,848 (29)	13,585 (82)	2.4 (1.2–5.0)	5,248 (53)	4,570 (47)	6,765 (69)	0.5 (0.4–0.8)
Labrador Retriever	8,204 (31)	3,212 (71)	1,321 (29)	3,224 (71)	2.6 (1.2–5.6)	1,920 (52)	1,751 (48)	2,223 (61)	0.5 (0.4–0.7)
German Shepherd Dog	6,959 (26)	3,391 (69)	1,531 (31)	4,271 (87)	2.1 (1.0–4.2)	1,056 (52)	981 (48)	1,538 (76)	0.5 (0.4–0.9)
Boxer	4,719 (18)	2,203 (72)	845 (28)	2,621 (86)	2.7 (1.3–5.2)	871 (52)	800 (48)	1,234 (74)	0.5 (0.4–0.8)
Golden Retriever	2,895 (11)	1,121 (70)	470 (30)	1,373 (86)	2.9 (1.3–5.6)	765 (59)	539 (41)	889 (68)	0.5 (0.4–0.8)
American Bulldog	1,383 (5)	774 (74)	265 (26)	846 (81)	1.9 (0.9–3.9)	181 (53)	163 (47)	253 (74)	0.6 (0.5–1.0)

[a]Percentages are relative to all intact dogs in the designated breed. [b]Percentages are relative to all spayed/neutered dogs in the designated breed. [c]Individual breed percentage is relative to all dogs in the respective size category.

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In total, the 73,768 dogs of these 10 breeds constituted 82.0% of the toy/small size group.

Most individual breeds reflected the overall toy/small size group demographically, with a few notable exceptions. Compared to the toy/small group, Maltese and Poodles were less likely to be purebred; Miniature Schnauzers were more likely. Among gonadectomized toy/small dogs, approximately 66% were purebred; among Miniature Schnauzers, 92%; among Dachshunds, 76%; among Poodles, 49%; and among Maltese, 45%. Among intact toy/small dogs, 79% were purebred overall, compared to 94% of intact Miniature Schnauzers, 70% of Poodles, and 65% of Maltese (Table 1). Median follow-up time for the selected breeds ranged from 490 to 890 days and 428 to 858 days for intact and gonadectomized dogs, respectively, compared to 762 (intact) and 640 (gonadectomized) among toy/small dogs overall **(Table 2)**. Like the toy/small group and entire study cohort, crude prevalence of OvOb for each focus breed (ie, *outcome events*) was significantly higher for gonadectomized dogs compared to intact.

In the overall toy/small group, 21% of intact dogs and 37% of gonadectomized dogs developed OvOb. Compared to the overall toy/small group, Pugs had notably higher incidences of OvOb dogs in both intact (43%) and gonadectomized (61%) groups (Table 2).

Effects of gonadectomy on OvOb outcomes compared to intact dogs—When adjusted relative risk of an OvOb outcome was compared between intact and gonadectomized dogs, most breeds did not differ significantly from the toy/small size group. No breed had a disproportionate influence on size group outcomes. In the toy/small group, the adjusted OvOb risk was higher in gonadectomized dogs compared to intact at all time points. This was also true within each individual breed, with limited exceptions.

Forest plots **(Figure 1)** illustrate hazard ratios for dogs gonadectomized at 3 months, 6 months, 1 year, and 2.5 years relative to intact dogs of their same breed and age at enrollment. Overweight or obese rates were significantly higher among neutered males compared to intact across breeds for nearly all ages, except Pugs and Maltese neutered at 3 months (no significant difference). Similar results were seen for females of most breeds, as spayed dogs had significantly higher OvOb rates than intact. Exceptions were Pugs and Maltese spayed at 3 or 6 months old and Miniature Schnauzers spayed at 3 months, 6 months, or 2.5 years. At ages represented in the forest plots, the hazard of OvOb in neutered versus intact males of all focus breeds was greater than their female counterparts, although differences were not statistically significant except in Chihuahuas 6 months of age and older. The difference in OvOb rates by sex for the entire toy/small size group was significant. Results for focus breeds through age 6 are in **Supplementary Figure S1**.

Effects of age at gonadectomy on OvOb among gonadectomized dogs—In the toy/small group, male and female dogs gonadectomized at 3 or 6 months had significantly lower OvOb rates than those gonadectomized at 1 year. Overweight or obese rates were also significantly higher for dogs gonadectomized after 1 year compared to at 1 year in the breed size group.

Of the focus breeds, Chihuahuas most closely mirrored the full toy/small group. Like the size group, male and female Chihuahuas gonadectomized before 1 year old had a significantly lower OvOb rate than those gonadectomized at 1 year, and those gonadectomized at 2.5 years had a significantly higher OvOb rate than those gonadectomized at 1 year **(Figure 2)**. This particular risk profile was not evident in other breeds.

Consistent with Chihuahuas and the overall toy/small group, male Miniature Schnauzers neutered at 3 or 6 months had a significantly lower OvOb rate

Table 2—Overweight/obesity rates among focus breeds.

	Intact[a]			Gonadectomized (spayed/neutered)[b]			
Breed	Outcome events (n [%])	Follow-up in days (median [IQR])	Rate per 100 years	Outcome events (n [%])	Follow-up in days (median [IQR])	Rate per 100 years	Rate ratio (95% CI)
Toy/small breed (combined)	13,703 (21)	762 (343–1,558)	8.4	8,858 (37)	640 (257–1,447)	16.5	1.96 (1.91–2.02)
Yorkshire Terrier	2,072 (17)	851 (363–1,668)	6.6	1,170 (33)	754 (293–1,626)	13.3	2.02 (1.88–2.17)
Chihuahua	2,328 (20)	680 (270–1,449)	8.8	1,489 (37)	475 (188–1,111)	19.3	2.20 (2.06–2.35)
Shih Tzu	1,960 (20)	781 (353–1,601)	8.2	1,153 (36)	710 (288–1,605)	14.9	1.82 (1.69–1.95)
Maltese	880 (16)	890 (384–1,712)	5.8	636 (30)	858 (342–1,808)	11.2	1.92 (1.73–2.12)
Poodle	891 (16)	882 (372–1,722)	5.9	542 (32)	812 (315–1,734)	12.5	2.13 (1.91–2.36)
Pomeranian	813 (23)	712 (328–1,452)	9.9	431 (41)	535 (219–1,305)	19.8	2.00 (1.78–2.25)
Dachshund	736 (26)	653 (316–1,407)	11.4	659 (48)	527 (195–1,075)	24.9	2.19 (1.97–2.43)
Miniature Schnauzer	459 (27)	756 (353–1,520)	11.1	261 (44)	650 (281–1,531)	19.0	1.71 (1.47–1.99)
Pug	431 (43)	490 (220–976)	24.2	403 (61)	428 (182–833)	37.1	1.54 (1.34–1.76)
Bichon Frise	310 (26)	840 (385–1,662)	9.8	199 (45)	714 (333–1,483)	18.8	1.91 (1.60–2.28)
Large breed (combined)	4,129 (25)	568 (243–1,174)	12.2	4,171 (42)	489 (197–1,099)	22.3	1.83 (1.75–1.91)
Labrador Retriever	1,485 (33)	531 (222–1,064)	17.1	1,823 (50)	426 (178–939)	29.1	1.70 (1.59–1.82)
German Shepherd Dog	899 (18)	620 (257–1,303)	8.4	621 (30)	540 (203–1,286)	14.7	1.74 (1.57–1.92)
Boxer	563 (18)	614 (263–1,233)	8.8	533 (32)	640 (234–1,333)	14.6	1.67 (1.48–1.88)
Golden Retriever	582 (37)	568 (274–1,148)	17.9	709 (54)	487 (237–1,069)	28.8	1.60 (1.44–1.79)
American Bulldog	291 (28)	481 (192–986)	15.9	172 (50)	434 (186–839)	32.0	2.01 (1.67–2.43)

[a]Percentages are relative to all intact dogs in the designated breed. [b]Percentages are relative to all spayed/neutered dogs in the designated breed.

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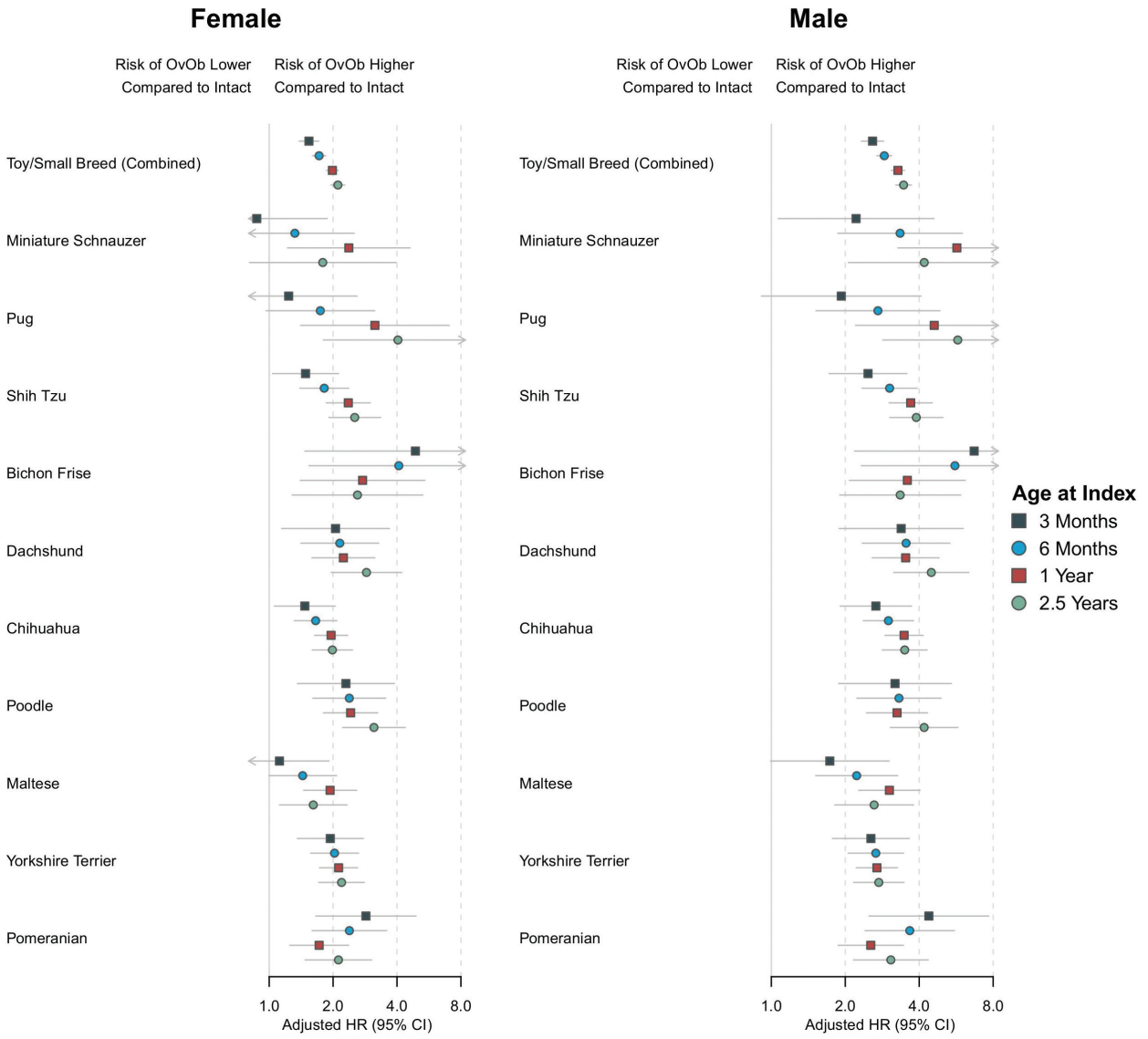

Figure 1—Gonadectomy and overweight or obese (OvOb) outcomes, comparing spayed/neutered to intact dogs. Forest plots illustrate OvOb hazard ratio (HR) estimates and 95% CIs for male and female toy-small-breed dogs gonadectomized at ages 3 months, 6 months, 1 year, and 2.5 years relative to intact dogs of their same breed, sex, and age at enrollment.

than Miniature Schnauzers neutered at 1 year. For all other focus breeds, there was no significant difference in OvOb rates between those gonadectomized at 3 or 6 months versus 1 year. In no instance was there a significantly higher OvOb rate for puppies of the focus breeds gonadectomized at 3 or 6 months compared to 1 year (Figure 2).

Comparing dogs gonadectomized at 2.5 versus 1 year of age, the OvOb rate was significantly higher in males neutered at 2.5 years for Chihuahuas, Dachshunds, Pomeranians, Poodles, Shih Tzus, and Yorkshire Terriers. These breeds were consistent with the toy/small group in this measure. There was no significant difference in OvOb outcomes between neutering at 2.5 versus 1 year for male Bichons Frises, Maltese, Miniature Schnauzers, and Pugs. Female Poodles and Yorkshire Terriers spayed at 2.5 years had a higher OvOb rate compared to dogs of the same breed spayed at 1 year (Figure 2). There was no significant difference among other focus breeds. Results for all focus breeds through age 6 are in **Supplementary Figure S2**.

Large breeds

In the original cohort, 26,369 dogs were assigned to the large-breed category, constituting 17.0% of the total study population. The 5 most frequently recorded large breeds were Labrador Retriever (31.1%), German Shepherd Dog (26.4%), Boxer (17.9%), Golden Retriever (11.0%), and American Bulldog (5.2%; Table 1). In total, 24,160 (91.6%) dogs in the large-breed size category were recorded as one of these breeds.

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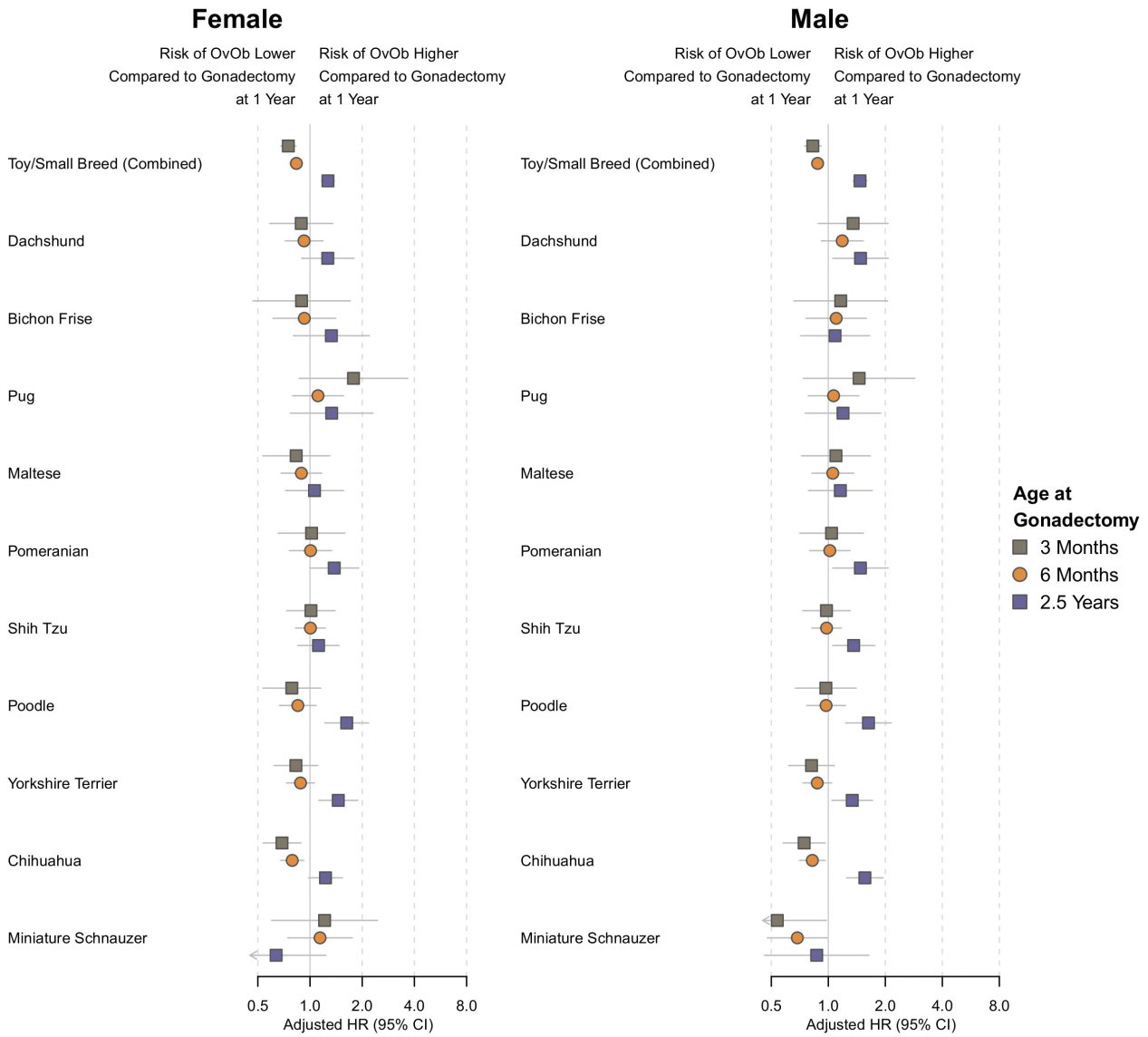

Figure 2—Age at gonadectomy and OvOb outcomes among gonadectomized dogs. Forest plots illustrate OvOb HR estimates and 95% CIs for male and female toy-small-breed dogs gonadectomized at ages 3 months, 6 months, and 2.5 years relative to dogs of their same breed and sex gonadectomized at 1 year old.

Most individual breeds did not differ greatly in demographics from the large size group, although only 71% of Labrador Retrievers were listed as purebred, versus 83% of the overall large group. Median follow-up time for the selected breeds ranged from 481 to 620 days and 426 to 640 days for intact and gonadectomized dogs, respectively, compared to 568 and 489 days in the overall large group (Table 2).

Certain breeds stood out as having generally high or low incidences of OvOb. In the overall large group, 25% of intact dogs and 42% of gonadectomized dogs developed OvOb. Golden Retrievers had notably higher proportions of OvOb dogs in both intact (37%) and gonadectomized (54%) groups. German Shepherd Dogs had notably lower OvOb incidences than the large-breed cohort among both intact (18%) and gonadectomized (30%) dogs, as did Boxers (18% intact, 32% gonadectomized; Table 2). As with the overall large group and entire study cohort, the crude incidence of OvOb for each individual breed was significantly higher for gonadectomized dogs compared to their intact counterparts.

Effects of gonadectomy on OvOb outcomes compared to intact dogs—Forest plots **(Figure 3)** illustrate adjusted hazard ratios for dogs undergoing gonadectomy at ages 3 months, 6 months, 1 year, and 2.5 years relative to intact dogs of the same breed and age. Like the large-breed size group overall, significant differences in OvOb were seen in males at these 4 time points for nearly all focus breeds and ages. The OvOb rate was significantly higher in spayed females relative to intact except in German Shepherd Dogs spayed at 3 months, American Bulldogs spayed at 1 year, and Boxers spayed at 3 months, 6 months, or 2.5 years.

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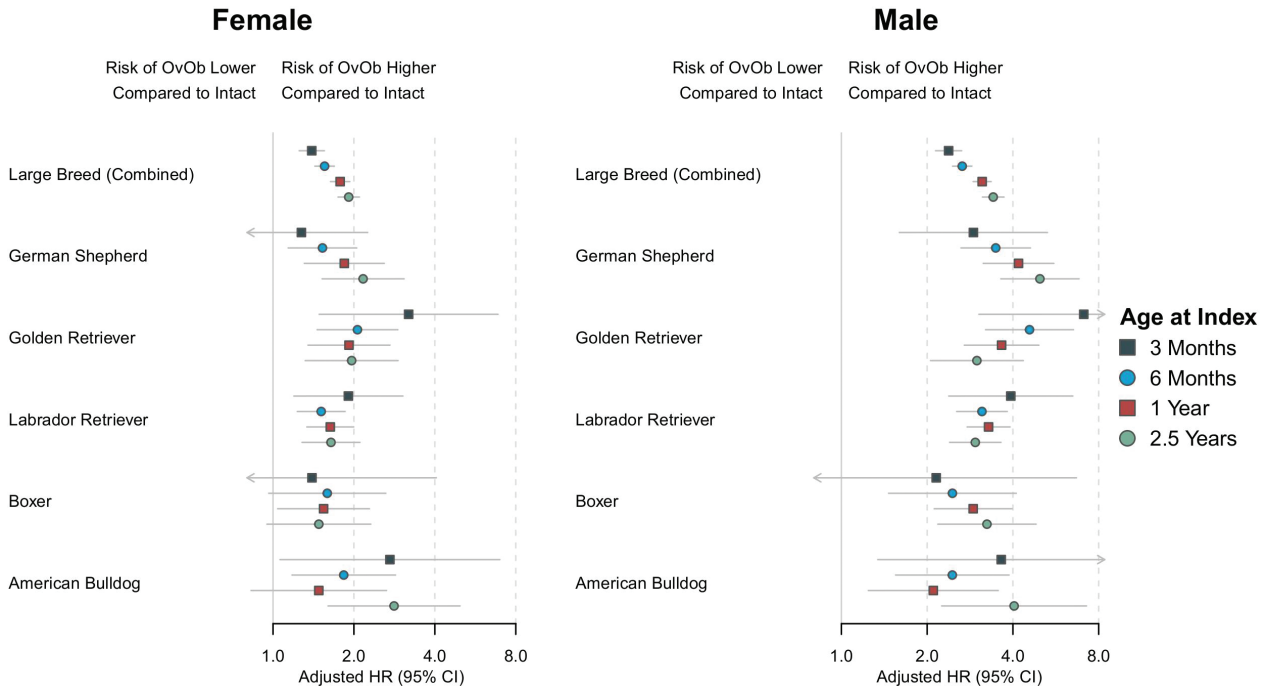

Figure 3—Gonadectomy and OvOb outcomes, comparing spayed/neutered to intact dogs. Forest plots illustrate OvOb HR estimates and 95% CIs for male and female large-breed dogs gonadectomized at ages 3 months, 6 months, 1 year, and 2.5 years relative to intact dogs of their same breed, sex, and age at enrollment.

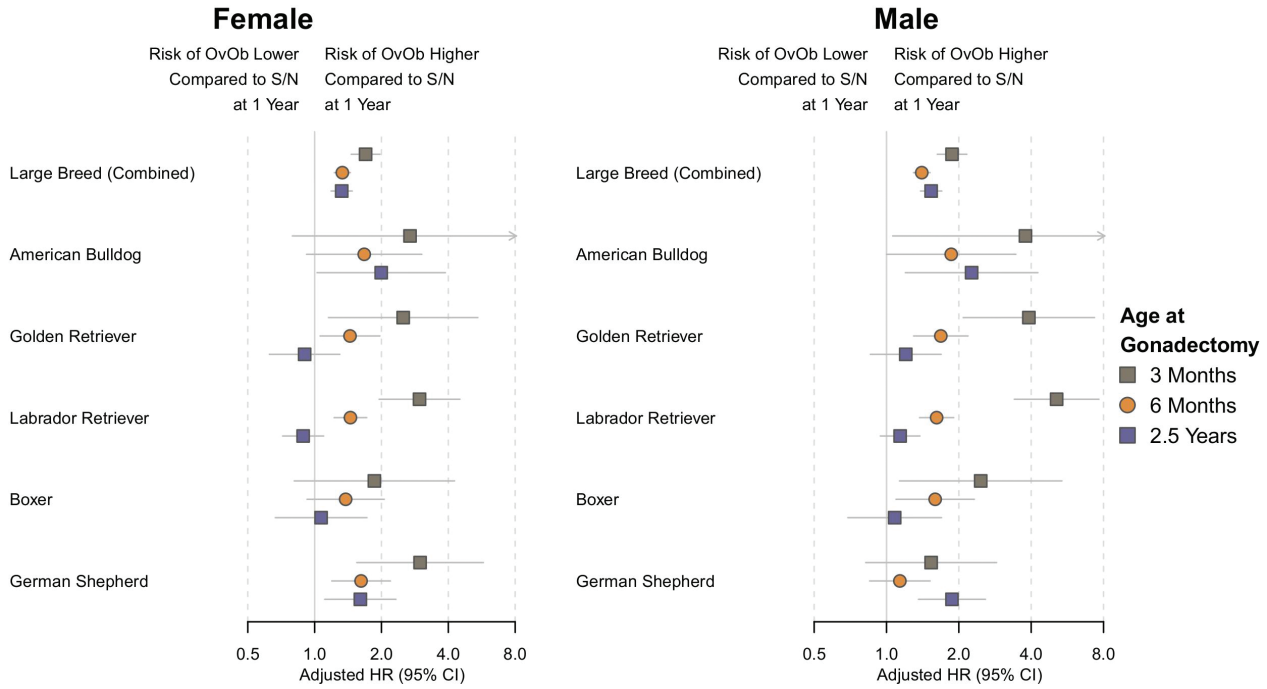

Figure 4—Age at gonadectomy and OvOb outcomes among gonadectomized dogs. Forest plots illustrate OvOb HR estimates and 95% CIs for male and female large-breed dogs gonadectomized at ages 3 months, 6 months, and 2.5 years relative to dogs of their same breed and sex gonadectomized at 1 year old.

At ages represented in the forest plots, neutered males of each breed experienced higher OvOb rates compared to intact counterparts than did spayed females compared to intact. Across the entire large-breed group, this sex-based difference was significant. There were also significant differences between male and female German Shepherd Dogs and Labrador Retrievers gonadectomized at 6 months and older compared to intact counterparts (Figure 3).

Hazard ratios for focus breeds at all time points through age 6 are in **Supplementary Figure S3**.

Effects of age at gonadectomy on OvOb among gonadectomized dogs—Among the large-breed

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cohort, gonadectomy at 3 or 6 months old was associated with a significantly higher OvOb rate than gonadectomy at 1 year for both males and females. Gonadectomy at 1 year old yielded the lowest OvOb rate, after which hazard ratios rose again for both sexes.[18]

Male Labrador Retrievers, American Bulldogs, Boxers, and Golden Retrievers followed this size group trend. For these dogs, neutering at 3 or 6 months was associated with a significantly higher OvOb rate than neutering at 1 year. This was not true for German Shepherd Dogs, for which there was no significant difference in hazard ratio between neutering at 1 year and doing so earlier. Female Golden Retrievers, Labrador Retrievers, and German Shepherd Dogs showed similar patterns as the large-breed size group in heightened OvOb rates when spayed prepubertally at 3 or 6 months. Female American Bulldogs and Boxers did not **(Figure 4)**.

The OvOb rate associated with gonadectomy at 2.5 years versus 1 year old varied by breed. This contrasted with the entire large-breed group, where the rate was higher in those gonadectomized at 2.5 years compared to 1 year for both sexes. For both males and females, gonadectomy at 2.5 years was associated with a significantly higher OvOb rate than at 1 year among American Bulldogs and German Shepherd Dogs only; there was no significant difference for Golden Retrievers, Labrador Retrievers, or Boxers (Figure 4). Results for focus breeds across all time points through age 6 are available in **Supplementary Figure S4**.

Subgroup analysis

The subgroup analysis was performed for Chihuahuas, German Shepherd Dogs, Golden Retrievers, and Labrador Retrievers that were recorded as purebred (Table 1). There were limited differences compared to the entire breed category (purebred plus mixed breed), with 3 exceptions. Compared to the entire Golden Retriever group, purebred Goldens had a more pronounced increase in OvOb rates associated with gonadectomy before 1 year, particularly in males. Labrador Retrievers showed the same results. Compared to the entire German Shepherd group, purebred females had a more pronounced increase in OvOb rates associated with gonadectomy before 1 year old **(Supplementary Figure S5)**.

Discussion

Gonadectomy offers significant benefits at both individual dog and population levels, eliminating or reducing risk of multiple adverse health outcomes and preventing unwanted births. As with many veterinary care decisions, however, there is complexity to the procedure, and associated risks are not uniform among breeds.

This research analyzed the risk of OvOb following gonadectomy, relative to remaining intact and relative to age at surgery, for popular toy-/small- and large-dog breeds. The analysis used the same framework as a foundational study[18] that evaluated relative risk associated with 5 breed size groups rather than individual breeds. Unexpected findings for toy/small and large size categories in that study prompted further exploration of OvOb among specific breeds in these 2 groups.

The 10 toy/small and 5 large breeds in this analysis constituted most dogs in those size categories; they also represented 75% of all dogs in the original study, as toy-/small-breed dogs constituted 58% of the original cohort and large-breed dogs constituted 17%.

This analysis suggests some heterogeneity, or variation, in relative risk of OvOb among individual breeds within both size groups, perhaps due in part to varied genetic lineages.[32] However, breeds differing substantially from size group peers are limited. Across individual breeds, gonadectomy generally increased OvOb rates relative to remaining intact. Among toy/small breeds, gonadectomy at 3 or 6 months posed less risk than, or was not statistically different from, gonadectomy at 1 year or older for both sexes. These data therefore did not support delaying gonadectomy in toy/small dogs to mitigate OvOb risk.

The 5 focus large breeds showed somewhat more variation than toy/small with age at gonadectomy. However, Labrador and Golden Retrievers of both sexes, female German Shepherd Dogs, male Boxers, and male American Bulldogs all had results suggesting that gonadectomy at 3 or 6 months is associated with a higher OvOb rate. In combination, they appear to influence results of the breed size group.

Heterogeneity in this breed-specific analysis includes underlying differences in general susceptibility to OvOb. Golden and Labrador Retrievers stood out among large breeds in their overall incidence of OvOb. While at least half of gonadectomized dogs of these 2 breeds had a BCS of 4 or 5, at least one-third of their intact counterparts did as well, indicating a propensity for OvOb regardless of reproductive status and a compelling need to focus on environmental, nutritional, and lifestyle factors that influence weight gain.

Among all breeds in this analysis, Pugs had the highest proportions of OvOb dogs in both intact and gonadectomized populations. Thus, while the relative OvOb rate among gonadectomized versus intact Pugs is lower than the other 14 breeds, *overall* risk is extremely high. This outcome aligns with prior research[11]; weight issues have even yielded a Pug-specific BCS chart.[33] This propensity is particularly concerning due to adverse health outcomes associated with brachycephaly and exacerbated by being overweight.[34] The need for further research on OvOb outcomes for brachycephalic dogs has been identified previously[11] and is substantiated by the present analysis.

In the overall toy-/small- and large-breed size groups, OvOb rates were higher for neutered males than spayed females across ages.[18] This was also true for all focus breeds, albeit to varying degrees. The finding that gonadectomy has a larger effect on OvOb in males than females has previously been reported in limited instances,[14,15] but differs from most studies, which found similar incidence of OvOb in both sexes.[6,7,11–13] The reason for this discrepancy is unknown.

Multiple factors have been shown to contribute to canine BCS, regardless of reproductive status, and shape

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how data about OvOb risks can be most useful to veterinarians, clients, animal shelters, and rescue organizations.

There is ample evidence that human behaviors and environmental factors shape pet OvOb outcomes through feeding practices and physical activity.[21–25] Studies within and outside the US have found a correlation between owner and dog body weight.[35,36] Studies have also found that owners often misidentify their dog's BCS, reflecting a need for more owner education about this element of canine health.[25,37]

Increasingly, genetic contributors are being identified, with data showing that a propensity for obesity is highly heritable.[8,38,39] Several studies[38,39] have demonstrated that disruption of the POMC (pro-opiomelanocortin) gene is strongly associated with high food motivation and obesity in Labrador Retrievers. Breed lineages also warrant consideration.[32]

There are constraints to these data and analysis. We could not account for factors that influence OvOb outcomes, such as feeding practices, exercise, and other environmental variables. Similarly, we did not exclude dogs with conditions that could affect OvOb risk except for hypothyroidism and hyperthyroidism[18]; a randomized controlled trial or prospective cohort study would address these questions.

Relatedly, it is uncertain how representative this sample is of the broader population. The large percentage of toy/small breeds is consistent with trends identified in the Banfield hospital network,[40,41] though higher than a national estimate.[42] The preponderance of toy/small breeds might be attributable to the urban and suburban concentration of clinics or to other demographic information not included in this data set.

This analysis relied on breed labels assigned within the medical records system. Analyses of DNA have demonstrated that breed labels assigned by owners and shelters can be inaccurate, especially for mixes.[43] Moreover, a dog's breed was assigned based on "primary" breed, of which there could be only one. During this study period, the popularity of intentional crossbreeds was rapidly increasing, particularly for Poodle mixes.[44,45] Consequently, for example, Labradoodles would have been recorded in the system as Labrador Retriever mixes.

Although breed designation was relevant for analyzing OvOb outcomes by size group,[18] it is even more pertinent for this breed-specific analysis. A subgroup analysis restricted to dogs labeled as purebred addressed possible incorrect mixed-breed categorization, focusing on breeds seen in higher numbers in shelters.[31] Findings of the subgroup analysis were consistent with those of the primary analysis, with purebred cohorts showing more pronounced increased risks of OvOb outcomes limited to 1 sex or specific ages at gonadectomy. They support the validity of breed assignments used in this study despite inherent limitations of breed designation.

Canine prepubertal and pubertal periods are not standardized or consistently defined in veterinary medical research.[46,47] Acknowledging this, the current analysis considered gonadectomy at 3 or 6 months to be prepubertal across all size groups. Given that toy/small breeds mature more quickly than larger breeds, it is possible that some of the toy/small dogs in the sample would have undergone or been undergoing puberty at 6 months old. Differences in outcomes for toy/small breeds at 3 versus 6 months were never statistically significant. Nonetheless, ages at which individual breeds reach sexual maturity should be considered when results are interpreted.

Numbers of dogs in a breed category ranged from 1,383 to 15,748; even the larger samples were significantly smaller than grouping multiple breeds by size. The subgroup analysis made sample sizes smaller still. Consequently, the level of precision (CIs in hazard ratios) varies considerably for differences identified among focus breeds. Smaller samples yield wider confidence intervals and less evidence that novel findings and deviations are real. Among breeds seen in smaller numbers and 3-month-old puppies seen for gonadectomy, levels of evidence could be quite low, which is relevant for considering practical applications of results.

Although time-to-event (survival) analyses are common in both veterinary and human public health research, they carry the potential for information bias if patients are monitored at disparate or limited frequencies. In the initial sample, intact and gonadectomized dogs had an annual median of 3 and 4 veterinary visits, respectively. With this frequency, weight gain would be identified relatively quickly and should not compromise results.

Exclusion criteria also have the potential to make results less generalizable. In this study, dogs that were not at an ideal weight (BCS = 3) at index were excluded to identify incident cases of OvOb. Although this could potentially skew results by including less obesity-prone dogs, only 3,968 individuals (about 2.5% of dogs) were excluded for this reason.[18] The analysis also did not accommodate for dogs with a temporary BCS of 4 or 5 that returned to a 3 or lower at a subsequent visit. As such, it maximized the dogs recorded as overweight or obese.

There remain unanswered questions about reasons for certain findings, including the heightened risk of developing OvOb in multiple large breeds undergoing gonadectomy at 3 and 6 months old, particularly in Golden and Labrador Retrievers; the high incidence of OvOb in most gonadectomized toy/small dogs relative to intact counterparts; the comparatively low OvOb rates in toy/small breeds gonadectomized at 3 or 6 months compared to those gonadectomized at 1 year; and the varied baseline prevalence of OvOb between breeds. The study was not designed to identify reasons for these trends, and it would be valuable to explore them further. There would also be value in further research on how alternate methods of fertility control (eg, vasectomy, ovary-sparing spay or hysterectomy, or nonsurgical fertility control options) might intersect with OvOb outcomes.

For veterinarians, these research findings can facilitate more individualized education and counseling about the risks and benefits of gonadectomy and the age at which it is performed. That said, OvOb risk is one of a constellation of considerations regarding

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optimal age for gonadectomy. As such, study findings should be one of several data points guiding decisions. The procedure's capacity to prevent unwanted litters and protect against some serious health risks is vital to these calculations.

Animal shelters and rescue organizations are tasked with balancing the health and welfare of dog populations with that of individual animals, and there are professional standards for spaying or neutering animals in the care of such shelters and organizations.[48,49] Moreover, shelters and rescue groups often have a brief window to treat dogs, and many must comply with regulations mandating spay/neuter before adoption.[50]

The study findings also have relevance for dog breeders, who should select for dogs with the lowest risk of experiencing common health problems of their breed, including obesity, and inform puppy buyers of these breed data.

Among breeds more susceptible to weight gain following gonadectomy, and particularly following prepubertal surgery, other strategies to maintain a healthy weight should be taken. Given the correlation of diet and exercise with OvOb outcomes,[21–25] OvOb risk should be addressed by making changes in these areas, especially for both dogs that are gonadectomized and breeds predisposed to OvOb regardless of reproductive status.

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Disclosures

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Supplementary Materials

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