

Long-term risks and benefits of early-age gonadectomy in dogs

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Objective—To evaluate the long-term risks and benefits of early-age gonadectomy, compared with traditional-age gonadectomy, among dogs adopted from a large animal shelter.

Design—Retrospective cohort study.

Animals—1,842 dogs.

Procedure—Dogs underwent gonadectomy and were adopted from an animal shelter before 1 year of age; follow-up was available for as long as 11 years after surgery. Adopters completed a questionnaire about their dogs' behavior and medical history. When possible, the dogs' veterinary records were reviewed. Associations between the occurrence of 56 medical and behavioral conditions and dogs' age at gonadectomy were evaluated.

Results—Among female dogs, early-age gonadectomy was associated with increased rate of cystitis and decreasing age at gonadectomy was associated with increased rate of urinary incontinence. Among male and female dogs with early-age gonadectomy, hip dysplasia, noise phobias, and sexual behaviors were increased, whereas obesity, separation anxiety, escaping behaviors, inappropriate elimination when frightened, and relinquishment for any reason were decreased.

Conclusions and Clinical Relevance—Because early-age gonadectomy appears to offer more benefits than risks for male dogs, animal shelters can safely gonadectomize male dogs at a young age and veterinary practitioners should consider recommending routine gonadectomy for client-owned male dogs before the traditional age of 6 to 8 months. For female dogs, however, increased urinary incontinence suggests that delaying gonadectomy until at least 3 months of age may be beneficial. (*J Am Vet Med Assoc* 2004; 224:380–387)

Reliable estimates of the number of healthy dogs that are euthanatized by animal shelters in the United States each year are difficult to determine, but

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Supported by a grant from the Kenneth A. Scott Charitable Trust, Cleveland, Ohio.

Presented in part at the 139th Annual American Veterinary Medical Association Convention, Nashville, Tenn, July 2002; the Tufts Animal Expo, Boston, Mass, September 2002; the American Humane Association Conference, Denver, Colo, September 2002; the Conference for Research Workers in Animal Diseases, St Louis, Mo, November 2002; and the North American Veterinary Conference, Orlando, Fla, January 2003.

The authors thank Dr. James Serpell for technical assistance.

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the number is in the millions.¹⁻⁴ In recent years, some shelters are finding that most of their unadopted dogs are adolescent or adult dogs that are relinquished because of behavior that was unacceptable to the adopter.⁵⁻⁷ These data suggest that unplanned litters of puppies must be reduced while also minimizing the frequency of preventable behavioral problems that might lead to relinquishment. Routine early-age gonadectomy of dogs has been viewed as an important step in reducing the number of dogs relinquished to shelters for 2 reasons. Comprehensive early-age gonadectomy by shelters ensures that no adopted dogs will breed and may reduce the incidence of certain medical or behavioral conditions that lead to relinquishment of adopted dogs.^{8,9}

To date, studies have established safe anesthetic protocols for early-age gonadectomy in dogs¹⁰ and revealed that gonadectomy at 7 weeks of age is associated with more rapid anesthetic recovery and fewer perioperative complications, compared with gonadectomy at 7 months of age.¹¹ One study¹² revealed no adverse medical or behavioral consequences in dogs with follow-up to 1 year of age. Another study¹³ found only 1 risk of early-age gonadectomy; dogs gonadectomized before 24 weeks of age were more likely to become infected with parvovirus, which was probably attributable to early-age exposure in 1 shelter. In a recent survey, however, 84% of practicing veterinarians perceived at least 1 risk associated with gonadectomy before 4 months of age that is not associated with gonadectomy performed at an older age, including 29% who thought that early-age gonadectomy increased the risk of at least 1 medical condition later in life.¹⁴

The purpose of the study reported here was to evaluate the long-term risks and benefits of early-age gonadectomy (before 5.5 months of age), compared with traditional-age gonadectomy, among dogs adopted from a large animal shelter.

Materials and Methods

Sampling and data collection—The sampling methods and contact procedures for this study have been described.¹⁵ In brief, study dogs were among those adopted from the Erie County, New York, Society for the Prevention of Cruelty to Animals between 1989 and 1998. During these years, this shelter was a full-service shelter with animal-control contracts. The shelter screened dogs for aggression before offering them for adoption, and aggressive dogs were euthanatized. All adopted study dogs had been gonadectomized between 6 weeks and 12 months of age and retained in the adoptive household for at least 3 months after adoption. The adopters of study dogs were contacted between January 2000 and January 2001 and asked to complete a questionnaire about their dogs.

The study questionnaire contained 95 questions grouped into 5 sections.^a Each adopter was asked whether

the dog was still in the household and, if not, what happened to the dog (section 1); the dog's behaviors and activities and, where appropriate, whether the adopter considered the behaviors a serious problem (section 2); the dog's medical history, including the dates of diagnoses for common medical problems (section 3); the adopter's household characteristics (eg, income and education; section 4); and the veterinarian who had cared for the dog and permission to review the dog's veterinary records (section 5). Because of uncertainty in pinpointing the exact time of onset of behavioral conditions in section 3, adopters were asked to identify only whether or not a behavior had occurred during the lifetime of the dog.

Methods for abstracting information from the veterinary records have been described.¹⁵ Seventy-one veterinary clinics in the region were visited, and the records of participating dogs were abstracted by use of a standardized form that contained 121 items, including the number of visits to that clinic, the dog's status on the last visit, the dog's vaccination and weight history, occurrence of medical and behavioral problems, and, for each problem, the date of first diagnosis and the number of episodes.⁴

Outcomes of interest—Fifty-six outcomes were evaluated. The following 19 outcomes were defined by combined information from the questionnaire and veterinary records: overall mortality rate from any cause, acariasis (any skin mite), aggression towards people, allergic skin disease, arthritis, balanoposthitis, cardiac disease (any etiology), diabetes mellitus, fractures, hepatic disease (any etiology), hip dysplasia, hyperactivity, hypoadrenocorticism, hypothyroidism, neoplasia, parvoviral infection, pneumonia, urinary incontinence, and vaginitis. The following 16 outcomes were defined by information from the questionnaire only: aggression towards animals, body condition (degree of obesity), destructive behaviors that persisted past 1 year of age, digging holes in the yard, escaping while owner was home, excessive barking, excitement around visitors, excessive jumping, excessive licking or chewing of skin, noise phobias, playful behaviors, relinquishment, separation anxiety, sexual behaviors, shyness, and urination in the house when frightened or excited. The following 21 outcomes were defined from the veterinary records only: abscesses, aggression towards veterinarian or veterinary staff, allergies to foods, autoimmune disorders, chronic renal failure, demodicosis, fight-bite wounds, gingivitis, hit by car, infectious tracheobronchitis (kennel cough), intervertebral disk disease, lacerations, orthopedic problems of the stifle joint (either cranial cruciate ligament tear or patellar luxation), pancreatic disorders, perivulvar dermatitis, pica, pyoderma, repeated infections, soft tissue injuries (or undiagnosed lameness), urinary tract infections (or cystitis), and urolithiasis.

For those outcomes based on combined information, the condition was considered present if indicated on either the questionnaire, veterinary record, or both. If indicated on the veterinary record, that date of diagnosis was used. If indicated on only the questionnaire (or if the veterinary record was not abstracted), then the questionnaire date was used. For analysis of overall mortality and relinquishment rates, all responses (including partial responses) were used. For all other outcomes, analysis was based on respondents completing most or all of the questionnaire.

For bone fractures, analysis was performed first with all fractures and then with fractures of only long bones (ie, humerus, radius, ulna, femur, tibia, or fibula). Body condition was assessed by asking adopters who still had their dog to compare the dog's present body shape with a series of 5 images validated by previous studies.¹⁶ The 2 heaviest images (obese and heavy dogs) were compared with clinically normal and thin dogs; very thin dogs were excluded from this analysis. To remove dogs that may have already had the con-

dition at the time of adoption, cases of canine parvovirus infection, kennel cough, and pyoderma were limited to those cases with onset after 1 year of age. Neoplastic conditions were considered malignant if the veterinarian provided a specific diagnosis, the owner described metastasis, or the dog was euthanatized for the condition. All neoplastic conditions were evaluated together and then mammary neoplasia was evaluated alone. The outcome of repeated infection was defined by 2 or more infections of the same body system as recorded in the veterinary records. Urinary incontinence was considered an outcome only for dogs that required medical treatment. For medical conditions that may have had repeated episodes (eg, tracheobronchitis), only the time until the first occurrence was used.

When evaluating behaviors for which we asked about severity of the behavior, dogs that had the condition at any time (regardless of severity) were compared with those that never had the condition. Dogs that had a severe problem with the behavior were compared with those that never had the behavior; in this comparison, dogs that had the behavior were not included if it was not considered a serious problem. A behavioral condition was considered a serious problem if the adopter considered it so or if the veterinary record indicated that the adopter had sought treatment for the condition. Dogs with aggression were first analyzed together and then dogs with aggression towards other dogs, family members, or strangers or that displayed any biting, biting children, and biting that required the person to receive medical care were examined individually. All cases of excessive barking were analyzed together and then barking or growling at visitors, barking that bothered household members, and barking that bothered neighbors were analyzed separately. Separation anxiety was considered present if indicated on the veterinary records or if the adopter reported a serious problem with 1 or more of the following sets of behaviors when the dog was left alone or about to be left alone: shaking, shivering, or trembling; vomiting or drooling; whining, barking, or howling; chewing, damaging, or destroying objects or furniture; and chewing or scratching at doors, walls, or windows. All sexual behavior was evaluated together and then separately by sexual behavior directed towards people, towards other dogs, and towards inanimate objects.

Statistical methods—Methods for multivariable analyses of the data have been described.¹⁵ In brief, incidence density rates (for medical conditions) or proportions of dogs with each outcome (for behavioral conditions) were calculated. Multivariable analyses were used to determine whether age at gonadectomy was related to occurrence of each outcome, while controlling for the effect of any potentially confounding variables. Most behavioral outcomes were evaluated with logistic regression, and most medical outcomes were analyzed by use of survival analysis (Cox proportional hazard model).

Age at gonadectomy was used on a continuous scale (from 1.4 to 12 months) when this variable had a linear relationship with the log-odds (for logistic regression) or log-hazard (for survival analysis). When this linear relationship was not present, age at gonadectomy was categorized into 2 groups. Group 1 consisted of dogs gonadectomized at < 5.5 months of age. This is the age at which many shelters routinely perform gonadectomy on dogs but at which few practicing veterinarians perform gonadectomy.¹⁴ Group 2 consisted of dogs gonadectomized at or after 5.5 months of age. This is the most common age for gonadectomy and is accepted by most practicing veterinarians.¹⁴ Most dogs have completed their vaccinations at this age also.

For all outcomes, the following variables were considered in multivariable models as possible confounders with age at gonadectomy: sex, purebred or mixed-breed, owner sur-

render or stray on admission to the shelter, whether the dog was kept in the shelter > 5 days before adoption, and presence of another dog in the household. In addition, for all behavioral outcomes and appropriate medical conditions, relinquishment for a behavioral problem (on shelter admission), frequency of exercise, and whether the dog had received any structured training outside the household were also considered in each model. For all analyses, a value of $P \leq 0.05$ was considered significant when evaluating age at gonadectomy. If the interaction between sex and age at neutering was significant with a value of $P \leq 0.1$, the model-building process was repeated separately for male and female dogs.

When making comparisons that did not require multivariable modeling, the χ^2 test was used for categorical data and the Student t test was used for normally distributed continuous data.¹⁷ Criteria for assessing causal relationships have been described.¹⁵

Results

Of 3,501 sampled dog adoptions, no current contact information could be found for 1,106 (31.6%) adopters. Two hundred ninety-six (8.5%) dogs were determined to be ineligible (in most instances because the adopter kept the dog < 3 months, the dog did not survive for ≥ 3 months, or the dog was determined to have been gonadectomized prior to admission to the shelter). Of the remaining 2,099 eligible dog adopters for whom we believed we had correct contact information, 1,659 (79.0%) completed the questionnaire, whereas 183 (8.7%) provided partial information about their dog. Among the 2,099 adopters, the dogs of responders (partial and complete) did not differ significantly (all comparisons, $P > 0.25$) from those of non-responders by age at gonadectomy, proportion that were strays, proportion that were originally relinquished for a behavioral problem, or time from adoption until contact for study. More responders adopted a female dog than did nonresponders ($P = 0.06$). For 977 (58.8%) dogs, the adopter provided consent to review veterinary records, and the records were successfully located.

Among adopters who completed the questionnaire, slightly more than half of their dogs were female and less than half had come into the shelter as strays (Table 1). Median follow-up time (ie, from adoption until questionnaire completion, the dog's death, or relinquishment) was 4.5 years (range, 0.3 to 11.3 years). Median age at end of follow-up was 5.0 years (range, 0.5 to 12.2 years); 167 dogs had follow-up past 10 years of age.

Table 1—Characteristics of 1,842 dogs (No. [%] with characteristic) adopted from a humane shelter in a study of long-term risks and benefits of early-age gonadectomy

Characteristic	Age at gonadectomy (mo)	
	< 5.5 (n = 948)	≥ 5.5 (894)
Sex		
Female	499 (52.6)	484 (54.1)
Male	449 (47.4)	410 (45.9)
Status on shelter admission ^a		
Owner surrender or impoundment	715 (77.4)	521 (60.0)
Stray	209 (22.6)	348 (40.0)

^aInformation missing for certain dogs.

Overall, 4 medical conditions and 8 behavioral conditions were significantly associated with age at gonadectomy (Table 2 and 3). None of the potential confounding variables remained in the final models. For conditions in which age at gonadectomy was categorized, the hazard ratios (HRs) and odds ratios (ORs) in the tables can be interpreted as an estimate of the relative risk of developing the condition for dogs gonadectomized at < 5.5 months of age, compared with dogs gonadectomized from ≥ 5.5 to 12 months of age. For conditions analyzed with age at gonadectomy on a con-

Table 2—Medical conditions other than obesity associated with age at gonadectomy in 1,659 dogs

Condition	Age at gonadectomy (mo)	Incidence density ^a	Hazard ratio ^b	95% CI	Overall P value
Cystitis ^c	< 5.5	1.38	2.76	1.08, 7.14	0.02
	≥ 5.5	0.43	1.0	NA	
Hip dysplasia	< 5.5	1.36	1.70	1.04, 2.78	0.03
	≥ 5.5	0.98	1.0	NA	
Urinary incontinence ^c	Continuous	1.19	1.20 ^d	1.06, 1.35	< 0.01

^aIncidence density/100 dog years at risk. ^bHazard ratio adjusted for dog's age at time of disease onset. ^cFor female dogs only. ^dHazard ratio/1-month decrease in age at gonadectomy. 95% CI = 95% Confidence interval for the hazard ratio. NA = Not applicable (referent category).

Table 3—Behavioral conditions associated with age at gonadectomy in 1,659 dogs

Behavior	Age at gonadectomy (mo)	Dogs with behavior (%)	Odds ratio	95% CI	Overall P value
Aggression towards household members ^a	< 5.5	29.0	1.32	1.05, 2.10	0.02
	≥ 5.5	21.5	1.0	NA	
Barking that bothered household members ^{a,b}	Continuous	34.2	1.08 ^c	1.02, 1.12	< 0.01
Barking or growling at visitors ^{a,b}	Continuous	65.4	1.08 ^c	1.02, 1.13	< 0.01
Escaping from home (serious problem)	Continuous	9.6	0.93 ^c	0.87, 0.98	< 0.01
Noise phobia ^b	Continuous	52.6	1.04 ^c	1.01, 1.08	< 0.01
Separation anxiety	< 5.5	14.2	0.72	0.55, 0.94	0.02
	≥ 5.5	18.7	1.0	NA	
Sexual behaviors ^b	Continuous	27.3	1.05 ^c	1.01, 1.09	< 0.01
Urination when frightened ^c	< 5.5	9.4	0.74	0.54, 1.01	0.06
	≥ 5.5	12.3	1.0	NA	

^aMale dogs only. ^bNot significant ($P > 0.05$) when considered a serious problem. ^cOdds ratio/1-month decrease in age at gonadectomy. See Table 2 for remainder of key.

tinuous scale, the OR or HR can be interpreted as the change in risk for each month earlier that the dogs were gonadectomized. In Tables 2 and 3, an OR or HR < 1.0 indicates that the condition decreased with early-age gonadectomy, while an OR or HR > 1.0 indicated that the condition increased with early-age gonadectomy.

The incidence densities can be converted to cumulative incidences by use of the formula $1 - \exp(-t[ID/100])$, where t is the number of years of follow-up, ID is the incidence density/100 dog years from Table 2, and \exp is the inverse of the natural logarithm.¹⁸ Use of this formula assumes that the risk of disease was constant throughout the dogs' lives and that there were no competing risks (ie, no other diseases caused death during the time of observation).

Overall mortality rate was not associated with age at gonadectomy, although overall relinquishment was lowest among dogs gonadectomized before 5.5 months of age. Among dogs gonadectomized before 5.5 months of age, 7.5% were relinquished (after the first 3 months), whereas among those gonadectomized ≥ 5.5 months, 10.4% were relinquished (age-adjusted HR, 0.65; $P = 0.01$).

Medical outcomes—A significant relationship with age at gonadectomy was found for cystitis, hip dysplasia, and urinary incontinence (Table 2). In addition, the prevalence of overweight body condition declined with decreasing age at gonadectomy (OR/1-month decrease in age at gonadectomy, 0.94; $P = 0.04$). Overall, 26.9% of dogs still in the adoptive household were overweight at the time of the study.

Among all dogs, early-age gonadectomy was associated with significantly increased incidence of hip dysplasia. Among dogs gonadectomized before 5.5 months of age, 6.7% developed hip dysplasia, whereas among those gonadectomized at ≥ 5.5 months of age, 4.7% developed the condition (difference in proportions, $P = 0.10$). The HR had a lower P value ($P = 0.03$) because the early-age gonadectomized dogs with hip dysplasia received the diagnosis at an earlier age (median age, 33 months) than the older gonadectomized dogs with hip dysplasia (median age, 44 months); thus, the rate of development was faster. Only 54% of the dogs with a diagnosis of hip dysplasia were reported to also have arthritis or joint problems requiring veterinary attention. The dogs with hip dysplasia that had been gonadectomized at ≥ 5.5 months of age were 3 times as likely to be euthanatized for the condition as those with hip dysplasia and gonadectomized before 5.5 months of age ($P = 0.02$).

For cystitis and urinary incontinence, there was significant interaction between age at gonadectomy and sex, suggesting different risks between males and females. Incidence of cystitis was significantly higher among females that were gonadectomized before 5.5 months of age. Four female dogs had 2 episodes of cystitis, but none had > 2 episodes, so the condition was not chronic for any dogs. Among female dogs, decreasing age at gonadectomy on a continuous scale was associated with increasing incidence of urinary incontinence that required medical treatment. Females gonadectomized before 3 months of age appeared to be at highest risk, compared with those

gonadectomized at ≥ 3 months of age (HR, 3.46; $P < 0.001$). The corresponding projected cumulative incidence during the first 6 years of life (when most cases of urinary incontinence were diagnosed) was 12.9% for female dogs gonadectomized before 3 months of age and 5.0% for female dogs gonadectomized at ≥ 3 months of age. None of the 49 female dogs with urinary incontinence, however, were relinquished to a shelter or given to another owner for any reason, and their rate of euthanasia was not higher than the overall rate.

Among all dogs, early-age gonadectomy was associated with significantly reduced incidence of pneumonia. When the questionnaire and veterinary information were compared, however, many cases identified as pneumonia by owners appeared to have been kennel cough diagnosed in the periadoption period. When the cases of pneumonia as reported by owners were restricted to those with onset after 1 year of age or those confirmed by veterinary records, the association with age at gonadectomy was no longer significant.

For all cases of parvoviral enteritis, dogs gonadectomized before 5.5 months of age had significantly greater incidence. Approximately one-third of cases of parvoviral enteritis were diagnosed within the first week after adoption and probably resulted from exposure to the virus before gonadectomy and adoption. When cases were restricted to those with onset after 1 year of age or those with onset after the periadoption period, the association disappeared.

Behavioral outcomes—Seven behavioral outcomes were significantly associated with age at gonadectomy (Table 3). One other outcome, urination when frightened, had a value of $P = 0.06$. Among male and female dogs, decreasing age at gonadectomy was associated with increased rates of noise phobias and sexual behaviors, whereas escaping considered a serious problem declined with decreasing age at gonadectomy. Separation anxiety and urination in the house when frightened were less frequent among dogs gonadectomized before 5.5 months of age. Urination when frightened was strongly associated with separation anxiety; dogs with separation anxiety were approximately twice as likely as other dogs to also urinate in the house when frightened ($P < 0.01$). For 3 other behaviors (aggression towards family member, barking or growling at visitors, and excessive barking that bothered a household member), a significant interaction was detected between age at gonadectomy and sex, suggesting different risks between males and females. In analyses stratified by sex, these 3 behaviors were significantly associated with age at gonadectomy for males but not females. Aggression towards family members was more frequent among male dogs gonadectomized before 5.5 months of age, and decreasing age at gonadectomy was associated with higher rates of barking or growling at visitors and excessive barking that bothered household members. These 3 behaviors were also significantly ($P < 0.01$) associated with each other. For dogs that did not have aggression, there was no association between age at gonadectomy and excessive barking.

When analysis was restricted to dogs with a serious problem, barking and growling at visitors, barking that bothered household members, noise phobias, sex-

ual behaviors, and urination when frightened were no longer significantly associated with age at gonadectomy. In contrast, decreasing age at gonadectomy was associated with lower rates of escaping from home considered a serious problem, but the association was not significant when all cases of escaping were analyzed. Among the 8 behavioral outcomes associated with age at gonadectomy, 4 were associated with increased risk of relinquishment: aggression towards family members, escaping considered a serious problem, separation anxiety, and urination when frightened. Only 1 behavior, aggression towards family members, was associated with increased risk of euthanasia.

Outcomes unrelated to age at gonadectomy—For the 43 other outcomes studied, no association was found between age at gonadectomy and the outcome. Nine of these outcomes were rare in our study (< 10 dogs with the condition), including autoimmune disorders, chronic renal failure, diabetes mellitus, hepatic disease, mammary neoplasia, pancreatic disorders, parvoviral enteritis with onset after 1 year of age, patellar luxation, and urolithiasis. Therefore, the statistical power for finding any subtle difference between groups for these outcomes was low. Nevertheless, for any dog gonadectomized before 1 year of age, the risk of any of these conditions developing (before the age of 11) appeared to be low. The upper 95% **confidence interval (CI)** of the expected cumulative incidences for any of these conditions in the first 11 years of life was < 1.5% (ie, < 1.5% of dogs would be expected to develop any of these conditions).

Discussion

No association was found between frequency of the outcome and age at gonadectomy for most of the medical and behavioral conditions evaluated in this study. This was true even for many conditions speculated to be increased with early-age gonadectomy, such as diabetes mellitus and immune deficiency. Diabetes mellitus appears to be rare among gonadectomized dogs, at least during the first 11 years of life. In our study, dogs gonadectomized before 5.5 months of age were not significantly more likely than dogs gonadectomized at ≥ 5.5 months of age to have any conditions that might be associated with long-term immune suppression, including parvoviral enteritis with onset after 1 year of age, demodicosis, infectious tracheobronchitis, or repeated infections of the same body system. One other study¹³ that followed 269 dogs adopted from shelters for a median of 48 months found that gonadectomy before 5.5 months of age was associated with increased incidence of parvoviral enteritis. In that study, as with ours, however, the increased rate of parvovirus infection probably represented increased susceptibility of dogs < 6 months of age during the peradooption period and not long-term immune suppression or long-term susceptibility as a result of early-age gonadectomy.

In our study, age at gonadectomy was not associated with frequency of long-bone fractures or arthritis. The incidence of hip dysplasia, however, was increased among the early-age gonadectomized dogs, although

the diagnosis of hip dysplasia was reported with signs such as arthritis in only a portion of those dogs. It is possible that the increase in bone length that results from early-age gonadectomy¹² results in changes in joint conformation, which could lead to a diagnosis of hip dysplasia. The early-age gonadectomized dogs in our study received a diagnosis of hip dysplasia at an earlier age than dogs gonadectomized from 5.5 to 12 months of age. Initially, we suspected that the earlier age at diagnosis might invalidate some of the hip dysplasia cases in the early-age gonadectomized dogs because results of other studies^{10,20} suggest that diagnosis at a young age can be unreliable. The difference in median age of diagnosis between groups (33 vs 44 months), however, was small, and most diagnoses in both age groups were made after the dogs were at least 12 months old. Therefore, the increased rate of hip dysplasia among the early-age gonadectomized dogs in our study cannot be fully attributed to a false-positive diagnosis because of the age at which they were evaluated. The lower rate of euthanasia among early-age gonadectomized dogs with hip dysplasia suggests that early-age gonadectomy may be associated with a less severe form of hip dysplasia. Whether this association is real or represents a type-I error is unclear. Also, a rigorous set of diagnostic criteria for hip dysplasia was not used, which probably resulted in misclassification of some dogs. In contrast to our results, Howe et al¹³ found no association between age at gonadectomy and the frequency of musculoskeletal problems.

Gonadectomy in female dogs has been repeatedly associated with increased risk of acquired urinary incontinence,²¹⁻²⁴ but studies^{13,25,26} have obtained conflicting results about the exact biological mechanism involved and whether early-age gonadectomy increases the risk more than gonadectomy at a traditional age. Howe et al¹³ found no association between early-age gonadectomy and incidence of urinary incontinence, but only 3 dogs in that study (among 153 females) developed the condition. In contrast, Thrusfield et al²⁵ found increased incidence of urinary incontinence among female dogs gonadectomized before their first estrous cycle, but that study had a low response rate, was potentially biased, and did not evaluate age at gonadectomy directly; the association was of borderline significance. Nevertheless, the overall incidence rate for urinary incontinence among gonadectomized female dogs (1.74 cases/100 dog years) was consistent with our estimate (1.19 cases/100 dog years). A Swiss study²⁶ concluded that spaying before the first estrous cycle decreased the overall incidence of urinary incontinence. The methodology was questionable, however, because the authors reported data only from dogs spayed before their first estrous cycle and made comparisons with dogs spayed after the first estrous cycle from another study²³ in which the incidence of urinary incontinence was quite high.

Acquired urinary incontinence can be a lifelong condition requiring daily medication,^{22,23} and problems with urination in the house are common reasons for relinquishment of dogs to shelters.^{6,27} Development of urinary incontinence in the dogs in our study, however, did not appear to be severe enough to cause the

adopters to relinquish their dogs or have them euthanatized at increased rates. Perhaps these dogs were retained in the household because the condition developed several years after gonadectomy when the adopters had already made a strong bond with their dogs (unlike urination that is caused by delayed house-breaking as an adolescent), or perhaps early-age gonadectomy is associated with a less severe form of urinary incontinence. Cystitis was also more common among the early-age gonadectomized female dogs, but none of those dogs had > 2 episodes of cystitis, so this does not appear to reflect a long-term susceptibility to the condition.

The proportion of overweight dogs was lowest among the early-age gonadectomized dogs in our study, in contrast to what had been suspected by some veterinarians.^{9,28,29} Prevention of obesity is important because of its association with increased risk of other medical problems such as musculoskeletal disorders.¹⁶ Analysis of overweight body condition was limited, however, to only those dogs still alive and retained in the adoptive household at the time of the study (70% of dogs with completed questionnaires). Therefore, we would not have identified any dogs with obesity that had led to relinquishment, euthanasia, or a fatal medical condition.

Although aggression and excessive barking were increased with early-age gonadectomy among male dogs, these associations were probably an artifact of the shelter's screening procedure for aggression and not a result of early-age gonadectomy. Dogs that had aggression on admission to the shelter, particularly those > 6 months of age, were euthanatized. Therefore, many of the late-age gonadectomized dogs that were prone to aggressive behavior were removed by the screening procedure, making it appear that the late-age gonadectomized dogs were less likely to have aggression. Because aggression and barking behaviors were highly correlated, removing older dogs that were prone to aggression also removed older dogs prone to excessive barking. Two other studies^{30,31} have revealed a decrease in aggression among male dogs after castration, so it seems likely that our association is attributable to differential screening of different age groups. Results of a previous study³² suggested that aggression in female dogs increases after gonadectomy, but we did not confirm this result.

Two previous studies^{30,31} determined that gonadectomy leads to a decrease in roaming behaviors. Therefore, it seems reasonable that early-age gonadectomy could lead to a decrease in roaming, which might explain the lower frequency of escaping behaviors found among the early-age gonadectomized dogs in our study.

Noise phobias have not previously been associated with sex, neuter status, or age at gonadectomy.^{13,33} One explanation for our findings is that the noise phobias were present in the early-age gonadectomized dogs because of anxiety in the periadoption period. With our study design, we could not determine whether the noise phobias were long-term effects of early-age gonadectomy or temporary behaviors associated with being adopted at a young age. Data on the age of onset

of noise phobias are mixed; in 1 study,³³ 41% of dogs had onset before 1 year of age, whereas a review study³⁴ concluded that onset was almost exclusively after 1 year of age.

A study³⁵ of dogs evaluated at a referral behavior clinic suggested that gonadectomized dogs and dogs adopted from a shelter were more likely to have separation anxiety, and another study³⁶ found that dogs with separation anxiety adopted from shelters were less likely to respond to treatment. The diagnosis of separation anxiety has not been associated with age of acquisition,³⁵ although dogs acquired after 6 months of age with separation anxiety were found to be less likely to respond to treatment.³⁶ This second finding suggests that the greater incidence we found with gonadectomy at ≥ 5.5 months of age may be attributable to adoption (rather than gonadectomy) in that age range. The correlation between urination when frightened and separation anxiety suggests that these conditions may share a common mechanism for development. Other studies^{35,37} have found correlations between separation anxiety and other anxious behaviors.

The greater incidence in sexual behaviors among early-age gonadectomized dogs was surprising. The sexual behaviors were not correlated with aggression, so this difference could not be explained simply by the shelter's screening procedures for aggression. We are not aware of any biological mechanism that would explain this association. It is possible that some of the playful behaviors of the puppies were interpreted as sexual behaviors by the adopters. Only 2.5% of adopters thought that their dogs ever had a serious problem with sexual behaviors.

Because some behavioral conditions were less frequent with early-age gonadectomy but others were more frequent, we examined whether any of these conditions were associated with relinquishment or euthanasia. Not surprisingly, aggression towards family members among male dogs was associated with increased relinquishment and euthanasia rates. As discussed, these results have limited applicability because of the shelter's screening policy for aggression. Escaping considered a serious problem and urination when frightened were also associated with increased risk of relinquishment. These results were consistent with findings in which both escaping behavior and house soiling were common reasons for relinquishment.⁶ Risk of relinquishment was greater among dogs with separation anxiety, and separation anxiety is known to be associated with a high euthanasia and relinquishment rate in general.³⁶ The association between urination when frightened and relinquishment may have occurred because affected dogs were also more likely to have separation anxiety and not because of urination per se. Excessive barking among males, noise phobias, and sexual behaviors were not associated with relinquishment in our study. Among these, only excessive barking was reported as a common reason for relinquishment in the other study.⁶ Thus, other than aggression and excessive barking among males, which could not be evaluated well with our study, all behavioral conditions with serious con-

sequences were less frequent among the early-age gonadectomized dogs.

Our study provides several improvements over previous studies of early-age gonadectomy, including a much larger sample size, longer follow-up times, and verification of medical and behavioral conditions with veterinary records for a large portion of the dogs. Nevertheless, as with any epidemiologic study, biases are possible. The dogs of adopters for whom we found no contact information or who did not respond to our study, for example, could have differed systematically from the dogs of contacted adopters. It is not expected, however, that the likelihood of the adopters' moving would be related to the health or behavior of their dogs. Because of the retrospective data collection, it was not possible to collect veterinary information for some dogs that died early in life and whose veterinary records were subsequently destroyed. Veterinarians and adopters were usually aware of a dog's age at gonadectomy, so prior beliefs about the effects of early-age gonadectomy could have led to differential diagnostic testing or differential care-seeking.

For our study, some dogs were undoubtedly misclassified as to the presence or absence of their conditions. We have no reason to believe, however, that dogs in the 2 groups were differentially misclassified, suggesting that associations may have been underestimated or missed because of misclassification (rather than overestimated).³⁸ Because the diagnostic criteria for medical conditions undoubtedly varied between veterinarians, the incidence rates in Table 2 should be viewed as only very rough estimates of rates that would be found with standardized criteria.

Our study could not have detected conditions with peak onset after 11 years of age. For these conditions, however, it is difficult to suggest plausible biological mechanisms that would support a cause-and-effect relationship between gonadectomy at an early age and development of the outcome. Similarly, this study could not have detected conditions that would have led to relinquishment, euthanasia, or death within the first 3 months after surgery. For extremely rare conditions, our study did not have the statistical power to detect subtle differences between the groups.

With the approximately 60 comparisons made in the analyses for this study, some of our significant results are likely to be attributable to type-I errors. Because of the limited evidence to support a causal relationship between age at gonadectomy and noise phobias, separation anxiety, or sexual behaviors, these associations seem likely to be a consequence of type-I errors.

For most behavioral and medical conditions, we found no difference between early-age gonadectomized and traditional-age gonadectomized dogs. On the basis of our results, we see no reason that animal shelters or practicing veterinarians should delay gonadectomy of male puppies because of concerns about long-term health or behavior. Gonadectomy of male dogs at 4 to 5 months of age rather than waiting until after 6 months of age may be better for the long-term health and well-being of the dogs and would eliminate the possibility of accidental matings. Another study¹¹

found that gonadectomy at this age was faster and had fewer perioperative complications; it is also likely less expensive.

For female dogs, the best time to neuter is more difficult to determine. Because urinary incontinence was greater among puppies gonadectomized before 3 months of age and incontinence can be a lifelong condition requiring ongoing treatment, it is reasonable to conclude that female dogs should not be gonadectomized until at least 3 to 4 months of age. This may be particularly prudent for a shelter that does not have an excess of puppies and is focused on reducing medical and behavioral conditions that could lead to relinquishment of adolescent and adult dogs. Conversely, for shelters with excess puppies, the advantages of gonadectomy of all dogs before adoption may outweigh the risk of urinary incontinence. For veterinary practitioners, the ideal time for gonadectomy of female dogs is probably after the completion of vaccinations at 4 to 5 months but before the dog's first estrous cycle, after which there is higher risk for mammary cancer and unplanned litters.

^aThe study questionnaire and veterinary abstract form are available from the first author.

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