Fifteen-year surveillance of pathological findings associated with death or euthanasia in search-and-rescue dogs deployed to the September 11, 2001, terrorist attack sites

Cynthia M. Otto DVM, PhD

Elizabeth Hare PhD

John P. Buchweitz PhD

Kathleen M. Kelsey MS, MBA

Scott D. Fitzgerald DVM, PhD

From the Penn Vet Working Dog Center (Otto, Hare, Kelsey) and Department of Clinical Sciences and Advanced Medicine (Otto), School of Veterinary Medicine, University of Pennsylvania, Philadelphia, PA 19104; Dog Genetics LLC, Astoria, NY 11102 (Hare); and Department of Pathobiology and Diagnostic Investigation (Buchweitz) and Diagnostic Center for Population and Animal Health (Fitzgerald), College of Veterinary Medicine, Michigan State University, East Lansing, MI 48824.

Address correspondence to Dr. Otto (cmotto@vet.upenn.edu).

OBJECTIVE

To compare the cause of death (COD; whether by natural death or euthanasia for poor quality of life caused by a primary pathological condition) between search-and-rescue (SAR) dogs deployed to the World Trade Center, Pentagon, or Fresh Kills Landfill on Staten Island following the 9/11 terrorist attacks and SAR dogs that were not deployed to these sites.

ANIMALS

95 deployed SAR dogs (exposed dogs) and 55 nondeployed SAR dogs (unexposed dogs).

PROCEDURES

Following natural death or euthanasia, 63 dogs (44 exposed and 19 unexposed) underwent a necropsy examination. For the remaining 87 dogs, the COD was categorized on the basis of information obtained from medical records or personal communications.

RESULTS

The median age of death was 12.8 years for exposed dogs and 12.7 years for unexposed dogs. The COD was not impacted by deployment status. In the 150 exposed and unexposed dogs, degenerative conditions were the most common COD followed by neoplasia. Respiratory disease was infrequent (overall, 7 [4.7%] dogs); 4 of 5 cases of pulmonary neoplasia occurred in unexposed dogs. However, in dogs that underwent necropsy, pulmonary particulates were reported significantly more often in exposed dogs (42/44 [95%]), compared with unexposed dogs (12/19 [63.2%]).

CONCLUSIONS AND CLINICAL RELEVANCE

No difference was found in the COD on the basis of disease category and organ system involved between exposed and unexposed SAR dogs. The long life spans and frequency of death attributed to degenerative causes (ie, age-related causes) suggested that the risk of long-term adverse health effects in this population of SAR dogs was low. (*J Am Vet Med Assoc* 2020;257:734–743)

Search-and-rescue dogs play an invaluable role by working with human first responders to help locate victims of natural or man-made catastrophic events. Handlers of SAR dogs invest countless hours and considerable resources in the initial training, certification, and ongoing training of these elite dogs.[1] Although several studies[2–5] have reported the hazards associated with disaster response, to our knowledge, no study exists on the long-term occupational hazards for SAR dogs.

On September 11, 2001, a coordinated terrorist attack was launched on the World Trade Center in New York City and the Pentagon Building in Washington, DC. These attacks led to massive destruction and a high toll in the loss of human life, numbering > 3,000 people within the buildings at the time of the attacks and including over 400 firefighters, paramedics, and police officers who responded to the incidents.[6] These fatalities were only the tip of the iceberg, as another 10,000 people were treated for injuries resulting from the attacks.[7] The first responders, including the dogs, were exposed to products of combustion, smoke, and thick layers of dust and ash covering everything.[8] The World Trade Center Health Registry was developed to monitor the short-term and long-term physical and mental health effects on the human first responders and the local community following the September 11, 2001, terrorist attacks,[9] whereas 2 long-term surveillance studies followed the canine teams.[4,10,11]

Although none of the dogs studied were on-site at the time of the attacks, SAR teams began to arrive within hours to days after the initial incident.[4] The

ABBREVIATIONS

AKC	American Kennel Club
COD	Cause of death
IQR	Interquartile (25th to 75th percentile) range
SAR	Search-and-rescue

SAR dogs were exposed to the smoke, ash, dust, and chemicals through inhalation (the primary health concern), dermal absorption, oral ingestion, and ocular exposure, with little protection other than their natural defenses. Classes of potential toxicants to which the dogs may have been exposed included the following: hydrocarbons, polychlorinated biphenyls, heavy metals, gases, alkalis, and asbestos.[12] Following the SAR teams' response to the terrorist bombing of the Alfred P. Murrah Federal Building in Oklahoma City on April 19, 1995, rumors of high rates of SAR dog illness and death circulated. No surveillance or credible scientific studies were ever published documenting any long-term effect of the Oklahoma City response on the dogs' health or behavior. This knowledge gap led to the plan to monitor the SAR dogs that were deployed to the terrorist attack sites of September 11, 2001, and to follow their health, longevity, and eventual COD in an orderly scientific manner that could answer concerns about the risks these dogs faced. Between October 2001 and June 2002, 95 deployed SAR dogs and 55 nondeployed SAR dogs were enrolled in a longitudinal monitoring study.[4] At the commencement of this study in 2001, most responding dog teams participating in this longitudinal surveillance study were members of the Federal Emergency Management Agency Urban SAR teams.[5] Police departments, regional search teams, and recovery teams were also vital to the effort. Dog cohorts were monitored, annual health data were collected, and final necropsies were performed after death, including examination of the tissue both histologically and toxicologically.[4,11,13]

After the first year, exposed dogs (those deployed to the World Trade Center and the Pentagon) had significantly higher blood globulins and bilirubin concentrations and alkaline phosphatase activities, compared with results for unexposed dogs.[4] It is unknown whether these findings were a result of exposure to hazards at the response sites. An interim report of the 5-year mortality and morbidity rates documented that the blood values did not remain elevated and reported that neither the age at death nor the cancer incidence was different between unexposed and exposed dogs.[11] On June 6, 2016, the last surviving 9/11 SAR dog and study participant, a 16-year 9-month-old Golden Retriever, was euthanized.[14] The complete data set of the 9/11 SAR dogs was compiled to establish the COD, incidence of specific diseases, and neoplasms in these dogs.

The purpose of the study reported here was to compare the COD (whether it be a natural death or by euthanasia for poor quality of life caused by a primary pathological condition) between SAR dogs deployed to the World Trade Center, Pentagon, or Fresh Kills Landfill on Staten Island following the 9/11 terrorist attacks and SAR dogs that were not deployed to these sites. On the basis of the high incidence of respiratory disease (eg, chronic sinusitis, allergic airway disease, and interstitial lung disease), gastroesophageal reflux, hematologic cancers, thyroid cancer, and solid tumors in the human first responders,[15,16] it was anticipated that the exposed SAR dogs would have a higher incidence of respiratory and gastrointestinal disease as well as neoplasia, compared with unexposed SAR dogs.

Materials and Methods

Study enrollment and selection of SAR dogs

As previously described,[4] between October 2001 and June 2002, 2 cohorts of SAR dog handlers were contacted to enroll their dogs in an Institutional Animal Care and Use Committee–approved health and behavioral surveillance study. The exposed cohort consisted of dogs that were deployed to the World Trade Center, Fresh Kills Landfill on Staten Island, and Pentagon disaster sites. Dogs that were not deployed, but had similar background and training, constituted the unexposed cohort.

Postmortem evaluation

As previously described,[13] at the time of each dog's death, whether naturally or by euthanasia for poor quality of life, handlers were requested to have a standard set of tissue samples collected at necropsy by their veterinarian and submitted to the Diagnostic Center for Population and Animal Health, Michigan State University, for pathological evaluation. After sample collection, the remains were cremated for return to the handler. If handlers declined the necropsy, medical records from their veterinarian were requested to document the COD. If handlers did not provide medical records, then the COD was determined on the basis of the handler's description of events leading to the dog's death. In some cases, information was provided by another handler or found in a news report. The reliability of the COD data was coded on the sum of both the source and confidence of the data. For the source of data, a value of 0 was assigned if no information was provided, 1 if the source was a third party, 2 if the source was the handler, 3 if the source was the dog's veterinarian, and 4 if the source was the veterinarian performing the necropsy. A value of 0 was assigned if no information was provided, 1 if the information was obtained indirectly, 2 if the information was obtained from the handler, 3 if information was obtained from the medical record, and 4 if information was obtained from a necropsy report.

For dogs undergoing necropsy, veterinarians were provided a description of the tissue samples to be collected and the procedures to be followed. Tissue samples were fixed in neutral-buffered 10% formalin for histologic examination and included the following: brain, tonsil, trachea, lungs (all lobes), thyroid, parathyroid, heart (right and left ventricular wall), spleen, mesenteric lymph node, adrenal gland, pancreas, liver, stomach, duodenum, jejunum, ileum, colon, kidney, urinary bladder, bone marrow (from femur), skeletal muscle, any tumors, and ovary or testis if dog was sexually intact. All tissue samples were sent to the Diagnostic Center for Population and Animal Health, where a board-certified veterinary pathologist, blinded to the dog's deployment status, histologically examined all formalin-fixed tissue samples after sectioning and routine H&E staining. Additional specialized stains that included Gram stain or immunohistochemical staining were ordered at the pathologist's discretion. A full histopathologic report was issued for each dog, and a COD as well as morphological diagnoses for each abnormal tissue and tumor were formulated and entered into the database. In addition, because of the concerns of pulmonary damage associated with the disaster, the lungs were examined for evidence of airborne contaminants such as carbon pigments (anthracosis) or refractile foreign particulate matter and scores of none (0), mild (1), moderate (2) or marked (3) were submitted on the basis of relative amounts seen.

Because of concerns of potential environmental toxicants[12] present after the 9/11 attacks, toxicological testing was performed on liver, kidney, and adipose tissue samples that were collected and submitted to the Diagnostic Center for Population and Animal Health. Toxicological analyses included heavy metal screening of both liver and kidney tissue samples by use of inductively coupled plasma-atomic emission spectroscopy[17]; principal minerals evaluated included arsenic, cadmium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, selenium, thallium, and zinc. Organic compound screening was performed on liver samples by use of gas chromatography coupled with mass spectrometry,[18] which screened for a wide variety of industrial compounds, pesticides, herbicides, household chemicals, and pharmaceuticals. Polychlorinated biphenyls analysis was performed on adipose tissue samples by gas chromatography, which included the use of an electron capture detector.[19] All detected toxicants were recorded in the database.

Database and categorical data

A master spreadsheet was maintained that contained information for each exposed and unexposed SAR dog, including age, sex, date of death, deployment site (ie, World Trade Center, Pentagon, Fresh Kills Landfill, or none), duration of deployment, presence at the World Trade Center during the first 48 hours of the emergency response, the COD, primary pathological findings (including disease category and organ system involved), incidental pathological findings, pulmonary pathological findings, and toxicants detected. Categories of disease included the following: accidental (eg, vehicular trauma, foreign body ingestion), degenerative (eg, handler reported old age changes, severe osteoarthritis or impaired mobility, renal failure, cardiomyopathy, and degenerative myelopathy), inflammatory (eg, nephritis, gastroenteritis, pancreatitis, and gastric dilatation–volvulus), neoplastic, and proliferative (eg, prostatic hyperplasia). By use of the approach described by Fleming et al,[20] all dogs were assigned a category of disease and a secondary classification of the organ system primarily affected on the basis of the available data. Organ systems included the following: cardiovascular, CNS, endocrine, gastrointestinal, lymphoid, musculoskeletal, respiratory, and urogenital. All categorical assignments were made by a board-certified veterinary pathologist (SDF) for the dogs on the basis of the necropsy data. A veterinarian (CMO) board certified in veterinary emergency and critical care and veterinary sports medicine and rehabilitation assigned categories to the remaining dogs and reviewed all of the cases for consistency. Categories of disease and affected organ systems in the deployed SAR dogs were compared with nonexposed SAR dogs and the general dog population examined at veterinary teaching hospitals as reported by Fleming et al.[20] Categories of disease that were reported[20] for the general dog population that were not assigned for the SAR dogs (ie, infectious, toxic, congenital, metabolic, and vascular) and the proliferative category that was assigned for the SAR dogs but not the general dog population were combined into a category referred to as other.

Cause of death was assigned a confidence score on the basis of the source of the information as follows: a necropsy report issued by the Diagnostic Center for Population and Animal Health (COD confidence score of 4), a report or records from the primary veterinarian (score of 3), communication with the handler (score of 2), and a third-party report (score of 1). In addition, the confidence in the diagnosis was scored on the basis of source of information as follows: necropsy report (diagnosis confidence score of 4), histologic reports for biopsy samples (score of 3), medical records that include laboratory reports (eg, hematology, serum biochemistry, cytology; score of 2), and medical records without laboratory reports (score of 1). For reports of dogs with cancer, it was noted whether the cancer was considered the COD, if they died with cancer but it was not considered the COD, or whether cancer was an incidental finding on necropsy.

Date of death was reported as the exact day, month, and year when available or the approximate day, month, and year on the basis of handler or SAR team member's recollection. Results were coded on the basis of accurate date or estimated date of death. Dogs for which no date of death information was available were considered lost to follow-up. Dates of death were obtained from medical records, communication with the handler, search of SAR organization or insurance company records, or social media.

Statistical analysis

Descriptive statistics were calculated by use of an open-source statistical software package[a] and a commercial statistical software package.[b]

Scores for the quality of the data used in assigning the COD were compared between exposed and unexposed dogs by use of the Mann-Whitney rank sum test.

Cox proportional hazards models[c] were used to examine the relationship between survival time and deployment status. The first model compared the unexposed and exposed dogs, including age on September 11, 2001, with the deployment status, number of days deployed, and interaction of age on September 11, 2001, with deployment status as covariates; the log-rank test score was 81.5 with 4 *df* ($P < 0.001$) for this model. The second model compared the unexposed dogs and exposed dogs at each deployment location (World Trade Center, Pentagon, or Fresh Kills Landfill), including age on September 11, 2001, location, number of days deployed, and the interaction of age on September 11, 2001, with location as covariates; the log-rank test score was 86.2 with 8 *df* ($P < 0.001$) for this model. The proportional hazards assumption was tested with Schoenfeld residuals.[d]

Tests for differences in distribution between categorical variables (eg, anthracosis and particulate scores) and deployment location groups were performed by use of the Fisher exact test[b] or Pearson χ^2 test.[e] Because the Pearson χ^2 test requires cells with ≥ 5 observations, dog breeds with small numbers were eliminated from the data set, leaving Border Collies, German Shepherd Dogs, Golden Retrievers, and Labrador Retrievers as well as mixed-breed dogs. A value of $\alpha = 0.05$ was used for these analyses.

Risk ratios for cancer were calculated by use of the unconditional maximum likelihod.[f] Logistic regression was used to test whether there was an association between blood globulin concentration, alkaline phosphatase activity, and total bilirubin concentration and death from cancer. Backward elimination of explanatory variables was performed.[a] The full model included deployment group, blood globulin concentration, alkaline phosphatase activity, total bilirubin concentration, sex, age, breed, number of days deployed, and 3 categories of location during specific days of deployment. Terms with values of $P < 0.05$ were included in the subsequent model. Quantitative predictors were tested for linearity in the log odds of fatal cancer.[g] In the second and final model, the only significant explanatory variable was blood globulin concentration.

Results

For the 95 exposed dogs and 55 unexposed dogs entered in the study, age at death was confirmed in 122 dogs (82 exposed and 40 unexposed), estimated in 21 dogs (8 exposed and 13 unexposed), and not available for 7 dogs (5 exposed and 2 unexposed). The mean ± SD deployment time was 10.16 ± 3.87 days at the World Trade Center (n = 60 dogs), 10.26 ± 2.67 days at the Pentagon (23), and 7.00 ± 4.47 days at Fresh Kills Landfill (12). Thirty-six dogs arrived at the World Trade Center prior to September 14, 2001.

The median age of death for exposed and unexposed dogs was 12.6 years (IQR, 10.9 to 14.4 years) when only confirmed ages were included and 12.8 years (IQR, 11.0 to 14.2 years) when confirmed and estimated ages were included. The median age of death was 12.8 years (IQR, 10.9 to 14.2 years) for exposed dogs and 12.7 years (IQR, 11.3 to 14.3 years) for unexposed dogs ($P = 0.998$).

Survival time was not significantly ($P = 0.68$) different between exposed and unexposed dogs (hazard ratio, 0.82; 95% CI, 0.32 to 2.13). Survival time was not significantly different between exposed dogs at any deployment location and unexposed dogs (World Trade Center: hazard ratio, 0.72, 95% CI, 0.24 to 2.13, $P = 0.56$; Pentagon: hazard ratio, 1.58, 95% CI, 0.44 to 5.71, $P = 0.48$; Fresh Kills Landfill: hazard ratio, 0.22, 95% CI, 0.03 to 1.45, $P = 0.12$). For both models, the proportional hazards assumption was supported by nonsignificant relationships between residuals and time. No significant relationship was found between survival time and the number of days deployed.

The median age of death for the 5 most common SAR types of dog were as follows: German Shepherd Dog: median age, 12.1 years (IQR, 10.6 to 13.2 years); Labrador Retriever: median age, 13.9 years (IQR, 12.5 to 14.9 years); Golden Retriever: median age, 11.9 years (IQR, 9.3 to 12.9 years); mixed-breed dog: median age, 13.7 years (IQR, 12.0 to 14.0 years); and Border Collie: median age, 12.9 years (IQR, 11.1 to 14.3 years). Of the SAR dogs, 65 were females (42 exposed [2 sexually intact] and 23 unexposed [3 sexually intact) and 85 were males (53 exposed [18 sexually intact] and 32 unexposed [9 sexually intact]). Overall, the median age of death for female SAR dogs (13.4 years [IQR, 11.7 to 14.7 years]) was not significantly ($P = 0.120$) different from the median age of death for male dogs (12.6 years [IQR, 10.8 to 14.0 years]). The median age of death for neutered SAR dogs (12.8 years [IQR, 11.3 to 14.3 years]) was not significantly ($P = 0.895$) different from that for sexually intact dogs (12.9 years [IQR, 11.3 to 14.4 years]).

For the 95 exposed dogs, 6 (6%) did not have any COD information. The breeds represented by the 89 exposed dogs with COD information included the following: Labrador Retriever (n = 28), German Shepherd Dog (26), Golden Retriever (10), Border Collie (7), Australian Shepherd (4), and Beauceron, Belgian Tervuren, Doberman Pinscher, English Springer Spaniel, Giant Schnauzer, and Rottweiler (1 each). There were also 8 mixed-breed dogs. For the 55 unexposed dogs, 8 (15%) did not have any COD information; 1 unexposed dog with no recorded date of death did have a third-party COD description. The 47 unexposed dogs with COD information included the following: German Shepherd Dog (n = 22); Labrador Retriever (11); Airedale Terrier, Belgian Malinois, Hovawart, and Golden Retriever (2 each); and Bloodhound, Border Collie, Louisiana Catahoula Leopard Dog, Newfoundland, and Rottweiler (1 each). There was also 1 mixed-breed dog.

The COD was determined by necropsy of 63 dogs that comprised 44 exposed dogs and 19 unexposed dogs. Veterinary medical records provided the COD for 8 exposed and 2 unexposed dogs. The COD was provided by handlers or third-party reports for 36 exposed and 25 unexposed dogs. Dogs with inconclusive information (eg, a dog with reported seizures as the COD but no etiology confirmed) or missing data were classified as unable to determine the category of disease associated with the COD (1 exposed dog and 1 unexposed dog). Median confidence scores for the COD and diagnosis combined was 2 (IQR, 1 to 8) for unexposed dogs and 6 (IQR, 2 to 8) for exposed dogs; no significant (P = 0.065) difference in confidence scores was found between exposed and unexposed dogs.

Toxicological testing was performed on liver, kidney, and adipose tissue samples from 51 SAR dogs. Adipose tissue samples were all negative for polychlorinated biphenyls (limit of detection, 0.5 ppm). Results of heavy metal screening of tissue samples were negative; no toxic effects were detected in either liver or kidney tissue samples. Approximately 10% of dogs tested had a mild increase in iron content in liver samples; although values above the reference range were still well below the toxic amount. Gas chromatography–mass spectrometry screening for organic toxins was performed on liver tissue samples; these were uniformly negative for toxic compounds. Approximately 40% of dogs tested were positive for pentobarbital, phenytoin, or both; compounds were typically included in veterinary euthanasia solutions and not considered toxicants.

On histologic evaluation, anthracosis was identified in sections of lung samples from 61 of 63 (96.8%) SAR dogs. Anthracosis was defined as mild in 27 of 44 (61.4%) exposed dogs and 12 of 19 (63.2%) unexposed dogs. Only 1 dog (exposed) had marked anthracosis and 2 dogs (unexposed) had none noted, whereas the remainder had moderate anthracosis **(Figure 1)**. No significant (P = 0.16) difference was detected in the severity of anthracosis between exposed and unexposed dogs. On necropsy, however, pulmonary particulates **(Figure 2)** were reported in 42 of 44 (95%) exposed dogs but only 12 of 19 (63.2%) unexposed dogs (P = 0.002). No detectable association was found between pulmonary particulate scores and whether SAR dogs had been deployed to the World Trade Center, Fresh Kills Landfill, or Pentagon (P = 0.424). No significant differences were found among breeds for the finding of anthracosis (P = 0.98) or pulmonary particulates (P = 0.66).

The most common COD was degenerative disease followed by neoplasia **(Table 1)**. No significant (P = 0.31) difference was found in the COD attributed to a disease category between exposed and unexposed dogs. Similarly, no significant (P = 0.49) difference was found in the COD attributed to a disease category by deployment location between exposed and unexposed dogs. When SAR dogs were grouped by breed **(Table 2)**, no significant (P = 0.52) differences were detected between breeds and categories of disease that were attributed to the COD.

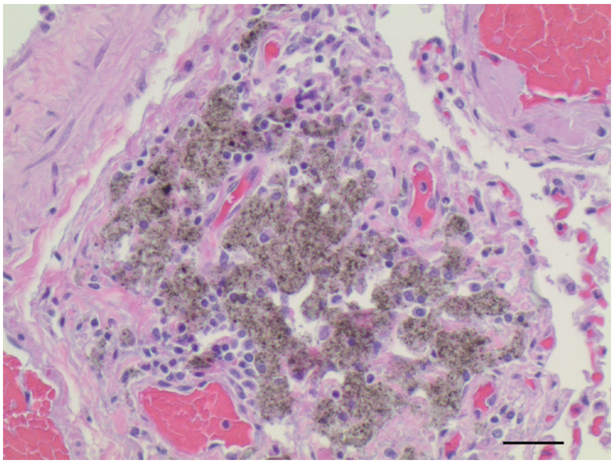

Figure 1—Photomicrograph of a section of lung tissue from an SAR dog that was deployed to the World Trade Center following the 9/11 terrorist attacks. In the center of the image is a large aggregate of peribronchial macrophages with intracytoplasmic black pigment, consistent with a moderate degree of anthracosis. H&E; bar = 250 µm.

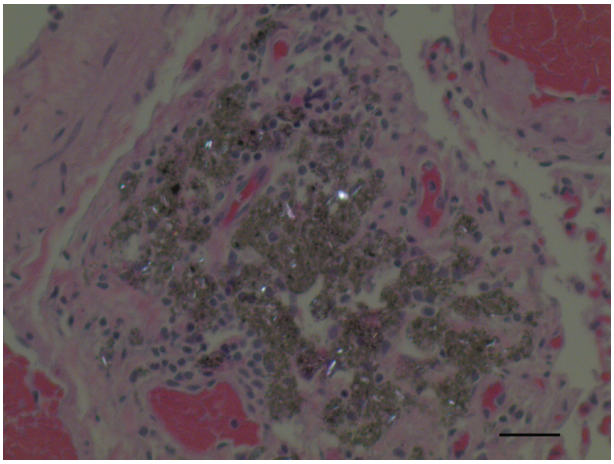

Figure 2—Photomicrograph of the same section of lung tissue as in Figure 1 viewed under polarized light. Note that macrophages contain intracytoplasmic, elongate, refractile foreign particulate material, consistent with a moderate degree of particulate material. H&E; bar = 250 µm.

The distribution of organ systems affected was not significantly (P = 0.15) different between exposed and unexposed dogs **(Table 3)**. Twenty dogs lacked data to classify an affected organ system, 1 dog had multiple affected organ systems, and 8 dogs had insufficient information to provide a definitive organ system. The most common organ system affected in SAR dogs was neurologic (29/150 [19.3%]) followed by cardiovascular (26/150 [17.3%]). Most of the neurologic deaths were attributed to degenerative conditions (17/29 [58.6%]), whereas 9 (31.0%) were indeterminant, 2 (6.9%) were confirmed neoplasia, and 1 (3.4%) was traumatic. Eighteen of 26 (69.2%) dogs with cardiovascular disease were affected by cancer

Table 1—Number (%) of SAR dogs with COD attributed to each category of disease for SAR dogs deployed to the World Trade Center, Pentagon, or Fresh Kills Landfill on Staten Island following the 9/11 terrorist attacks (exposed dogs) and SAR dogs that were not deployed to those locations (unexposed dogs).

				Deployment location		
Category of disease	**All SAR dogs (n = 150)**	**Unexposed SAR dogs (n = 55)**	**Exposed SAR dogs (n = 95)**	**World Trade Center (n = 60)**	**Pentagon (n = 23)**	**Fresh Kills Landfill (n = 12)**
Accident	6 (4.0)	0 (0.0)	6 (6.3)	4 (6.7)	2 (8.7)	0 (0.0)
Degenerative	50 (33.3)	16 (29.1)	34 (35.8)	25 (41.7)	5 (21.7)	4 (33.3)
Inflammatory	12 (8.0)	7 (12.7)	5 (5.3)	3 (5.0)	2 (8.7)	0 (0.0)
Neoplastic	48 (32.0)	18 (32.7)	30 (31.6)	16 (26.7)	9 (39.1)	5 (41.7)
Proliferative	3 (2.0)	1 (1.8)	2 (2.1)	1 (1.7)	0 (0.0)	1 (8.3)
Unable to determine	31 (20.7)	13 (23.6)	18 (18.9)	11 (18.3)	5 (21.7)	2 (16.7)

Table 2—Number (%) of SAR dogs of various breeds or type (ie, mixed-breed dogs) with COD attributed to each category of disease. Breeds or type that were evaluated were represented by ≥ 5 SAR dogs.

Category of disease	**All types with ≥ 5 dogs (n = 113)**	**Border Collie (n = 8)**	**German Shepherd Dog (n = 47)**	**Labrador Retriever (n = 37)**	**Mixed-breed dog (n = 9)**	**Golden Retriever (n = 12)**
Accident	5 (4.4)	0 (0.0)	0 (0.0)	3 (8.1)	1 (11.1)	1 (8.3)
Degenerative	44 (38.9)	2 (25.0)	18 (38.3)	15 (40.5)	6 (66.7)	3 (25.0)
Inflammatory	7 (6.2)	1 (12.5)	4 (8.5)	1 (2.7)	0 (0.0)	1 (8.3)
Neoplastic	42 (37.2)	5 (62.5)	19 (40.4)	12 (32.4)	1 (11.1)	6 (50.0)
Proliferative	2 (1.8)	0 (0.0)	2 (4.3)	0 (0.0)	0 (0.0)	0 (0.0)
Unable to determine	11 (9.7)	0 (0.0)	4 (8.5)	6 (16.2)	1 (11.1)	1 (8.3)

Table 3—Number (%) of SAR dogs with COD attributed to an organ system for SAR dogs deployed to the World Trade Center, Pentagon, or Fresh Kills Landfill on Staten Island following the 9/11 terrorist attacks (exposed dogs) and SAR dogs that were not deployed to those locations (unexposed dogs).

				Deployment location		
Organ system	**All SAR dogs (n = 150)**	**Unexposed SAR dogs (n = 55)**	**Exposed SAR dogs (n = 95)**	**World Trade Center (n = 60)**	**Pentagon (n = 23)**	**Fresh Kills Landfill (n = 12)**
Missing information	20 (13.3)	11 (20)	9 (9.5)	7 (11.7)	1 (4.3)	1 (8.3)
Cardiovascular	26 (17.3)	7 (12.7)	19 (20)	13 (21.7)	2 (8.7)	4 (33.3)
Neurologic	29 (19.3)	11 (20)	18 (18.9)	12 (20)	4 (17.4)	2 (16.7)
Endocrine	2 (1.3)	1 (1.8)	1 (1.1)	1 (1.7)	0 (0)	0 (0)
Urinary	18 (12)	3 (5.5)	15 (15.8)	9 (15)	3 (13)	3 (25)
Gastrointestinal	16 (10.7)	8 (14.5)	8 (8.4)	5 (8.3)	3 (13)	0 (0)
Hematopoietic	3 (2)	1 (1.8)	2 (2.1)	1 (1.7)	1 (4.3)	0 (0)
Integumentary	2 (1.3)	1 (1.8)	1 (1.1)	0 (0)	0 (0)	1 (8.3)
Lymphoid	6 (4)	0 (0)	6 (6.3)	3 (5)	2 (8.7)	1 (8.3)
Musculoskeletal	12 (8)	5 (9.1)	7 (7.4)	5 (8.3)	2 (8.7)	0 (0)
Respiratory	7 (4.7)	5 (9.1)	2 (2.1)	0 (0)	2 (8.7)	0 (0)
Nonspecific	8 (5.3)	2 (3.6)	6 (6.3)	4 (6.7)	2 (8.7)	0 (0)
Multiple systems	1 (0.7)	0 (0)	1 (1.1)	0 (0)	1 (4.3)	0 (0)

(all hemangiosarcoma), 6 (23.1%) had heart failure, and 2 (7.7%) died of hemorrhagic shock secondary to trauma. Overall, 18 of 150 (12.0%) dogs died of urogenital causes, 16 (10.7%) of gastrointestinal disease, 12 (8.0%) of musculoskeletal disease, 7 (4.7%) of respiratory disease, 6 (4.0%) of lymphoid disease, 3 (2.0%) of hematopoietic disease, and 2 (1.3%) each of endocrine and integumentary causes. The 7 dogs with a COD that involved the respiratory system included 2 unexposed dogs with confirmed pulmonary neoplasia, 2 unexposed dogs with suspected pulmonary neoplasia, and 1 exposed dog with confirmed pulmonary neoplasia.

Thirty of 95 (31.6%) exposed dogs and 18 of 55 (32.7%) unexposed dogs had a diagnosis of neoplasia as the COD. No significant ($P = 1.00$) difference in the overall risk of cancer (risk ratio, 1.01; 95% CI, 0.80 to 1.27) was found on the basis of deployment status. When cancers were defined by the organ system affected, no significant differences were detected in exposed dogs versus unexposed dogs for cardiovascular (11 exposed, 7 unexposed; $P = 1.00$), lymphatic (ie, lymphosarcoma; 6 exposed, 0 unexposed; $P = 0.09$), or respiratory (1 exposed, 4 unexposed; $P = 0.06$) systems. The remaining organ systems represented < 4% of all cancers reported as follows: musculoskeletal (3 exposed and 1 unexposed), gastrointestinal (2 exposed and 2 unexposed), urogenital (2 exposed and

1 unexposed), hematopoietic (2 exposed and 0 unexposed), neurologic (1 exposed and 1 unexposed), endocrine (1 exposed and 1 unexposed), and integument (1 exposed and 1 unexposed) systems.

For all SAR dogs, no relationship was found between age at the time of deployment, breed, duration of deployment, sex, and blood values (ie, blood globulin concentration, alkaline phosphatase activity, and bilirubin concentration) during the first year of the surveillance and the lifetime development of neoplasia.

Discussion

Ninety-five of the estimated 300 dogs involved in the response to the terrorist attacks of September 11, 2001, were included in the study reported here and were part of a long-term health monitoring program.[11] In the present study, the unexposed cohort comprised SAR dogs that were of similar demographics and training regimen but that did not respond to the disaster.[4,11] The only significant difference found between the exposed and unexposed SAR dogs in this study was the higher incidence of pulmonary particulates found on necropsy of exposed dogs, compared with unexposed dogs. No significant difference was found in the COD attributed to disease category and organ system involved between exposed and unexposed dogs. For exposed dogs, no significant effect of deployment site on the COD was detected. In comparison to the SAR dogs described in the present report, the 27 New York Police Department dogs that were monitored between 2001 and 2006 included more sexually intact males (ie, 20 dogs) and had longer exposure, working a combined total of 1,428 days.[10] Only 6 dogs in that study died or were euthanized at the end of a 5-year monitoring period. Neoplastic (hemangiosarcoma and osteosarcoma), inflammatory (inflammatory bowel disease, immune-mediated hemolytic anemia, and gastric dilatation-volvulus), and degenerative (debilitating osteoarthritis) disease were identified as the COD in that study.[10] At the end of the 5-year monitoring period for the 27 New York Police Department dogs, the median age of the surviving dogs was 8.8 years (range, 7.4 to 13.9 years); thus, no information about longevity can be determined from that study.[10]

The World Trade Center Health Registry has been continuously monitoring the health and behavior of approximately 17% of the eligible people (rescue and recovery workers and community members) affected by the 9/11 disaster.[9] Approximately 33.5% of the 91,469 rescue and recovery and related workers from 449 agencies have participated in the monitoring. To date, only 3% of the workers have died,[21] whereas all of the SAR dogs are now deceased. For the human deaths to date, the standardized mortality rate for rescue and recovery workers was lower than expected, compared with the general New York City population.[21] In the study reported here, the long life spans and frequency of death attributed to degenerative causes (ie, age-related causes) suggested that the risk of long-term adverse health effects in our population of SAR dogs was also low.

Rescue and recovery workers exposed to the September 11, 2001, terrorist attacks had a higher risk of death from malignant melanoma, motor vehicle accidents, and suicides.[21] Only community members (those with residential, office, school, or transit exposures) in the monitoring program had a higher risk of death from cancer, compared with the general New York City population.[21] This finding is in contrast to the report of Li et al,[16] in which rescue and recovery workers had an overall higher rate of cancer diagnosis than predicted. However, when firefighters who responded were compared with firefighters who did not respond, the relative risk for cancer was not different.[22]

In the study reported here, pulmonary neoplasia was found in 4 unexposed dogs and 1 exposed dog. Interestingly in humans, the diagnosis of lung cancer was less common in the 9/11 responders, compared with the general New York City population.[16] In both rescue recovery workers and community members monitored by the World Trade Center Health Registry, incidences of prostate cancer and skin melanoma were higher than predicted.[16] In our study, prostate cancer was found in 1 castrated unexposed dog and 1 sexually intact male exposed dog. Prostate carcinoma is rare in dogs, but castration increases the risk.[23] One exposed dog in the present study died of malignant skin melanoma. In humans, thyroid cancer was diagnosed in rescue and recovery workers at a higher rate than predicted[16]; 1 unexposed dog in the present study had thyroid carcinoma, which was an incidental finding during necropsy. Although not found for the rescue and recovery workers, non–Hodgkin lymphoma was identified as the COD at a higher incidence among community participants.[16,21] In the present study, 6 exposed dogs had a diagnosis of lymphoma, compared with none of the unexposed dogs. Lymphoma is 1 of the 3 most common neoplasms in dogs and is reported to represent 6% of all forms of cancers in dogs.[24] In the study presented here, no significant difference was found in the incidence of lymphoma between unexposed and exposed dogs; however, because of the small number of affected dogs in this study, it is not possible to say that there was no effect of deployment.

Consistent with the previous report[11] that exposed dogs were more likely to have radiographic evidence of cardiac abnormalities; all 6 dogs that died of heart disease were in the exposed group. Although comparisons between the dogs and humans is less relevant because of the low incidence of vascular disease in dogs, it is interesting to note that the human rescue and recovery workers had a lower incidence of death attributed to cardiac disease than the New York City population.[21]

Anthracosis is defined as the presence of brown to black pigmented material usually found within macrophage aggregates associated with airways in the lungs and is believed to be the result of inhalation of fine particulate material from the combustion of carbon-containing materials. This condition is relatively commonly encountered in domestic animals from urban and industrialized areas, as well as areas with heavy vehicular traffic, or cohabitating in a household with human smokers. On the basis of the high incidence of this condition in both deployed and nondeployed SAR dogs in our study, it appears to be something of an occupational hazard. At least 1 study[25] has found a correlation between higher amounts of anthracosis in dogs and an increased risk of lung cancer.[25] However, our study failed to document the increased incidence of pulmonary neoplasia in exposed SAR dogs, compared with unexposed SAR dogs. Frequently associated with aggregates of anthracosis-laden macrophages is the presence of filamentous birefringent linear particulate material, which is evident when examined microscopically under polarized light. Such particulate materials are believed to result from degradation of silicates or metals, which might occur naturally in the environment, or might be the result of exposure of SAR dogs to recent sites of explosions and destruction of buildings. Although a higher percentage of exposed dogs had pulmonary particulates than unexposed dogs, the incidence of particulate material within the lungs of SAR dogs, whether they were exposed or not, was not associated with increased incidence of cancer, chronic pneumoconiosis, or fibrosis in our study.

Although deployment status did not impact longevity of the SAR dogs of our study, the median life span of our SAR dogs appeared longer than might be expected for some individual breeds. The AKC publishes the expected life span for each registered breed.[26] Although most of the SAR dogs were purebred, it is possible that they were genetically different from the typical AKC-registered dogs. Compared with the AKC expected life span of 7 to 10 years for German Shepherd Dogs, SAR German Shepherd Dogs in our study lived to a median age of 12.1 years (IQR, 10.6 to 13.2 years). Labrador Retrievers have an expected life span of 10 to 12 years,[26] but SAR Labrador Retrievers in our study lived to a median age of 13.9 years (IQR, 12.5 to 14.9 years). Similarly, a study[27] from primary care veterinary hospitals in the United Kingdom reported the median survival time of German Shepherd Dogs as 11 years and Labrador Retrievers as 12.5 years. In the same study,[27] however, mixed-breed dogs in the United Kingdom had a similar life span to SAR mixed-breed dogs in the present study. In contrast, SAR Golden Retrievers and Border Collies of the present study had expected life spans or shorter life spans than reported by the AKC[26] or by O'Neill et al[27]; however, the number of SAR dogs in each of these breed categories was limited in our study.

A study[28] of exceptional longevity in Labrador Retrievers defined the typical life span of a Labrador Retriever as 12 years. Calorie restriction is known to enhance longevity in Labrador Retrievers.[29] Although the body condition score of the SAR dogs in our study was not provided, it is likely that the SAR dogs were kept at a lower (ie, thinner) body condition than typical pet Labrador Retrievers. Compared with males, human females are more likely to have exceptional longevity; in dogs, the female advantage appears to be related to the presence of ovaries.[28] In SAR dogs of the present report, no significant difference was found in longevity between males and females; however, only 5 of the female SAR dogs were sexually intact at the time of deployment. In 1 retrospective study,[30] neutering was associated with an increase in longevity.

One predictor of exceptional longevity in Labradors was the slower loss of lean body mass.[28] It is recognized in humans that both diet and exercise impact the development of sarcopenia and loss of lean body mass.[31] It is unknown whether the general athleticism and exercise routines of the SAR dogs contributed to their longevity or, alternatively, whether the SAR dogs' value and close partnerships with their human handlers resulted in better medical care, leading to greater longevity.

Overall, degenerative conditions (33.3%) were the most common COD in SAR dogs of the present study. In a study[32] of military working dogs, degenerative joint disease was the most common COD (19%); when combined with geriatric conditions, degenerative conditions increased to 33% as the COD for military working dogs. Neoplasia is the most common COD in adult dogs, although there are breed-specific variations.[20,28,33] For both SAR dogs in the present study and military working dogs in a previous study,[32] neoplasia was the second most common COD (32% and 18%, respectively).

Although the present study was the first longitudinal study of SAR dogs after a major disaster, there were limitations to this study. The major limitation was the small number of dogs that were followed. The total number of dogs responding to the September 11, 2001, terrorist attack has never been confirmed but was estimated at approximately 300. Similar to the World Trade Center Health Registry,[9] the present study captured information on approximately a third of potential participants. In addition, the deployment location, date of arrival, and duration of exposure varied among SAR dogs. Similar to that of human first responders, the SAR dogs that responded also participated in other training and responses that could have resulted in hazard or toxin exposure. Similar to a human study[22] that compared firefighters exposed to the World Trade Center site with nonexposed firefighters, the inclusion of unexposed SAR dogs in the present study helped account for other SAR-related hazards. Another limitation was the frequency of necropsies and reliance on interpretation of clinical data to assign the primary COD disease categories. All participants were asked to have a necropsy performed (at no cost to the handler); however, only 63 of 150 dogs were necropsied. Tissue sample collection was performed in most cases by clinical veterinarians rather than trained pathologists; however, a single board-certified pathologist performed all of the histologic examinations and toxicological analyses. The lack of necropsy data could contribute to unrecognized pathological findings and skewed data; however, most published COD data rely on clinical and laboratory data rather than necropsy and autopsy data.[33] Some dogs were lost to follow-up, resulting in incomplete information about their date of death or COD. Finally, there was no way to control other training or mission-related exposures of the SAR dogs in the present study.

In conclusion, the SAR dogs responding to the 9/11 terrorist attacks did not show any detectable increased mortality rate related to deployment. The exposed dogs did have increased pulmonary particulates, but this did not translate to disease. Although there have been reports[8,12,15,16,22] of illness in people affected by the disaster, the human mortality rate is lower than expected on the basis of the New York City cohort.[21] Overall, SAR dog longevity is greater than expected on the basis of the breed. Working (SAR and military) dogs' deaths are frequently associated with degenerative conditions. Future studies to determine factors that contribute to the longevity of SAR dogs are warranted.

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Footnotes

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