

A systematic review of the safety of potassium bromide in dogs

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Objective—To critically evaluate and summarize available information on the safety of potassium bromide in dogs.

Design—Systematic review.

Sample—111 references reporting safety information relevant to potassium bromide published between 1938 and 2011.

Procedures—PubMed searches without date limitations were conducted with the terms “potassium bromide” and “sodium bromide” in December 2009 and October 2011. Additional articles were identified through examination of article reference lists and book chapters on seizures in dogs and pharmacology.

Results—Reversible neurologic signs were the most consistently reported toxicoses and were generally associated with adjunctive potassium bromide treatment or high serum bromide concentrations. Dermatologic and respiratory abnormalities were rare in dogs. Insufficient information was available to assess the effects of potassium bromide on behavior or to determine the incidence of vomiting, weight gain, polyphagia, pancreatitis, polyuria, polydipsia, or reproductive abnormalities associated with potassium bromide administration. Evidence suggested that administration of potassium bromide with food may alleviate gastrointestinal irritation and that monitoring for polyphagia, thyroid hormone abnormalities, and high serum bromide concentrations may be beneficial.

Conclusions and Clinical Relevance—Results suggested that potassium bromide is not an appropriate choice for treatment of every dog with seizures and that practitioners should tailor therapeutic regimens and clinical monitoring to each dog. Abrupt dietary changes or fluid therapy may compromise seizure control or increase the likelihood of adverse events. Availability of an appropriately labeled, approved potassium bromide product could provide better assurance for veterinarians and their clients of the quality, safety, and effectiveness of the product for veterinary use. (*J Am Vet Med Assoc* 2012;240:705–715)

Potassium bromide was first reported as a treatment for epilepsy in people in 1857¹ and was described as an animal treatment before 1876.² The drug was widely available over the counter during the early part of the 20th century, and in 1938, sales of products containing bromide in the United States were second only to sales of products containing acetylsalicylic acid.³ Although bromide salts are still used to treat specific types of refractory seizures in children,^{4,5} the use of KBr in humans has decreased throughout the 20th century owing to the availability of other antiseizure medications that have fewer toxic effects.⁶ Undesirable effects of bromides in humans include lethargy, sleepiness, confusion, hallucinations, muscle pain, ataxia, nausea, vomiting, anorexia, acneiform and erythematous rashes, nodular and pustular skin lesions, stupor, and coma.^{3,7}

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ABBREVIATIONS

ADE	Adverse drug event
GI	Gastrointestinal
KBr	Potassium bromide
NaBr	Sodium bromide
PB	Phenobarbital
PD	Polydipsia
PU	Polyuria

In dogs, PB and KBr are still considered the standard treatment for long-term management of seizures associated with idiopathic epilepsy,^{8–10} the most common neurologic disorder in dogs.⁹ In a recent Australian survey,¹¹ 80% of veterinarians reported that they used KBr to manage seizures in dogs. Although KBr has traditionally been used in combination with PB, it is increasingly being used as a single agent for treatment of dogs with seizures^{12–14} and it has been recommended as a first-line anticonvulsant in some dogs with newly diagnosed epilepsy.^{8,14} Concern regarding serious ADEs associated with PB, such as pancytopenia¹⁵ and hepatotoxicosis,¹⁶ and the restrictions associated with dispensing PB related to its classification as a controlled substance also make KBr a more convenient choice than PB for seizure management.¹⁷

Potassium bromide and, to a lesser extent, NaBr are compounded and marketed in the United States as a solution or in capsules. Potassium bromide, NaBr, and PB have not been approved by the US FDA for use in humans or animals in the United States. This means that these drugs have not been reviewed by the FDA to determine whether they are safe and effective or to show that they are produced in a consistent manner according to recognized quality standards. For unapproved drugs, there is no mandatory requirement for reporting of ADEs by drug manufacturers; therefore, the FDA Center for Veterinary Medicine receives relatively few ADE reports related to these products. Without FDA approval and mandatory ADE reporting, the safety, effectiveness, and quality of KBr products available to practitioners and patients in the United States cannot be ensured, potentially leaving veterinarians and pet owners unaware of adverse effects and other risks involved with the use of KBr. Because KBr is commonly used in the veterinary community, it is important that veterinarians have the information necessary to prescribe it in the safest manner possible. The purpose of the study reported here was to systematically review and critically evaluate the published literature on the safety of KBr in dogs.

Materials and Methods

A PubMed search was conducted in December 2009 with the term “potassium bromide” to identify articles related to the safety of bromide. Additional articles were identified through manually searching reference lists in the identified publications, in other relevant articles, and in book chapters on seizures in dogs and pharmacology. The literature search was repeated in October 2011, adding the term “sodium bromide,” to identify articles that had been published following the original PubMed search and to more completely encompass potential adverse effects expected with KBr treatment because the initial search identified information relevant to KBr safety in articles reporting results of studies that used NaBr.

Published reports that did not involve systemic administration of bromides to humans or animals or did not assess physiologic effects were excluded because they were not applicable to this review. Individual reports were not excluded on the basis of study design, species of interest, condition being treated, or language of publication. Foreign language references were evaluated first on the basis of the title and then on the basis of a review of the abstract; references that appeared potentially relevant on the basis of the title or abstract were translated into English.

Potentially relevant publications were reviewed to determine the physiologic systems involved and the strength of evidence linking each reported ADE to KBr or NaBr. Review and historical articles with no original data and reports of bromide use in humans or dogs in which toxicity was not examined were excluded. Relationships among treatment groups were examined, the evidence was evaluated for causality of adverse events, and it was determined whether findings were statistically significant. Articles were classified as providing primary, supportive, or anecdotal evidence on the basis of an evaluation of the strength of evidence presented in the article, as described.¹⁸ Publications that contained quantitative or descriptive data investigating adverse effects of bromide treatment in mammals were considered to provide primary evidence. Publications reporting

studies in which safety monitoring was conducted but no ADEs were seen were also considered to provide primary evidence. Publications in which ADEs were described in the context of a study, but without data, and publications that discussed important ADEs but lacked sufficient case detail to definitively attribute the reported ADEs to KBr or NaBr administration were considered to provide supportive evidence. Publications were classified as providing anecdotal evidence if they contained opinions or observations by experts rather than objective, supportive safety data. The strength of evidence available in each article was summarized, and spreadsheet templates were used to organize reports of bromide-associated toxicoses by specific body systems. Findings were summarized by system; additional literature on physiologic mechanisms was incorporated to provide interpretive context.

Results

The PubMed searches retrieved 843 publications. Searches of reference lists in these articles and in book chapters and additional targeted searches yielded 93 additional publications, resulting in a total database of 936 publications. Of these, 703 were eliminated because they did not discuss systemic use of KBr or did not contain physiologic information or because bromide was used only to measure the extracellular water compartment. Of the 233 remaining publications, 38 were in a foreign language. Of these, 20 had English titles or abstracts that appeared relevant and were translated. Eight of these 20 were included in the systematic review.^{19–26} Twelve translated articles and 12 other foreign-language publications that could be evaluated without translation on the basis of their titles, abstracts, tables, or figures were found to lack sufficient specific data on ADEs associated with bromides. Six other foreign-language publications were not translated because they were judged to provide information similar to information that had already been reviewed. These 30 publications were not included in the review.

Publications that discussed the use of bromide as a treatment in humans or animals included 42 historical or review articles that contained only descriptive summaries and no original data. Another group of publications discussed use of bromides in humans ($n = 14$), horses (2), rats (4), or chicks (1), but no ADEs were reported. It was unclear in these 21 publications whether ADEs were not evaluated, were not reported, or were truly not observed. In 22 other publications, KBr was used in dogs but no ADEs could be directly attributed to bromide administration. In these publications, there was insufficient description to determine whether ADEs were evaluated at all or were not observed, affected animals had other treatments or conditions likely to produce observed signs, physiologic measurements were described but no clinical changes were observed, or the provided information was vague and the types of ADEs described were documented in other references containing data. Seven publications reported findings only in nonmammalian species, including flies, fish, and birds. Although these 92 publications did not provide data for assessing bromide toxicity, some of them provided background and contextual information that was used in the descriptive review.

The 111 publications that provided data on drug safety included those in which KBr or NaBr was used

as a monotherapy or as a part of combination treatment (usually with PB). There were few controlled trials involving dogs that evaluated the safety of KBr when used alone; however, there were many reports of ob-

servational studies. On the basis of our critical review, 38 publications provided primary evidence relevant to KBr safety (Table 1); these publications contained data related to dogs,^{15,27–37,a} cats,^{38,39} rats,^{40–49} mice,^{50,51} cat-

Table 1—Characteristics of 38 publications that provided primary evidence regarding adverse effects of KBr relevant for dogs.

Author	Year	Species	No. treated	Drug	Study design	Body system affected and signs
Bel et al ⁵⁴	2001	Humans	1	NaBr	Case report	Dermatologic (vegetative skin lesions)
Boothe ^a	2002	Dogs	23	KBr	Randomized controlled trial	Neurologic (ataxia, obtundation, hyperactivity, and abnormal behaviors), GI (vomiting, polyphagia, and 10% weight increase), and PU and PD
Boothe et al ³⁸	2002	Cats	17	KBr	Cross-sectional study	GI (vomiting and weight gain), PU and PD, and respiratory (coughing and bronchial asthmatic changes)
Boothe et al ³⁸	2002	Cats	7	KBr	Experimental study	No ADEs reported during observation period
Buchberger et al ⁴⁰	1990	Rats	36	NaBr	Experimental study	Neurologic (hypoactivity), GI (decreased weight and anorexia), dermatologic (ruffled fur), endocrine (decreased thyroxine and triiodothyronine and increased thyroid-stimulating hormone concentrations), and death
Chang et al ²⁷	2006	Dogs	4	KBr	Cross-sectional survey	Neurologic (lethargy, ataxia, and restlessness), GI (vomiting, diarrhea, and polyphagia), and dermatologic (pruritus)
Diener et al ⁵⁵	1998	Humans	5	KBr	Case series	GI (vomiting and diarrhea), pancreatitis, dermatologic (folliculitis, subcutaneous nodules, and necrotizing panniculitis), and fever
Disse et al ⁴¹	1996	Rats	18	NaBr	Experimental study	Reproductive (in offspring of treated dams: lower body and brain weight, delayed behavioral development, and modified neuroplasticity)
Genicot et al ¹⁹	1991	Cattle	11	KBr	Experimental study	GI (polyphagia and lower weight gain compared with controls)
Goldstein ⁵⁰	1979	Mice	30	NaBr	Experimental study	Neurologic (sedation, loss of righting reflex, and ataxia) and death
Hafiji et al ⁵⁶	2008	Humans	1	Pipobroman (bromide-containing drug)	Case report	Neurologic (delusions, hallucinations, and depression) and dermatologic (erythematous, papulonodular eruption with erosions, pustules, and necrosis)
Hanes and Yates ³	1938	Humans	400	Bromide	Case series	Neurologic (headache, delusions, emotional changes, lethargy, memory loss, and ataxia), dermatologic (rash and papules), and reproductive (loss of libido)
Hansen and Hubner ⁵¹	1983	Mice	100	NaBr	Experimental study	Neurologic (restlessness and behavioral changes) and GI (weight loss)
Harned et al ⁴²	1944	Rats	97	NaBr	Experimental study	Reproductive (in offspring of treated dams: stillbirths, neonatal deaths, delayed growth, and slower maze learning)
Harris and Derian ²⁸	1949	Dogs	3	NaBr	Experimental study	Neurologic (lethargy and incoordination), GI (diarrhea and oral ulceration), and dermatologic (pustular dermatitis)
Jacobs et al ¹⁵	1998	Dogs	1	KBr and clorazepate dipotassium	Case series	No ADEs reported during 8-week follow-up period
Kagitani-Shimono et al ⁵⁷	2005	Humans	2	PB	Case series	No ADEs reported during 2- to 5-year follow-up period
Kantrowitz et al ²⁹	1999	Dogs	4	NaBr	Case series	No ADEs reported during 2- to 5-year follow-up period
Knight and Reina-Guerra ⁵²	1977	Cattle	8	KBr	Cross-sectional study	Endocrine (no thyroid hormone changes among dogs treated with KBr alone)
Loeber et al ⁴³	1983	Rats	15	KBr and PB	Experimental study	Neurologic (ataxia)
March et al ³⁰	2002	Dogs	55	NaBr	Experimental study	Endocrine (decreased thyroxine and growth hormone concentrations and decreased growth) and reproductive (decreased spermatogenesis)
Millikan and Paul ⁵⁸	1946	Humans	14	KBr	Uncontrolled clinical trial	Neurologic (caudal paresis, ataxia, hyporeflexia, and agitation)
Newsome et al ⁴⁴	1978	Rats	20	NaBr	Experimental study	Neurologic (sleepiness, ataxia, slurred speech, grogginess, disorientation, and hallucinations) and GI (nausea and vomiting)
Palmer and Clarke ³¹	1933	Dogs	2	NaBr	Experimental study	Endocrine (increased thyroxine concentration) and GI (no anorexia and possibly decreased growth)
Paull et al ³²	2003	Dogs	5	KBr	Experimental study	No ADEs reported during observation period
						Endocrine (no thyroid hormone changes); no ADEs reported during 6-month follow-up period

Table 1 continued—Characteristics of 38 publications that provided primary evidence regarding adverse effects of KBr relevant for dogs.

Author	Year	Species	No. treated	Drug	Study design	Body system affected and signs
Perkins ⁵⁹	1950	Humans	27	Various bromides	Case reports	Neurologic (paresis, ataxia, tremor, hallucinations, disorientation, sleepiness, headache, muscle pain, hyporeflexia or hyperreflexia, anisocoria, depression, irritability, stupor, coma, and increased CSF total protein concentration), GI (stomach cramps, foul breath), dermatologic (rash), fever, and death
Raidal and Edwards ⁵³	2008	Horses	12	KBr	Experimental study	Neurologic (ataxia and proprioceptive deficits)
Rosenblum ³³	1958	Dogs	24	NaBr	Experimental study	Neurologic (ataxia, stupor, shivering, and coma), GI (salivation, weight loss, vomiting, and diarrhea), dermatologic (nonsuppurative, macular, and scaly dermatitis), and death
Rossmeis and Inzana ³⁴	2009	Dogs	31 52	KBr or KBr and PB None (epileptic controls) KBr	Case-control study	Neurologic (paresis, ataxia, mydriasis, aggression, stupor, and coma) and GI (regurgitation and megaesophagus)
Sangster ⁶⁰	1983	Humans	24	KBr	Experimental study	Neurologic (sleepiness and grogginess), GI (nausea), and endocrine (increased thyroxine and triiodothyronine concentrations)
Steiner et al ³⁵	2008	Dogs	98 118 121	KBr PB KBr and PB	Cross-sectional study	Pancreatitis (no evidence for ADEs on the basis of canine pancreatic lipase immunoreactivity)
Schwartz et al ³⁶	2011	Dogs	1	KBr	Case report	No ADEs reported during 8-week follow-up period
van Leeuwen et al ⁴⁵	1983	Rats	500	NaBr	Experimental study	Reproductive (male and female infertility, fewer offspring, and postnatal death) and endocrine (decreased thyroxine and increased thyroid-stimulating hormone concentrations)
van Logten et al ⁴⁶	1973	Rats	16	NaBr	Experimental study	Neurologic (incoordination and decreased grooming)
van Logten et al ⁴⁷	1974	Rats	100	NaBr	Experimental study	Neurologic (incoordination and decreased grooming), endocrine (growth retardation), and reproductive (decreased spermatogenesis and fewer corpora lutea)
Velický et al ⁴⁸	1997	Rats	120	KBr	Experimental study	Endocrine (decreased thyroxine and triiodothyronine concentrations and parenchymatous goiter-like changes in thyroid gland)
Vobecký et al ⁴⁹	2005	Rats	10 dams and 80 pups	KBr	Experimental study	Reproductive (decreased survival of young, retarded growth, and decreased milk production) and GI (anorexia and weight loss)
Wagner ³⁹	2001	Cats	26	KBr	Cohort study	Respiratory (cough and severe dyspnea) and death
Yohn et al ⁵⁷	1992	Dogs	1	KBr	Case report	Neurologic (depression, stupor, hyporeflexia, anisocoria, paresis, and muscle pain)

tle,^{19,52} horses,⁵³ and humans.^{54–60} Among these 38 publications providing primary evidence, there were 22 experimental studies (5 involving dogs and 17 involving other species), 2 clinical trials (1 involving dogs and 1 involving humans), 1 cohort study involving cats, 1 case-control study involving dogs, 4 cross-sectional studies (3 involving dogs and 1 involving cats), and 9 case reports or case series (3 involving dogs and 6 involving other species). One publication included data from 2 types of studies.

Sixty publications were classified as providing supportive evidence, such as descriptive information that supported ADEs documented in the primary evidence publications. These publications involved dogs,^{13,17,20,61–74,b,c} cats,²¹ rabbits,^{22,61} rats,^{75–82} mice,⁸³ cattle,⁸⁴ goats,^{84,85} horses,^{84,86} and humans.^{5,7,23,24,87–109} These publications described important ADEs, but were limited in their ability to clearly attribute ADEs to bromide administration. Some publications evaluated KBr only when administered in combination with PB or other anticonvulsant drugs. Some patients had concurrent diseases or com-

plex medical histories, making it difficult to determine whether clinical signs could be attributed to bromide administration. Other publications loosely described bromism or general signs, but did not provide quantitative data.

Thirteen publications were considered to provide anecdotal evidence. These included 5 letters to the editor discussing publications that had already been examined,^{26,110–113} 5 brief reports that provided comments about adverse effects but did not provide data,^{25,114–117} and 3 abstracts of presentations that described preliminary results from small studies involving KBr administration but did not mention whether adverse events were identified.^{d–f}

On the basis of the identified publications, body systems for which ADEs were reported included the neurologic (including behavioral), GI (including pancreatitis), reproductive, endocrine, dermatologic, and respiratory systems. Additionally, PU and PD were frequently mentioned; however, these were considered to be relatively nonspecific signs and were not associated with a single body system.

Discussion

Evaluation of the safety of a new animal drug is a critical part of the FDA drug approval process. Preapproval assessment of potential ADEs is generally based on preliminary data about the structure and pharmacology of the compound, experimental studies, and observations from clinical trials.¹¹⁸ This information is used to predict safety for the larger population of animals that will be treated if the drug is approved and marketed. For drugs such as KBr, which have already been widely used in animal populations, information on health effects with clinical use can be directly observed, rather than relying solely on inference from experimental studies. However, the number of published articles that directly address safety questions may be limited. In the present study, we identified a considerable body of pharmacological, primary, and supportive evidence regarding the *in vivo* safety of KBr.

Potassium bromide is a halide salt that is thought to exert its antiepileptic activity by passing through neuronal chloride ion channels, thereby hyperpolarizing neuronal membranes, raising the seizure threshold, and stabilizing neurons against excitatory input from epileptic foci.¹² Bromide ions have a smaller hydrated diameter than chloride ions do and therefore passively cross these neuronal channels more readily.⁷ Bromide distributes into the CSF and interstitial tissues of the brain and is actively transported out of the CNS via the choroid plexus. At pharmacological doses, the active transport mechanism is overwhelmed and bromide accumulates in the brain and CSF.¹²

When given orally as NaBr, the estimated bioavailability of bromide in dogs is 46%,¹¹⁹ but bioavailability may differ considerably among individuals. Generally, KBr and NaBr solutions would be expected to have similar GI absorption, although because of molecular weight differences, a solution of 250 mg of KBr/mL would be equivalent to a solution of 211 mg of NaBr/mL. The prandial state of the animal would not be expected to affect bromide absorption because bromide is water soluble and absorbed along the entire GI tract.¹²⁰ Corn syrup or flavored sweeteners have been added to compounded bromide solutions to improve palatability.¹²¹ The addition of low-digestible carbohydrates, such as mannitol and sorbitol, may alter the osmolarity of intestinal fluids and result in changes to the rate of GI transit.¹²²

Bromide is not subject to hepatic metabolism, making it suitable for use in dogs with hepatic disease.^{9,123} It is excreted unchanged by the kidneys, where it is freely filtered by the glomeruli and then undergoes tubular reabsorption in competition with chloride.⁶² Bromide is reabsorbed more readily than is chloride¹¹⁹ and distributes throughout the body, essentially replacing chloride in body fluids.¹²⁰ Therefore, the reported mean volume of distribution of 0.45 L/kg (0.20 L/lb) approximates the extracellular fluid space.¹² The mean elimination half-life of bromide when KBr is orally administered to dogs has been estimated to be from 24.9¹²⁴ to 46 days.¹¹⁹ Dietary chloride has been shown to be a key variable affecting the elimination half-life of bromide.¹²⁵ Generally, regular administration of KBr for 4 to 5 half-lives

is required for serum bromide concentrations to reach steady state. Therapeutic serum bromide concentrations may be achieved more quickly by administration of loading doses of KBr.

Animals with decreased renal function may be predisposed to bromide toxicosis owing to a decreased ability to eliminate bromide as a result of reduced glomerular filtration rate.^{34,65} Increased chloride intake leads to increased urinary elimination of bromide,⁹ likely as a result of competition for tubular reabsorption between chloride and bromide.¹²⁵ Trepanier and Babish¹²⁵ found that an increase in dietary chloride content from 0.2% to 1.3% led to a decrease in serum bromide half-life from 69 to 24 days. They also found that, among 11 commercial dry dog foods, chloride content ranged from 0.33% to 1.32% on a dry-matter basis. Abrupt diet changes in dogs receiving KBr could either compromise seizure control or raise safety concerns.⁷² Use of IV fluids containing chloride could also reduce serum bromide concentration to subtherapeutic concentrations during fluid therapy.¹⁰ Loop diuretics, such as ethacrynic acid and presumably furosemide, may also increase bromide elimination by blocking chloride and bromide reuptake.⁶⁵ It has also been suggested, albeit anecdotally, that NaBr rather than KBr should be used in patients with adrenal insufficiency because these patients may have difficulty maintaining potassium homeostasis.¹²³ Because of factors affecting the dose-response relationships for KBr, treatment is generally titrated to effect for individual dogs.⁶⁹

Given the pharmacological properties of bromide and specific information in the 111 publications identified in the present study, the effects of KBr could be summarized for multiple physiologic systems. Bromide toxicosis in dogs was most frequently associated with high serum bromide concentrations; however, authors have reported that toxicoses can be seen at low concentration in unusually sensitive dogs.^{30,33} One study¹²⁶ found that most dogs that develop signs of toxicoses with bromide monotherapy had serum bromide concentrations in the range of 2.4 to 4 mg/mL but also found that dogs were successfully treated without signs of toxicoses at serum concentrations as high as 4 to 4.8 mg/mL. Another publication³⁰ reported clinical signs of toxicosis at serum bromide concentrations of approximately 4 mg/mL, but no signs of toxicoses at concentrations of 1.78 to 2.7 mg/mL.³⁰ In a laboratory study,³³ unspecified minimal signs of toxicosis were found in dogs given 100 mg of NaBr/kg/d (45.5 mg/lb/d) for 6 weeks; mean serum concentration was 2.7 mg/mL. However, in the same study, 3 deaths occurred between weeks 4 and 6 in another group of dogs treated with 200 mg of NaBr/kg/d (90.9 mg/lb/d). The importance of monitoring clinical signs for individual animals should be emphasized because effective and toxic serum bromide concentrations have been reported to differ between dogs³⁴ and an overlap in toxic versus nontoxic serum concentrations has been demonstrated. In fact, the use of clinical signs to judge appropriateness of treatment may be more important than monitoring serum bromide concentration alone.

Neurologic and behavioral signs were the most commonly reported ADEs associated with bromide ad-

ministration in dogs and other species in clinical and experimental studies reviewed in the present study. Sedation and, conversely, irritability and restlessness have been reported in dogs^{3,8,27–31,a,c} and humans.^{3,22} A sedative, calming effect has also been reported in horses.¹²⁷ Cattle treated with KBr had a decrease in aggressive behavior, compared with untreated controls.¹⁹ Signs of more severe bromism were also similar across species and included signs of depression,⁵⁶ behavioral changes,^{40,50,51,58} ataxia,^{27,28,33,34,50,52,53,58,a,c} hind limb paresis,^{30,31,35} mydriasis,^{34,35,37,59} stupor,⁵⁹ and coma.^{33,34,59,65,69} In humans, headache,^{3,59} sleepiness,^{58–60} muscle pain,^{37,59} and hallucinations^{56,58} have also been reported. Neurologic signs have been described when KBr was used alone or in addition to PB.^{30,34,37,65,b} In clinical studies, observed behavioral changes could also stem from the prodromal or postictal phases of seizure activity rather than from bromide toxicosis.¹²⁸ Adverse neurologic effects are reversible and may be alleviated within several days by decreasing the PB dose by 10% to 30% (when bromide is given in combination with PB) and within hours by treating with saline (0.9% NaCl) solution IV.^{12,37,65,113,121}

Gastrointestinal ADEs have also been reported. Vomiting has been commonly described as an adverse effect of both KBr and NaBr administration, but a large number of the reports identified in the present study were anecdotal and lacked supportive data. Vomiting was seen in 2 of 20 dogs receiving 400 to 500 mg of NaBr/kg/d (181.8 to 227.3 mg/lb/d) with food.³³ The vomiting in one of those dogs was so severe that drug administration was discontinued. Another study³⁰ found that KBr at dosages as high as 30 mg/kg (13.6 mg/lb), PO, every 12 hours for 115 days with food did not result in vomiting. Occasional vomiting was reported in the medical histories of 2 of 22 dogs following KBr treatment; however, these dogs were also receiving PB.⁷⁴ Vomiting was reported in 1 of 17 cats receiving KBr.³⁸ Nausea and vomiting have also been reported occasionally for human patients being treated with bromides.^{55,58–60} In dogs, transient diarrhea and bloody feces were seen in an experimental study³³ when serum bromide concentrations were 1.8 to 4 mg/mL, but it was unclear how frequently and in how many dogs diarrhea occurred. Three dogs treated with 0.2 g of NaBr/kg/d (0.09 g/lb/d) developed severe, intermittently bloody diarrhea, of which 2 developed oral ulcerations.²⁸ Diarrhea has also been occasionally reported with clinical use in dogs²⁷ and humans,^{4,55} as have other GI problems. Two reviews anecdotally mentioned megasophagus as a potential adverse effect of KBr treatment in dogs.^{9,34} These adverse GI effects have rarely been severe enough to require cessation of KBr treatment in any species. Potassium bromide and NaBr have long been reported, albeit anecdotally, as gastric irritants, and vomiting has been attributed to this irritant effect.^{12,33,34,38,63,121} Administration with food or as a divided dose may be effective in preventing GI irritation.^{12,30,58,121} For publications identified in the present study, adverse GI effects could not be clearly attributed to KBr administration, although there was anecdotal support.

Weight loss leading to emaciation has been seen experimentally in rodents^{40,49,51,57} and in 10 of 20 dogs receiving large doses of NaBr with controlled caloric in-

take.³³ Weight gain was seen in 1 of 17 client-owned cats being treated with KBr.³⁸ In a 221-day study of 22 Belgian White and Blue Cattle (11 of which were treated with KBr), average daily gain was significantly less in KBr-treated animals, compared with untreated animals, in the first 53 days, but time spent eating was significantly increased in the treated animals from days 168 to 221.¹⁹ Polyphagia, a commonly reported adverse effect of both PB and KBr, has been suggested to be a result of increased caloric need or a behavioral effect and may be involved in these weight changes. In most publications that reported polyphagia in the present study, it was difficult to distinguish whether this was actually related to KBr treatment because there was concurrent administration of other drugs. In 1 study,⁶⁹ polyphagia was reported in 7 of 23 dogs following the addition of KBr to PB treatment. Given that all of these dogs continued to receive PB, it was unclear whether the polyphagia was due to KBr alone or to the combination of drugs. In a small study,²⁷ polyphagia was reported by owners of 1 of 4 dogs receiving KBr monotherapy, 6 of 11 dogs receiving PB monotherapy, and 8 of 10 dogs receiving both KBr and PB. On the basis of publications identified in the present study, monitoring food consumption and weight patterns may be warranted in dogs receiving KBr treatment, particularly because polyphagia can lead to garbage ingestion and other complications.⁶⁹

Most KBr-related studies in dogs have not assessed pancreatic outcomes; however, several small studies have explored a possible association between pancreatitis and treatment with a combination of PB and KBr. Schwartz-Porsche and Jurgens²⁰ reported clinical signs of pancreatitis in 2 of 22 dogs and pancreatic fibrosis at necropsy in 2 of 7 dogs receiving KBr. However, there was no comparison group of untreated dogs and all dogs had previously been treated with maximal doses of either PB or primidone. Hess et al¹²⁹ reported pancreatitis to be more common in dogs with epilepsy, although no treatments were compared. Gaskill and Cribb⁶³ reported that pancreatitis developed in 3 of 6 dogs after KBr was added to PB treatment. They also found, using serum samples from private practices submitted for KBr or PB testing to a diagnostic laboratory, that a higher percentage of dogs with measurable serum concentrations of bromide and PB (10/17) also had high serum amylase or lipase activities, compared with dogs with only measurable PB concentrations (8/88). A history supportive of pancreatitis was reported for a higher percentage of the dogs with measurable serum bromide and PB concentrations (5/17), compared with dogs with only PB concentrations (2/88). Steiner et al³⁵ used a similar approach with 121 serum samples submitted for KBr or PB testing to relate serum and PB concentrations and canine pancreatic lipase immunoreactivity. There were no significant differences in proportions of dogs with canine pancreatic lipase immunoreactivity > 102.1 µg/L (ie, dogs with canine pancreatic lipase immunoreactivity greater than the upper reference limit) or > 199.9 µg/L (ie, dogs with canine pancreatic lipase immunoreactivity diagnostic for pancreatitis) for dogs with measurable serum concentrations of only bromide, only PB, or both bromide and PB. Interpretation of results from studies that use diagnostic laboratory sub-

missions is difficult because of biases associated with ascertaining exposure and disease status for this type of convenience sample. Additionally, practitioners may be more likely to submit samples from dogs with poor seizure control, signs of toxicosis, or health problems than from otherwise healthy dogs with well-regulated epilepsy. Pancreatitis has been associated with a large number of other drugs in humans, but not with KBr or PB,¹³⁰ although it has been mentioned in some case reports.⁵⁵ However, pancreatitis in dogs has been associated with abnormal food consumption¹³¹ and polyphagia has been reported for dogs treated with PB, KBr, or a combination of both.²⁷ Two dogs with pancreatitis were described in a study⁶⁹ of 23 dogs, but pancreatitis was attributed to polyphagia and garbage ingestion. Additionally, the clinical signs of pancreatitis (vomiting, lethargy, diarrhea, and signs of abdominal pain)¹²⁹ have been individually reported as ADEs, making identification of pancreatitis more complicated. On the basis of our literature review, there was not enough evidence to determine whether dogs receiving KBr were at higher risk of developing pancreatitis.

None of the identified publications in the present study directly assessed the safety of bromide in reproductively active dogs. In humans, reversible impotence and loss of libido were among the first recognized effects of bromides.^{1,3} Reversible decreases in fertility have been reported in both female and male rats at NaBr doses $\geq 4,800$ mg/kg (2,181.8 mg/lb),^{43,45,47} but fetal viability was not affected at dosages of up to 1,200 mg of NaBr/kg/d (545.5 mg/lb/d). Bromide crosses the placenta and is excreted in milk.⁴⁹ In rats, gestational treatment of dams led to decreased survival time, lower weight gain, and postnatal developmental delays in offspring.^{41,49} Even at lower dosages of 120 mg of NaBr/kg/d (54.5 mg/lb/d) during gestation, offspring had a slower rate of maze learning than did controls.⁴² Given the variety of reproductive effects seen in other species, more research is needed to determine whether KBr can be safely used in reproductively active dogs. In general, reproductive effects may be of lesser concern because it is usually recommended that dogs with idiopathic epilepsy be neutered.

Delayed growth was also reported in studies^{41–43,47,49} of rats that were exposed as juveniles, but not in utero, and small studies reported other effects potentially related to cellular replication. Six dogs treated with NaBr were described as having delayed callus formation following induced fractures, compared with controls in a Russian study²⁵ in the 1950s. A study on rabbits²² and another on rats⁴⁷ reported that animals treated with NaBr had lower erythrocyte counts than did controls. These effects have not been reported in other studies; further information is needed to determine whether these findings have relevance for clinical use of KBr.

Therapeutic administration of KBr in dogs was not found to affect thyroid weight or serum total thyroxine, free thyroxine, triiodothyronine, and thyroid-stimulating hormone concentrations or to cause histologic changes.^{29,32} In rats and humans, effects have not been reported at therapeutic doses,^{43,60} but the thyroid has been identified as a target organ at higher doses. Changes in goitrogenic cellular amounts, identified on the basis of light

and electron microscopic evaluation of thyroid tissue, were reported in rats receiving 10, 50, 100, 200, and 400 mg of bromide (as KBr) for various durations.^{48,80–82} At very high doses (19,200 mg of NaBr/kg of feed [8,727.3 mg/lb of feed]), histologic changes in rat thyroid tissue (eg, increased number of smaller follicles, higher amounts of follicular epithelium, decreased amounts of colloid, and a more granular appearance) and reduced thyroxine concentration indicated decreased thyroid activity.⁴³ A statistically significant decrease in total thyroxine concentration was also identified in animals treated in another study⁴⁵ with similar design at doses $\geq 4,800$ mg/kg. In humans, a bromide intake of 9 mg/kg (4.1 mg/lb) led to increases in serum thyroxine and triiodothyronine concentrations in females, although individual serum concentrations remained within reference limits for the duration of the study.⁶⁰ Similar changes were not observed in male subjects or in any subjects treated with 4 mg of bromide/kg (1.8 mg/lb). No precise mechanism of action has been identified; however, effects on transport and perhaps synthesis of thyroid hormones caused by bromide inhibition of active iodide absorption by the thyroid gland have been suggested.³² Although no effects of KBr on the thyroid gland have been reported for dogs, monitoring serum thyroid hormone concentrations and evaluating thyroid tissues at necropsy would be helpful because available dog studies were small in size.

Polyuria and PD have been reported with clinical use of KBr in dogs. Polyuria and PD were documented in 13 of 23 dogs when KBr was added to PB treatment.⁶⁹ In a randomized, controlled trial^a of 43 epileptic dogs treated with either KBr or PB monotherapy, dogs in both groups developed PU and PD after 1 month of treatment. By 6 months, dogs treated with PB reportedly no longer had PU or PD; none of the dogs treated with KBr had PU, but PD was still present in 4% of these dogs.^a In a cross-sectional client survey,²⁷ PU and PD were not described by owners of the 4 dogs receiving KBr monotherapy, but were reported for more than half of the 11 dogs treated with PB and for all 10 dogs treated with both KBr and PB. Polydipsia has also been reported in a cat treated with KBr.³⁸ This limited and conflicting information makes it difficult to draw conclusions about the relationship between KBr administration and PU and PD.

Skin lesions were rarely reported in experimental overdose studies or in summaries of clinical cases of bromide intoxication in dogs identified in the present study. When reported, skin lesions in dogs were described as nonsuppurative white macules with scales³³ or as pustular dermatitis.²⁸ Pruritic skin lesions were anecdotally listed as an occasional adverse effect in dogs in 2 reviews.^{9,121} In a survey, owners reported pruritus in 1 of 4 dogs treated with KBr; however, no skin changes were described.²⁷ Skin lesions were not commonly reported in rats but, when observed, were ascribed to poor grooming secondary to neurologic effects.^{46,47} In a report³ of 400 human cases of bromism, cutaneous lesions were a relatively common adverse effect and have been reported in other studies.^{5,54–56,59,95} Lesions reported in human cases include acne, bromoderma tuberosum, bromoderma nodosum, and necro-

tizing panniculitis. These lesions may be accompanied by fever, joint and muscle pain, and atrophy of subcutaneous fat.⁵⁵ The mechanisms are unknown, but dermatologic lesions have been attributed to both allergic and toxic reactions to accumulated bromide.⁵⁶ Overall, dermatologic reactions are not expected to be a problem with clinical KBr use in dogs because of the very small number of cases reported to date.

Respiratory problems were not reported in clinical or toxicity studies in dogs or humans identified in the present study. One author⁶² mentioned, as part of a review chapter, that he had encountered several cases of coughing in dogs being treated with KBr. In cats, coughing and dyspnea are a major concern and have been reported following KBr treatment. In 1 study,³⁸ 6 of 17 cats developed coughing during KBr treatment and 1 had a severe bronchial lung pattern on thoracic radiographs. Sarkisov,²¹ in the 1950s, reported that 14 cats treated with NaBr recovered less completely from experimentally induced bacterial pneumonia than did 15 control cats. Treated cats had a clinically prolonged course and developed histologic changes, including thickened bronchiolar walls, alveolar exudate, and emphysema. In another study,³⁹ 11 of 26 cats treated clinically with KBr developed coughing and dyspnea. Two of these cats treated continuously with KBr had severe signs for several months and subsequently died. High eosinophil counts were present in bronchoalveolar lavage samples collected from 2 of the 11 cats. Feline bronchial asthma, one of the most commonly diagnosed respiratory conditions of cats, is traditionally associated with eosinophilic infiltration.¹³² Eosinophils preferentially use bromide to form oxidants that can cause cytotoxicosis, despite low serum bromide concentrations.¹³³ Studies have not examined the effects of high serum bromide concentrations on eosinophil function. Although the literature supports a concern for KBr administration and respiratory disease in cats, adverse respiratory effects are not expected in dogs on the basis of publications reviewed in the present study.

In the present study, we were able to identify a substantial number of publications providing information relevant to evaluation of the safety of KBr in dogs. The publications that provided primary evidence for this review followed > 170 dogs treated with KBr or NaBr and > 210 dogs treated with KBr combined with PB. However, many of these studies were relatively small, and there was a lack of large randomized, experimental or clinical trials that compared KBr administered alone with a placebo or an active control. Generally, randomized controlled trials and experimental laboratory studies provide the strongest evidence of drug effects.¹⁸ In these types of studies, individuals are randomly assigned to treatment groups to minimize bias and subjects are more intensively monitored for adverse events during the study period.¹³⁴ This makes attribution of effectiveness and ADEs of a particular drug much clearer. Randomized trials may also provide information about the frequency of particular ADEs and their relative importance in the study population. However, a limitation of these studies is that results may not reflect or predict how the drug will behave in a more diverse or less healthy general population.¹³⁵ Additionally, ad-

verse events that are rare or do not develop in the short period of the clinical trial may not be recognized.¹³⁴ Drawing on a full range of publications and including smaller nonrandomized or observational studies may avoid information loss and biases that occur in systematic reviews that use strict exclusion criteria.¹³⁶ A number of reviews of human drugs have found that case reports and spontaneous reporting systems provide better information than do clinical trials about new and unexpected ADEs.^{137,138} Therefore, the consistency, quality, and quantity of the evidence were evaluated in each article that dealt with safety issues related to KBr, rather than excluding studies on the basis of the type of study design. Important safety information was found in studies of all types. Case studies,^{7,13,15,36,37,63,65,84} for example, provided valuable specifics for several kinds of ADEs not reported in other study types.

The present systematic literature review differed from the laboratory-based studies more traditionally used to determine safety of new animal drugs (ie, evaluation of clinical and pathological changes in 4 groups of healthy laboratory dogs, with each group receiving either 0, 1, 3, or 5 times the therapeutic dose).¹¹⁸ Although data were available from several studies^{28,30,32,33} on bromide overdose, results in other publications provided summary information rather than the detailed individual data that are generally submitted for new animal drug approval. Much of the available literature was from client-owned pets with idiopathic epilepsy that were treated with KBr or PB under conditions of clinical use. Although the amount of detail for each animal was more limited, these pet owner reports included adverse events that were subtle and occurred after longer periods of administration (eg, PU and PD or behavioral signs). These may not be as readily noted in a laboratory setting or in a short-term clinical trial involving a selected population. Furthermore, the present systematic review allowed the evaluation of > 50 years of literature on the use of KBr in dogs, providing a volume and variety of evidence that far exceeded the data traditionally available to determine the safety of new animal drugs. Related findings in laboratory animals and humans that supported the available information for dogs could also be integrated. If KBr becomes more frequently used as monotherapy, future analyses may allow more complete systematic reviews and meta-analyses as well as further information on the safety questions raised in the present review.

On the basis of known pharmacological properties of bromides and specific information in the 111 publications identified in the present study, safety concerns for KBr could be evaluated and summarized for multiple physiologic systems. Bromide toxicosis in dogs was most frequently associated with high serum bromide concentrations; however, unusually sensitive dogs may also develop signs of toxicosis. The importance of monitoring clinical signs for individual animals should be emphasized because clinical signs may be a more useful measure of successful treatment than serum bromide concentration. Considerations that may affect the safety of KBr in individual animals include kidney and adrenal function, the amount of chloride in the diet, and the administration of IV fluids. Most adverse effects appeared to be reversible, but specific estimates of

incidence and comparative frequency of ADEs would provide a more thorough safety profile of KBr.

Neurologic signs were the most common type of ADE identified in the present study. Signs included sedation, irritability, restlessness, depression, behavioral changes, ataxia, hind limb paresis, mydriasis, stupor, and coma. Adverse neurologic effects were reported to be reversible and alleviated within several days by decreasing the PB dose or within hours by IV administration of saline solution. Adverse GI effects such as vomiting, transient diarrhea, and bloody feces have been reported in dogs but do not appear to require cessation of KBr treatment for resolution. Polyphagia and anorexia have been commonly reported for dogs receiving PB or KBr. Eating patterns and weight should be monitored in dogs receiving KBr, particularly because polyphagia can lead to garbage ingestion and other complications. There was not enough evidence at this time to conclude that dogs receiving KBr were at higher risk of developing pancreatitis than were dogs receiving other treatments. Pancreatitis may be related to polyphagia and garbage ingestion as well as to KBr treatment. Use of KBr in reproductively active dogs is of concern owing to the variety of reproductive effects reported in other species.

Results of the present review suggested that potential effects of KBr on thyroid function do not appear to be clinically important in dogs; however, more research is needed. Dermatologic reactions are not of concern with clinical KBr use in dogs, and respiratory disease in dogs is unlikely, considering the large amount of literature available and the very small number of cases reported.

Practitioners should use this information on KBr safety to tailor dosing and monitoring regimens specifically to individual dogs. Potassium bromide is not an appropriate therapeutic choice for every dog, which magnifies the importance of a valid veterinarian-client-patient relationship when determining whether an individual dog is a candidate for KBr treatment. Communication of the spectrum of potential adverse effects to owners and encouragement of close home monitoring for ADEs, especially for dogs on concurrent medications and with concurrent diseases, are important safety measures. Ultimately, availability of an FDA-approved KBr product with appropriate labeling information would provide better assurance for veterinarians and their clients of the quality, safety, and effectiveness of this product for animal use.

- a. Boothe D. Comparison of phenobarbital and bromide as first choice anticonvulsant therapy in the canine epileptic (abstr), in *Proceedings*. 20th Annu Am Coll Vet Intern Med Forum 2002;369.
- b. Dewey CW, Ducote JM, Coates JR, et al. Intrarectally administered potassium bromide loading in normal dogs (abstr), in *Proceedings*. 17th Annu Am Coll Vet Intern Med Forum 1999;238.
- c. Mason MF. *Halide distribution in body fluids in chronic bromide intoxication*. PhD dissertation, Graduate School of Arts and Sciences, Duke University, 1935;61–74.
- d. Dreifuss FE, Bertram EH. Bromide therapy for intractable seizures (abstr). *Epilepsia* 1986;27:593.
- e. George K, Boothe DM, Nguyen J, et al. Disposition of bromide in cats following oral administration of the potassium salt (abstr), in *Proceedings*. 14th Annu Am Coll Vet Intern Med Forum 1996;757.
- f. Trepanier LA. Pharmacokinetics and clinical use of bromide (abstr), in *Proceedings*. 11th Annu Am Coll Vet Intern Med Forum 1993;878–880.

References

1. Sieveking EH. Analysis of fifty-two cases of epilepsy as observed by the author. *Medical Times and Gazette* 1857;524–526.
2. Law J. *A guide to the prevention and treatment of disease in domestic animals*. 2nd ed. New York: Trow's, 1887.
3. Hanes FM, Yates A. An analysis of four hundred instances of chronic bromide intoxication. *South Med J* 1938;31:667–671.
4. Korinthenberg R, Burkart P, Woelfle C, et al. Pharmacology, efficacy, and tolerability of potassium bromide in childhood epilepsy. *J Child Neurol* 2007;22:414–418.
5. Nabatame S, Saito Y, Sakuma H, et al. Bromoderma in a patient with migrating partial seizures in infancy. *Epilepsy Res* 2010;91:283–288.
6. Friedlander WJ. The rise and fall of bromide therapy in epilepsy. *Arch Neurol* 2000;57:1782–1785.
7. Lugassy D, Nelson L. Case files of the medical toxicology fellowship at the New York City poison control: bromism: forgotten, but not gone. *J Med Toxicol* 2009;5:151–157.
8. Thomas WB. Idiopathic epilepsy in dogs and cats. *Vet Clin North Am Small Anim Pract* 2010;40:161–179.
9. Chandler K. Treatment and monitoring of epilepsy in dogs. *In Pract* 2011;33:98–104.
10. Taylor SM. Seizures. In: Nelson RW, Couto CG, eds. *Small animal internal medicine*. 4th ed. St Louis: Mosby Inc, 2009;1036–1053.
11. Kluger EK, Malik R, Govendir M. Veterinarians' preferences for anticonvulsant drugs for treating seizure disorders in dogs and cats. *Aust Vet J* 2009;87:445–449.
12. Trepanier LA. Use of bromide as an anticonvulsant for dogs with epilepsy. *J Am Vet Med Assoc* 1995;207:163–166.
13. Dewey CW, Cerda-Gonzalez S, Levine JM, et al. Pregabalin as an adjunct to phenobarbital, potassium bromide, or a combination of phenobarbital and potassium bromide for treatment of dogs with suspected idiopathic epilepsy. *J Am Vet Med Assoc* 2009;235:1442–1449.
14. Platt S, Cherubini, GB. Refractory epilepsy in dogs. *Companion Anim* 2010;15:81–86.
15. Jacobs G, Calvert C, Kaufman A. Neutropenia and thrombocytopenia in three dogs treated with anticonvulsants. *J Am Vet Med Assoc* 1998;212:681–684.
16. Dayrell-Hart B, Steinberg SA, Van Winkle TJ, et al. Hepatotoxicity of phenobarbital in dogs: 18 cases (1985–1989). *J Am Vet Med Assoc* 1991;199:1060–1066.
17. Rossmeisl JH Jr, Zimmerman K, Inzana KD, et al. Assessment of the use of plasma and serum chloride concentrations as indirect predictors of serum bromide concentrations in dogs with idiopathic epilepsy. *Vet Clin Pathol* 2006;35:426–433.
18. Holmes MA. Philosophical foundations of evidence-based medicine for veterinary clinicians. *J Am Vet Med Assoc* 2009;235:1035–1039.
19. Genicot B, Mouligneau F, Lekeux P. Effect of an oral sedative on the behavior and the zootechnologic performance of fattening bulls of the white-blue Belgian breed [in German]. *Zentralbl Veterinarmed A* 1991;38:668–675.
20. Schwartz-Porsche D, Jurgens U. Effectiveness of bromide in therapy resistant epilepsy of dogs [in German]. *Tierarztl Prax* 1991;19:395–401.
21. Sarkisov DS. Characteristics of recurrent development of inflammatory changes in the lung following administration of sodium bromide. *Arkh Patol* 1956;18:67–73.
22. Neuman Z. Effect of caffeine, benzedrine, and sodium bromide on erythropoiesis. *Pol Arch Med Wewn* 1956;26:1365–1374.
23. Pfeifle J, Grieben U, Bork K. Bromoderma tuberosum caused by anticonvulsive treatment with potassium bromide [in German]. *Hautarzt* 1992;43:792–794.
24. Steinhoff BJ, Paulus W. Chronic bromide intoxication caused by bromide-containing combination drugs [in German]. *Dtsch Med Wochenschr* 1992;117:1061–1064.
25. Levchenko MA. Effect of sodium bromide on the course of bone fracture healing and on phosphor, calcium and cholesterol metabolism in dogs [in Russian]. *Ortop Travmatol Protez* 1955;2:14–18.
26. Limodin J, Delage A, Martin M, et al. Prescription of bromides, or how to avoid bromide salts toxicity [in French]. *Presse Med* 1991;20:1005–1006.
27. Chang Y, Mellor DJ, Anderson TJ. Idiopathic epilepsy in dogs: owners' perspectives on management with phenobarbitone and/or potassium bromide. *J Small Anim Pract* 2006;47:574–581.

28. Harris RS, Derian BA. Niacinamide in bromide intoxication. *South Med J* 1949;42:973–978.
29. Kantrowitz LB, Peterson ME, Trepanier LA, et al. Serum total thyroxine, total triiodothyronine, free thyroxine, and thyrotropin concentrations in epileptic dogs treated with anticonvulsants. *J Am Vet Med Assoc* 1999;214:1804–1808.
30. March PA, Podell M, Sams RA. Pharmacokinetics and toxicity of bromide following high-dose oral potassium bromide administration in healthy Beagles. *J Vet Pharmacol Ther* 2002;25:425–432.
31. Palmer JW, Clarke HT. The elimination of bromides from the blood stream. *J Biol Chem* 1933;99:435–444.
32. Paull LC, Scott-Moncrieff JC, DeNicola DB, et al. Effect of anticonvulsant dosages of potassium bromide on thyroid function and morphology in dogs. *J Am Anim Hosp Assoc* 2003;39:193–202.
33. Rosenblum I. Bromide intoxication. I. Production of experimental intoxication in dogs. *J Pharmacol Exp Ther* 1958;122:379–385.
34. Rossmesl JH, Inzana KD. Clinical signs, risk factors, and outcomes associated with bromide toxicosis (bromism) in dogs with idiopathic epilepsy. *J Am Vet Med Assoc* 2009;234:1425–1431.
35. Steiner JM, Xenoulis PG, Anderson JA, et al. Serum pancreatic lipase immunoreactivity concentrations in dogs treated with potassium bromide and/or phenobarbital. *Vet Ther* 2008;9:37–44.
36. Schwartz M, Muñana KR, Olby NJ. Possible drug-induced hepatopathy in a dog receiving zonisamide monotherapy for treatment of cryptogenic epilepsy. *J Vet Med Sci* 2011;73:1505–1508.
37. Yohn SE, Morrison WB, Sharp PE. Bromide toxicosis (bromism) in a dog treated with potassium bromide for refractory seizures. *J Am Vet Med Assoc* 1992;201:468–470.
38. Boothe DM, George KL, Couch P. Disposition and clinical use of bromide in cats. *J Am Vet Med Assoc* 2002;221:1131–1135.
39. Wagner SO. Lower airway disease in cats on bromide therapy for seizures (abstr), in *Proceedings. 19th Annu Am Coll Vet Intern Med Forum* 2001;562.
40. Buchberger W, Holler W, Winsauer K. Effects of sodium bromide on the biosynthesis of thyroid hormones and brominated/iodinated thyronines. *J Trace Elem Electrolytes Health Dis* 1990;4:25–30.
41. Disse M, Joó F, Schulz H, et al. Prenatal exposure to sodium bromide affects the postnatal growth and brain development. *J Hirnforsch* 1996;37:127–134.
42. Harned BK, Hamilton HC, Cole VV. The effect of the administration of sodium bromide to pregnant rats on the learning ability of the offspring. *J Pharmacol Exp Ther* 1944;82:215–226.
43. Loeber JG, Franken MA, van Leeuwen FXR. Effect of sodium bromide on endocrine parameters in the rat as studied by immunocytochemistry and radioimmunoassay. *Food Chem Toxicol* 1983;21:391–404.
44. Newsome WH, Yagminas AP, Villeneuve DC, et al. The effect of sodium bromide ingestion on the goitrogenic action of ethylenethiourea in the male rat. *Bull Environ Contam Toxicol* 1978;20:678–686.
45. van Leeuwen FXR, Dentonkelar EM, van Logten MJ. Toxicity of sodium-bromide in rats—effects on endocrine system and reproduction. *Food Chem Toxicol* 1983;21:383–389.
46. van Logten MJ, Wolthuis M, Rauws AG, et al. Short-term toxicity study of sodium bromide in rats. *Toxicology* 1973;1:321–327.
47. van Logten MJ, Wolthuis M, Rauws AG, et al. Semichronic toxicity study of sodium bromide in rats. *Toxicology* 1974;2:257–267.
48. Velický J, Titlbach M, Duskova J, et al. Potassium bromide and the thyroid gland of the rat: morphology and immunohistochemistry, RIA and INAA analysis. *Ann Anat* 1997;179:421–431.
49. Vobecký M, Pavelka S, Babický A. Bromide transfer through mother's milk and its impact on the suckling rat. *Biol Trace Elem Res* 2005;103:37–48.
50. Goldstein DB. Sodium bromide and sodium valproate: effective suppressants of ethanol withdrawal reactions in mice. *J Pharmacol Exp Ther* 1979;208:223–227.
51. Hansen K, Hubner H. Effects of bromide on behaviour of mice. *Food Chem Toxicol* 1983;21:405–408.
52. Knight HD, Reina-Guerra M. Intoxication of cattle with sodium bromide-contaminated feed. *Am J Vet Res* 1977;38:407–409.
53. Raidal SL, Edwards S. Pharmacokinetics of potassium bromide in adult horses. *Aust Vet J* 2008;86:187–193.
54. Bel S, Bartralot R, Garcia D, et al. Vegetant bromoderma in an infant. *Pediatr Dermatol* 2001;18:336–338.
55. Diener W, Sorni M, Ruile S, et al. Panniculitis due to potassium bromide. *Brain Dev* 1998;20:83–87.
56. Hafizi J, Majmudar V, Mathews S, et al. A case of bromoderma and bromism. *Br J Dermatol* 2008;158:427–429.
57. Kagitani-Shimono K, Imai K, Otani K, et al. Epilepsy in Wolf-Hirschhorn syndrome. *Epilepsia* 2005;46:150–155.
58. Millikan CH, Paul WD. Results of administration of varying doses of sodium bromide. *J Iowa State Med Soc* 1946;36:39–48.
59. Perkins HA. Bromide intoxication; analysis of cases from a general hospital. *Arch Intern Med (Chic)* 1950;85:783–794.
60. Sangster B, Blom JL, Sekhuis VM, et al. The influence of sodium-bromide in man—a study in human volunteers with special emphasis on the endocrine and the central nervous system. *Food Chem Toxicol* 1983;21:409–419.
61. Czerwinski AL. Bromide excretion as affected by chloride administration. *J Am Pharm Assoc Am Pharm Assoc* 1958;47:467–471.
62. Dewey CW. Anticonvulsant therapy in dogs and cats. *Vet Clin North Am Small Anim Pract* 2006;36:1107–1127.
63. Gaskill CL, Cribb AE. Pancreatitis associated with potassium bromide/phenobarbital combination therapy in epileptic dogs. *Can Vet J* 2000;41:555–558.
64. Kluger EK, Malik R, Ilkin WJ, et al. Serum triglyceride concentration in dogs with epilepsy treated with phenobarbital or with phenobarbital and bromide. *J Am Vet Med Assoc* 2008;233:1270–1277.
65. Nichols ES, Trepanier LA, Linn K. Bromide toxicosis secondary to renal insufficiency in an epileptic dog. *J Am Vet Med Assoc* 1996;208:231–233.
66. Pearce LK. Potassium bromide as an adjunct to phenobarbital for the management of uncontrolled seizures in dogs. *Progr Vet Neurol* 1990;1:95–101.
67. Piperisova I, Neel JA, Papich MG. What is your diagnosis? Marked hyperchloremia in a dog. *Vet Clin Pathol* 2009;38:411–414.
68. Platt SR, Adams V, Garosi LS, et al. Treatment with gabapentin of 11 dogs with refractory idiopathic epilepsy. *Vet Rec* 2006;159:881–884.
69. Podell M, Fenner WR. Bromide therapy in refractory canine idiopathic epilepsy. *J Vet Intern Med* 1993;7:318–327.
70. Schubert TA, Chidester RM, Chrisman CL. Clinical characteristics, management and long-term outcome of suspected rapid eye movement sleep behaviour disorder in 14 dogs. *J Small Anim Pract* 2011;52:93–100.
71. Schwartz-Porsche D, Jurgens N, May T, et al. Pharmacokinetics of bromide and bromide therapy in canine epilepsy, in *Proceedings. 4th Annu Symp Eur Soc Vet Neurol* 1990;32–34.
72. Shaw N, Trepanier LA, Center SA, et al. High dietary chloride content associated with loss of therapeutic serum bromide concentrations in an epileptic dog. *J Am Vet Med Assoc* 1996;208:234–236.
73. Sisson A. Current experiences with anticonvulsants in dogs and cats, in *Proceedings. 15th Annu Am Coll Vet Intern Med Forum* 1997;569–598.
74. Volk HA, Matiassek LA, Lujan Feliu-Pascual A, et al. The efficacy and tolerability of levetiracetam in pharmacoresistant epileptic dogs. *Vet J* 2008;176:310–319.
75. Balcar VJ, Erdő SL, Joó F, et al. Neurochemistry of GABAergic system in cerebral cortex chronically exposed to bromide in vivo. *J Neurochem* 1987;48:167–169.
76. Cozzolino MF, Pereira KF, Chopard RP. Analysis of thyroid gland microvascularization in rats induced by ingestion of potassium bromide: a scanning electron microscopy study. *Ann Anat* 2005;187:71–76.
77. Hayashi K, Ueshima S, Ouchida M, et al. Therapy for hyperthermia-induced seizures in Scn1a mutant rats. *Epilepsia* 2011;52:1010–1017.
78. Siklós L, Párducz A, Halász N, et al. An unbiased estimation of the total number of synapses in the superior cervical ganglion of adult rats established by the dissector method. Lack of change after long-lasting sodium bromide administration. *J Neurocytol* 1990;19:443–454.
79. Taylor A, Taylor NC. The effect of sodium bromide on tumor growth. *Cancer Res* 1964;24:751–753.
80. Velický J, Titlbach M, Lojda Z, et al. Expression of the proliferating cell nuclear antigen (PCNA) in the rat thyroid gland after exposure to bromide. *Acta Histochem* 1997;99:391–399.
81. Velický J, Titlbach M, Lojda Z, et al. Long-term action of potassium bromide on the rat thyroid gland. *Acta Histochem* 1998;100:11–23.
82. Velický J, Titlbach M, Lojda Z, et al. The effect of bromide on the ultrastructure of rat thyrocytes. *Ann Anat* 2004;186:209–216.

83. Grewal MS, Swineyard EA, Jensen HV, et al. Correlation between anticonvulsant activity and plasma concentration of bromide. *J Pharmacol Exp Ther* 1954;112:109–115.
84. Knight HD, Costner GC. Bromide intoxication of horses, goats, and cattle. *J Am Vet Med Assoc* 1977;171:446–448.
85. Liggett AD, Jain AV, Blue JL. Pseudohyperchloremia associated with bromide intoxication in a goat herd. *J Am Vet Med Assoc* 1985;187:72–74.
86. Fielding CL, Magdesian KG, Elliott DA, et al. Pharmacokinetics and clinical utility of sodium bromide (NaBr) as an estimator of extracellular fluid volume in horses. *J Vet Intern Med* 2003;17:213–217.
87. Anzai S, Fujiwara S, Inuzuka M. Bromoderma. *Int J Dermatol* 2003;42:370–371.
88. Berglund M, Nielsen S, Risberg J. Regional cerebral blood flow in a case of bromide psychosis. *Arch Psychiat Nervenkr* 1977;223:197–201.
89. Ernst JP, Doose H, Baier WK. Bromides were effective in intractable epilepsy with generalized tonic-clonic seizures and onset in early childhood. *Brain Dev* 1988;10:385–388.
90. Frances C, Hoizey G, Lamiable D, et al. Bromism from daily over intake of bromide salt. *J Toxicol Clin Toxicol* 2003;41:181–183.
91. Greenblatt M, Levin S, Schegloff B. Electroencephalographic findings in cases of bromide intoxication. *Arch Neurol Psychiatry* 1945;53:431–436.
92. Hsieh PF, Tsan YT, Hung DZ, et al. Bromism caused by mix-formulated analgesic injectables. *Hum Exp Toxicol* 2007;26:971–973.
93. Joyce DA, Matz LR, Saker BM. Renal failure and upper urinary tract obstruction after retrograde pyelography with potassium bromide solution. *Hum Toxicol* 1985;4:481–490.
94. Macleod N. Cure of morphine, chloral, and cocaine habits by sodium bromide. *Br Med J* 1899;1:896–898.
95. Maffei L, Musolino MC, Cambiaghi S. Single-plaque vegetating bromoderma. *J Am Acad Dermatol* 2008;58:682–684.
96. Mizukami Y, Funaki N, Hashimoto T, et al. Histologic features of thyroid gland in a patient with bromide-induced hypothyroidism. *Am J Clin Pathol* 1988;89:802–805.
97. Novo ML, Izumi T, Yokota K, et al. Urinary excretion of N-acetyl-beta-glucosaminidase and beta-galactosidase by patients with epilepsy. *Brain Dev* 1993;15:157–160.
98. Oguni H, Hayashi K, Oguni M, et al. Treatment of severe myoclonic epilepsy in infants with bromide and its borderline variant. *Epilepsia* 1994;35:1140–1145.
99. Pleasure JR, Blackburn MG. Neonatal bromide intoxication: prenatal ingestion of a large quantity of bromides with transplacental accumulation in the fetus. *Pediatrics* 1975;55:503–506.
100. Robe PA, Sadzot B, Frank G. Sodium bromide encephalopathy with decreased serum Cl⁻ level and increased anion gap: report of one case. *Eur Neurol* 2004;51:246–247.
101. Saito Y, Sugai K, Nakagawa E, et al. Treatment of epilepsy in severely disabled children with bilateral brain malformations. *J Neurol Sci* 2009;277:37–49.
102. Sangster B, Krajnc EI, Loeber JG, et al. Study of sodium bromide in human volunteers, with special emphasis on the endocrine system. *Hum Toxicol* 1982;1:393–402.
103. Takayanagi M, Yamamoto K, Nakagawa H, et al. Two successful cases of bromide therapy for refractory symptomatic localization-related epilepsy. *Brain Dev* 2002;24:194–196.
104. van Gelderen CE, Savelkoul TJ, Blom JL, et al. The no-effect level of sodium bromide in healthy volunteers. *Hum Exp Toxicol* 1993;12:9–14.
105. Vasuyattakul S, Lertpattanasuwan N, Vareesangthip K, et al. A negative anion gap as a clue to diagnose bromide intoxication. *Nephron* 1995;69:311–313.
106. Wenk RE, Lustgarten JA, Pappas NJ, et al. Serum chloride analysis, bromide detection, and the diagnosis of bromism. *Am J Clin Pathol* 1976;65:49–57.
107. Woody RC. Bromide therapy for pediatric seizure disorder intractable to other antiepileptic drugs. *J Child Neurol* 1990;5:65–67.
108. Wuth O. Rational bromide treatment. *J Am Med Assoc* 1927;88:2013–2017.
109. Yoshikawa S, Kayes SG, Parker JC. Eosinophils increase lung microvascular permeability via the peroxidase-hydrogen peroxide-halide system. Bronchoconstriction and vasoconstriction unaffected by eosinophil peroxidase inhibition. *Am Rev Respir Dis* 1993;147:914–920.
110. Howard S. A place for bromides? (lett). *Br J Addict* 1988;83:446.
111. Papich MG, Davidson G, Schnatz RG. Appreciation for study on bromide administration in dogs (lett). *J Am Vet Med Assoc* 2009;235:659.
112. Sisson A. Medical management of recurrent seizures in dogs and cats (lett). *J Vet Intern Med* 1990;4:181.
113. Trepanier LA. Bromism (lett). *J Am Vet Med Assoc* 1992;201:1820.
114. Boothe D. Management of refractory seizures, in *Proceedings*. 15th Annu Am Coll Vet Intern Med Forum 1997;88–90.
115. Schwartz-Porsche D. Epidemiological, clinical, and pharmacokinetic studies in spontaneously epileptic dogs and cats, in *Proceedings*. 4th Annu Am Coll Vet Intern Med Forum 1986;61–63.
116. Sisson AE. Diagnosis and treatment of seizure disorders of dogs and cats, in *Proceedings*. 8th Annu Am Coll Vet Intern Med Forum 1990;349–356.
117. Trepanier LA. Update on bromide and phenobarbital (abstr), in *Proceedings*. 26th World Small Anim Vet Assoc World Cong 2001.
118. *International cooperation on harmonisation of technical requirements for registration of veterinary products. Guidance for industry: target animal safety for veterinary pharmaceutical products*. VICH GL 43. Available at: www.fda.gov/downloads/animalveterinary/guidance-complianceenforcement/guidanceforindustry/ucm052464.pdf. Accessed Sep 1, 2011.
119. Trepanier LA, Babish JG. Pharmacokinetic properties of bromide in dogs after the intravenous and oral administration of single doses. *Res Vet Sci* 1995;58:248–251.
120. Podell M, Fenner WR. Use of bromide as an antiepileptic drug in dogs. *Compend Contin Educ Pract Vet* 1994;16:767–774.
121. Boothe DM. Anticonvulsant therapy in small animals. *Vet Clin North Am Small Anim Pract* 1998;28:411–448.
122. Adkin DA, Davis SS, Sparrow RA, et al. The effects of pharmaceutical excipients on small intestinal transit. *Br J Clin Pharmacol* 1995;39:381–387.
123. Podell M. Antiepileptic drug therapy. *Clin Tech Small Anim Pract* 1998;13:185–192.
124. Stolle A, Schwartz-Porsche D, Jurgens U, et al. The cumulation phase of bromide in combination therapy of canine epilepsy, in *Proceedings*. 18th World Cong World Small Anim Assoc 1993;270.
125. Trepanier LA, Babish JG. Effect of dietary chloride content on the elimination of bromide by dogs. *Res Vet Sci* 1995;58:252–255.
126. Dowling PM. Update on therapy of canine epilepsy. *Can Vet J* 1999;40:595–598.
127. Ho EN, Wan TS, Wong AS, et al. Control of the misuse of bromide in horses. *Drug Test Anal* 2010;2:323–329.
128. Shihab N, Bowen J, Volk HA. Behavioral changes in dogs associated with the development of idiopathic epilepsy. *Epilepsy Behav* 2011;21:160–167.
129. Hess RS, Kass PH, Shofer FS, et al. Evaluation of risk factors for fatal acute pancreatitis in dogs. *J Am Vet Med Assoc* 1999;214:46–51.
130. Nitsche CJ, Jamieson N, Lerch MM, et al. Drug induced pancreatitis. *Best Pract Res Clin Gastroenterol* 2010;24:143–155.
131. Lem KY, Fosgate GT, Norby B, et al. Associations between dietary factors and pancreatitis in dogs. *J Am Vet Med Assoc* 2008;233:1425–1431.
132. Venema CM, Patterson CC. Feline asthma: what's new and where might clinical practice be heading? *J Feline Med Surg* 2010;12:681–692.
133. Justino GC, Rodrigues M, Florencio MH, et al. Structure and antioxidant activity of brominated flavonols and flavanones. *J Mass Spectrom* 2009;44:1459–1468.
134. Papanikolaou PN, Christidi GD, Ioannidis JP. Comparison of evidence on harms of medical interventions in randomized and nonrandomized studies. *Can Med Assoc J* 2006;174:635–641.
135. Shrier I, Boivin JF, Steele RJ, et al. Should meta-analyses of interventions include observational studies in addition to randomized controlled trials? A critical examination of underlying principles. *Am J Epidemiol* 2007;166:1203–1209.
136. Turner RM, Spiegelhalter DJ, Smith GC, et al. Bias modelling in evidence synthesis. *J R Stat Soc Ser A Stat Soc* 2009;172:21–47.
137. Loke YK, Derry S, Aronson JK. A comparison of three different sources of data in assessing the frequencies of adverse reactions to amiodarone. *Br J Clin Pharmacol* 2004;57:616–621.
138. Aagaard L, Hansen EH. Information about ADRs explored by pharmacovigilance approaches: a qualitative review of studies on antibiotics, SSRIs and NSAIDs. *BMC Clin Pharmacol* 2009;9:1–14.