Economic evaluation of an oral rabies vaccination program for control of a domestic dog–coyote rabies epizootic: 1995–2006

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Objective—To conduct a benefit-cost analysis of the results of the domestic dog and coyote (DDC) oral rabies vaccine (ORV) program in Texas from 1995 through 2006 by use of fiscal records and relevant public health data.

Design—Retrospective benefit-cost analysis.

Procedures—Pertinent economic data were collected in 20 counties of south Texas affected by a DDC-variant rabies epizootic. The costs and benefits afforded by a DDC ORV program were then calculated. Costs were the total expenditures of the ORV program. Benefits were the savings associated with the number of potentially prevented human postexposure prophylaxis (PEP) treatments and animal rabies tests for the DDC-variant rabies virus in the epizootic area and an area of potential disease expansion.

Results—Total estimated benefits of the program approximately ranged from $89 million to $346 million, with total program costs of $26,358,221 for the study period. The estimated savings (ie, damages avoided) from extrapolated numbers of PEP treatments and animal rabies tests yielded benefit-cost ratios that ranged from 3.38 to 13.12 for various frequencies of PEP and animal testing.

Conclusions and Clinical Relevance—In Texas, the use of ORV stopped the northward spread and led to the progressive elimination of the DDC variant of rabies in coyotes (*Canis latrans*). The decision to implement an ORV program was cost-efficient, although many unknowns were involved in the original decision, and key economic variables were identified for consideration in future planning of ORV programs. (*J Am Vet Med Assoc* 2008;233:1736–1741)

Rabies is an acute, viral, encephalitic disease unique to mammals.[1] Following the onset of symptoms, the neurologic effects of infection with the rabies virus are usually fatal. In 2006, cases of rabies in wildlife accounted for 6,393 of the 6,943 (92%) animal cases reported in the United States.[2]

Major economic damages of rabies result from public health investigations, animal rabies tests, PEP treatments, livestock deaths, pet vaccinations, and public education efforts.[3–5] Numerous researchers have used accounting-type data to characterize these impacts.[3,4] Retrospective economic assessments[6–11] have revealed that costs spike during rabies epizootics, and a few have quantified costs associated with rabies and ORV programs. Additionally, the economics of ORV programs were modeled in 2 studies[12,13] by means of benefit-cost analysis, with increased PEP and pet vaccinations as the main expenses incurred because of rabies. An investigation[11,13] of an epizootic of raccoon (*Procyon lotor*)-variant rabies in New Jersey revealed that the costs of pet vaccination increased by approximately 20% when negligent owners rushed to have their companion animals protected.

Abbreviations

DDC	Domestic dog and coyote
ORV	Oral rabies vaccination
PEP	Postexposure prophylaxis

During 1988, an epizootic of DDC-variant rabies began in south Texas.[14] Domestic dogs (*Canis familiaris*) were the main host reservoir, but the virus is capable of sustained transmission and maintenance in coyotes (*Canis latrans*).[1,15] In the subsequent 6 years, DDC-variant rabies was confirmed in 531 animals, mostly domestic dogs (216) and coyotes (270), within an 18-county area.[16] It was estimated that the epizootic was spreading northward from the Rio Grand Valley at a mean rate of 70 to 80 km/y (approx 45 miles/y).[17]

In January and February of 1995, aerial baiting was used to dispense 19, 23, or 27 baits/km^2 over all or portions of 24 counties in south Texas (38,850 km^2).[17] Baits consisted of a recombinant form of vaccinia virus that expressed the immunogenic glycoprotein fraction of the rabies virus and was contained in a polyethylene sachet in a hollow cube of dog-food or fish-meal material. Published data from these initial (1995) campaigns

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to control rabies indicated that new cases of DDC rabies in coyotes ceased in the northernmost counties of the ORV zone (ie, spread had stopped).[16]

Between 1996 and 2003, the area of the epizootic was rebaited annually and DDC-variant rabies was progressively eliminated from the United States, as the baited area moved southward toward the Rio Grande River.[17] During that time (1996 through 2003), 9.35 million baits (19 to 27 baits/km^2) were dispensed over 390,052 km^2. Data for these later campaigns to control rabies suggested a decline of cases of DDC-variant rabies in the regions in which baits were dropped, from 142 in 1995 to 0 by 2003.[16] Review of the records from the Texas Department of State Health Services revealed that human PEP treatments and animal tests related to DDC-variant rabies peaked at 176 in 1992 and 966 in 1995, then declined to 0 in 2002. Mean number of cases in 1996 through 2006 was 346. Currently, an ORV zone measuring approximately 65 km in width that is north of the Rio Grande River is maintained to prevent the reemergence of the DDC variant back into the United States.[18]

Benefit-cost analysis is a common tool used by economists to evaluate government programs and determine the efficiency of management efforts a priori.[19] Nevertheless, the method can be used to retrospectively examine completed programs by use of preexisting data. In this type of analysis, the monetary benefits and costs of program actions are identified and compared. One accepted methodology to value nonmarket services (eg, preventing disease in wildlife) is the damage-avoided method.[20] This method uses the value of resources protected as a measure of the benefits.[21]

The purpose of the study reported here is to provide a retrospective benefit-cost analysis of the DDC ORV program in south Texas from 1995 through 2006. The total actual cost of the program was compared to the estimated benefits from potentially prevented PEP treatments and animal rabies tests in the area of the epizootic and an area of potential disease expansion.

Materials and Methods

Epizootic area—For the analysis, the region of the DDC-variant rabies epizootic (epizootic area) included 20 counties in which the population density of humans ranged widely. Sparsely populated counties (< 1 person/25 hectares) included Brooks, Dimmit, Duval, Jim Hogg, Kenedy, La Salle, McMullen, and Zavala. Moderately populated counties (1 to 6 people/25 hectares) included Atascosa, Frio, Jim Wells, Kleberg, Live Oak, Starr, Webb, Willacy, and Zapata. Densely populated counties (> 10 people/25 hectares) included Cameron, Hidalgo, and Nueces.[21]

Benefit-cost analysis—A damage-avoided approach to benefit-cost analysis was used. It was posited that the ORV baiting program contained and eliminated DDC-variant rabies in south Texas and prevented the spread of this variant through the rest of the state (ie, an additional 232 counties where the disease was predicted to spread). Costs incurred as a result of the DDC ORV program included those for baits, air time, fuel, ground baiting, surveillance, and project planning and evaluation. Total cost was defined as the total expenditures for the DDC ORV program in Texas from 1995 through 2006 as reported by the Texas Department of State Health Services and the USDA Wildlife Services. The benefits were presumed equal to the savings that resulted from the 12-year program. Those savings theoretically included fewer human PEP treatments, human deaths, animal tests for DDC-variant rabies virus, and vaccinations of domestic animals. However, because of data limitations, only the number of humans that received PEP treatment and numbers of other animals tested for infection with the rabies virus were used to estimate the savings. These potential savings were estimated for 2 areas of Texas: within the 20-county epizootic area in south Texas and in the remaining 232 counties of Texas (an area of potential disease expansion).

To determine the savings, total performed PEP treatments of humans and tests of other animals for the rabies virus were estimated as if the DDC ORV program had never been undertaken. That is, the annual numbers of PEP treatments and animal tests carried out in the epizootic area prior to ORV baiting (pre-ORV) were used as proxies for rabies-related damages. Another study[22] revealed that testing of potentially rabid animals increases following a rabies epizootic, suggesting that these costs would remain elevated for a prolonged period.

Data regarding annual PEP treatments and animal tests associated with DDC-variant rabies in the epizootic area from 1988 through 2006 were obtained from records of the Texas Department of State Health Services Zoonosis Control Branch. Their policy was to test only nonhuman animals that had potentially exposed a human or domestic animal to rabies; active surveillance was not routinely conducted.[23] Therefore, when a human was identified as having potentially been exposed to rabies and the suspect animal was not available for testing or quarantine, the person immediately received the first series of PEP treatments. When an animal was captured for testing or was quarantined, a decision was made to cease or complete the full series of PEP treatments.

In the first year of the study (1995), ORV baiting began during January, and the vaccine did not actively protect the coyote population until mid-April at the earliest.[17] Thus, data from 1995 were included in the pre-ORV calculations (1988 through 1995), and years 1996 through 2006 were considered the period when potential ORV savings were accrued. Although this method of classification was arbitrary, comprehensive vaccination of the entire coyote population in the ORV area during the earlier ORV program was considered remote and unlikely to yield immediate reductions in numbers of PEP treatments or animals submitted for rabies-virus tests.

It was assumed that without the DDC ORV program, 2 events would have occurred. First, the numbers of PEP treatments and animal tests in the epizootic area would have likely continued at pre-ORV values; second, the DDC-variant virus would have spread north-

ward, out of the epizootic area, to the rest of the state. To estimate the number of PEP treatments administered and animal tests performed in epizootic area in the absence of the program, the mean number of PEP treatments and animal tests in the pre-ORV period (1988 through 1995) was projected at a fixed constant into the ORV period (1996 through 2006). The difference between the estimated number and the actual number in the ORV period was determined to be the potential savings attributed to the DDC ORV program in the epizootic area.

Potential expansion area—The savings in costs associated with PEP treatments and animal tests that would have accrued for those Texas counties outside the epizootic area (the potential expansion area) if the DDC ORV program had never been initiated were also estimated. The frequency of PEP treatments and animal tests in the epizootic area during the pre-ORV period served as a proxy for extrapolation to the area of potential disease spread.

An initial (albeit simplistic) model of the potential spread of the DDC-variant rabies was based on a projected annual mean case-advancement rate.[17] This mean rate was determined empirically by use of data from geographic locations of animals identified as infected with the rabies virus from 1988 through 1994 in the south Texas counties in which DDC-variant rabies virus was epizootic.[17] In 1995, this was considered a worst-case public-health scenario for the state. The potential spread of the virus into urban San Antonio and beyond was regarded as likely to increase the number of cases of DDC-variant rabies and to make control of the epizootic doubtful.[17]

Although it was unlikely that the spread of DDC-variant rabies virus would advance at a fixed (70 to 80 km/y) geographic rate, this rate was used for 3 reasons. First, evidence suggested that the spread of other variants of rabies virus can advance rapidly and irregularly because of unexpected translocations of animals, making alternative scenarios for rabies movement also suspect.[24] Second, use of a fixed rate of spread allowed straightforward population-based projections of numbers of PEP treatments and animal rabies tests. Third, it was the basis for the 1995 decision to begin the DDC ORV program.[17] An assessment of the economic efficiency of this government-funded program was sought and not a model of potential scenarios of rabies spread. Considering the myriad hypothetical scenarios for heterogenous spread of the DDC-variant rabies virus, it was reasoned that extrapolations of fixed radii would provide a standardized point of comparison for other, more biologically based scenarios of the benefits and costs of ORV programs in the future.

To estimate the numbers of PEP treatments and animal tests prevented by stopping the progression of DDC-variant rabies outside of the epizootic area into the rest of Texas, the numbers of PEP treatments and animal tests within the epizootic area were calculated. The annual numbers of PEP treatments and animal tests from the pre-ORV period were then averaged across all counties in the epizootic area, including 2 counties in which no PEP treatments were administered. Thus, the estimates of the numbers of PEP treatments and animal tests were annual means within each of the 20 counties and averaged for the pre-ORV period on a per-100,000-residents basis. This approach was similar to standard measurements of epizootic rabies frequencies used in other studies.[7,9,11,18] The numbers of PEP treatments and animal tests were used as the foundation for savings projections northward through the potential expansion area. Human population statistics were used as a straightforward method for extrapolating the number of potentially prevented PEP treatments and animal tests throughout Texas.

It was determined that, in the epizootic area, the annual number of PEP treatments administered/100,000 people was 56 and the annual number of animal tests performed/100,000 people was 243. Because of the unpredictable nature of disease spread, numbers within the epizootic area were used as the maximum potential case rate to estimate respective frequencies in the potential expansion area, and 2 reduced frequencies (50% and 25%) were also estimated to provide more conservative scenarios of disease spread.

To determine savings attributable to PEP treatments and animal tests in the potential expansion area, the frequency of PEP treatments and animal tests in the epizootic area from 1988 through 1995 was extrapolated on the basis of human population densities, following the projected annual expansion of the DDC-variant rabies virus northward through Texas at 70 to 80 km/y (approx 45 miles/y).[17] Counties encompassed annually by the predicted 70- to 80-km disease expansion radii accounted for the remaining 232 counties included in the analysis (ie, 2 counties were not included in the savings estimate because the hypothetical spread of DDC-variant rabies virus did not encompass these counties during the study period). Inclusion of a county into each annual savings calculation occurred in the specific year that the annual radius of 70 to 80 km reached at least the geographic midpoint of a county.

After predicting the numbers of PEP treatments and animal tests that may have occurred in the absence of the DDC ORV program in both the epizootic and potential expansion areas, actual numbers were subtracted from predicted numbers to estimate numbers of PEP treatments and animal tests that were hypothetically prevented. In the potential expansion area, actual numbers of PEP treatments and animal tests were zero because DDC-variant rabies virus was never allowed to spread. Then, the monetary savings from PEP treatments and animal tests that were hypothetically prevented were determined by multiplying the numbers of prevented PEP treatments and animal tests by their respective costs. The costs of human PEP treatment (biologics, emergency room visits, and doctor visits) and nonhuman animal testing (animal control and public health costs) were estimated on the basis of published data,[10] which indicated that typical costs associated with PEP treatments and animal tests were $2,540 and $450, respectively, in 2006 dollars.

Benefit-cost analysis—Total benefits of the DDV ORV program were set to equal saved expenditures associated with PEP treatments and animal tests attributable to DDC-variant rabies virus as follows:

$$TB^I = PEP^I_{saved} + AT^I_{saved}$$

in which TB represents total benefits, PEP_{saved} represents saved costs of PEP treatments, AT_{saved} represents saved costs of animal tests, and I represents the potential frequency of disease (ie, 100%, 50%, or 25% of the frequency of disease reported for the epizootic area). The predicted number of PEP treatments was the sum of estimates for the epizootic area and the population-based potential expansion area at certain frequencies. The sum was cumulative, meaning that savings from prevented PEP treatments continued to compound year after year as the DDC-variant rabies virus spread to new counties. The difference between predicted and actual savings from prevented PEP treatments represented the savings (benefits) resulting from the entire DDC ORV program over the relevant time period (1996 through 2006).

Saved costs of human PEP treatments were calculated by means of the following formula:

$$PEP^I_{saved} = (PEP^I_{predicted} - PEP_{actual}) \times PEP_{costs}$$

in which $PEP_{predicted}$ represents the predicted number of PEP treatments, PEP_{actual} represents the actual number of PEP treatments, and PEP_{costs} represents the estimated cost of PEP treatments.

Saved costs of animal tests were calculated as follows:

$$AT^I_{saved} = (AT^I_{predicted} - AT_{actual}) \times AT_{costs}$$

in which $AT_{predicted}$ represents the predicted number of animal testing, AT_{actual} represents the actual number of animal testing, and AT_{costs} represents the estimated cost of testing animals for the rabies virus.

The estimates of costs associated with PEP treatments and animal tests were in 2006 dollars. Therefore, the total benefit represented the 2006 value of the entire DDC ORV program over the study period.

Benefit-cost ratios—Standard benefit-cost ratios[20,25–28] were calculated at 3 frequencies (100%, 50%, and 25%) of human PEP treatments and animal tests for rabies that were estimated for the epizootic area. A ratio of 1.0 indicated that the benefits (savings) and costs were equal, or in other words, 1 unit of costs yielded 1 unit of benefits. A benefit-cost ratio > 1.0 indicated that the benefits of the program outweighed the costs and that the moneys allocated were economically efficient.

In programs that span several years, many times the best determination of efficiency is over the entire lifetime of the project rather than over 1 year,[19] therefore the ratios used compared the benefits and costs (in 2006 dollars) of the entire program as opposed to on an annual basis. The costs of the entire DDC ORV program were compared to the total benefits that would have accrued from 1995 through 2006.

The benefit-cost ratios associated with the epizootic area were determined by use of the following equation:

$$Ratio^I = (PEP^I_{saved} + AT^I_{saved})/(TDSHS_{expenditures} + FG_{expenditures})$$

in which $TDSHS_{expenditures}$ represents funding provided by the state and $FG_{expenditures}$ represents funding provided by the federal government.

Sensitivity analysis—A limited sensitivity analysis was performed to determine the minimum number of PEP treatments and animal tests needed for the DDC ORV program to break even or have a benefit-cost ratio of 1.0 over the study period. The benefit-cost ratio was constructed in terms of a range of frequencies of PEP treatments and animal tests to reduce uncertainty about the magnitude of the impact predicted and the cost values estimated for each. The initial analysis incorporated this uncertainty by use of the most plausible assumptions to estimate the potential number of each of these unknown quantities. Such an analysis acknowledges the uncertainty in the benefit-cost ratios and evaluates the sensitivity of the results to a change in one of the variables (number of PEP treatments or animal testing).

Results

Total estimated benefits of the DDC ORV program from 1995 through 2006 at the 3 frequencies of human PEP treatments and animal tests for rabies (100%, 50%, and 25% of frequencies estimated for the epizootic area) were $345,800,684, $174,692,341, and $89,138,169, respectively (**Table 1**). The total cost of the DDC ORV program was $26,358,221.

Economic efficiency of the DDC ORV program (benefit-cost ratios > 1.0) was achieved for all 3 estimated frequencies of PEP treatments and animal tests. When the numbers of prevented PEP treatments and animal tests were presumed to be the same as those for the epizootic area (ie, 100%), the potential benefits were approximately 13 times the costs, whereas when the numbers of prevented PEP treatments and animal tests were presumed to be 50% or 25% those of the epizootic area, the benefits were approximately 7 or 3 times the costs, respectively (Table 1). Overall, for every dollar spent on the DDC ORV program, between $3.38 and $13.12 in savings was realized.

Table 1—Total benefits, total costs, and benefit-cost ratios (values in 2006 dollars) associated with a DDC ORV program in south Texas conducted from 1995 through 2006, calculated on the basis of various estimated frequencies of human PEP treatments and animal tests for rabies in an epizootic and potential expansion area.

Frequency (%)	Program benefits	Program costs	Benefit-cost ratio
100	$345,800,684	$26,358,221	13.12
50	$174,692,341	$26,358,221	6.63
25	$89,138,169	$26,358,221	3.38

According to the results of the sensitivity analysis, if the spread of DDC rabies through the rest of Texas occurred at only 7% of the frequency within the epizootic area, then the DDC ORV program would have approximately broken even over the study period (1995 through 2006). The benefit-cost ratio at that frequency was 1.04 ($27,539,166/$26,358,221).

Discussion

Retrospective evaluation indicated that the decision to implement an ORV program to control the spread of DDC-variant rabies virus and progressively eliminate this virus variant in coyotes of south Texas was economically efficient. Although an ORV program to control a variant of the rabies virus associated with Arctic fox (*Alopex lagopus*) and transmitted via red foxes (*Vulpes vulpes*) also progressively eliminated the disease in foxes of Ontario, Canada, no economic assessment of that program was reported.[29] Results of our analysis confirmed the cost-effectiveness of this type of ORV strategy to progressively eliminate rabies in canids.

We sought to conservatively estimate the benefits of the DDC ORV program in south Texas. Incorporation of more of the costs of rabies (eg, pet and livestock vaccinations, rabies educational programs, human deaths, or pet and livestock replacements) as sources of potential savings would undoubtedly have increased the projected efficiency of the program.[5,11,18] Total costs associated with human exposure to a rabid animal can be subdivided into direct and indirect costs.[10] Direct costs refer to those associated with the PEP vaccine and other biologics, whereas indirect costs refer to those associated with over-the-counter medicines, travel to physicians, and lost time from work associated with treatment, for example. Indirect costs account for about a third of the total costs associated with human exposure to a rabid animal[10] but were not included in the calculation of benefits in our study. Although 2 human deaths attributable to infection with the DDC-variant rabies virus reportedly occurred in south Texas during the epizootic of 1988 through 1995, no estimate of these values was included. Potential benefits from the prevention of human death were omitted from analysis. Additionally, vaccination of pets and some livestock undoubtedly increased during the DDC-variant rabies epizootic, but data regarding these variables were difficult to obtain and judged unreliable. Other studies[11,13] have revealed that increased pet vaccinations contribute substantially to costs associated with a rabies epizootic.

Estimation of a range of possible frequencies of PEP treatments and animal tests was useful; however, we recommend incorporation of different scenarios of disease spread and resulting risks of human exposure when feasible. Choosing an appropriate frequency with which to perform PEP treatments and animal tests may depend on a suite of factors, including densities of human and coyote populations, baiting efficacy, bait density, consumption of baits by nontarget animals, and other factors. Techniques designed to reduce uncertainty can only aid programmatic decision making in benefit-cost analyses.

Economic efficiency is one of many factors that play a role in determining the usefulness of ORV programs. The retrospective study reported here revealed that the decision to implement an ORV program in a wide geographic region was cost-efficient, even though many unknowns were involved in the original decision. The analysis of benefits and costs associated with the Texas DDC ORV program identified key economic variables and procedures that will improve a priori analyses and decision making in future ORV planning.

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Selected abstract for *JAVMA* readers from the *American Journal of Veterinary Research*

Evaluation of *Mycoplasma hyopneumoniae* bacterins for porcine torque teno virus DNAs
Steven Krakowka et al

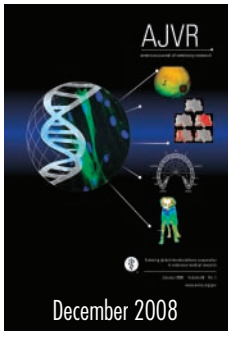
Objective—To determine whether commercial *Mycoplasma hyopneumoniae* bacterins sold for use in swine contain porcine torque teno virus (TTV).

Sample Population—22 commercially available *M hyopneumoniae* bacterins.

Procedures—Direct and nested PCR assays for genogroup-specific TTV DNAs were performed on serials of *M hyopneumoniae* bacterins by use of published and custom-designed primer pairs at 3 laboratories in North America and Europe.

Results—Of the 22 bacterins tested by use of direct and nested PCR assays, 7 of 9 from the United States, 2 of 5 from Canada, and 4 of 8 from Europe contained genogroup 1– and genogroup 2–TTV DNAs. In some bacterins, the TTV DNAs were readily detected by use of direct PCR assays.

Conclusions and Clinical Relevance—Analysis of these data indicated that many of the commercially available *M hyopneumoniae* bacterins were contaminated with TTV DNA. It is possible that some of these bacterins could inadvertently transmit porcine TTV infection to TTV-naïve swine. (*Am J Vet Res* 2008;69:1601–1607)



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