Feedlot Sessions

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The Economics of Diagnostic Testing

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Abstract

Biosecurity is the attempt to keep infectious agents away from a herd or feedlot. Diagnostic screening tests of all incoming (apparently healthy) cattle can be used to identify and remove animals that carry contagious pathogens, with the desired result of reducing disease risk. To determine if such a biosecurity strategy is economically rewarding, veterinarians must know the sensitivity and specificity of the diagnostic test, prevalence of carrier animals, cost of testing and cost of the disease should it enter the population. In some situations additional tests, either in series or in parallel, may increase the economic return for a testing strategy. In other situations, cost of screening for biosecurity purposes may be greater than the cost of a rare disease, but the potential disruption in cash flow from that rare occurrence may cause some producers to institute testing to avoid that rare possibility.

Résumé

La biosécurité a pour but, notamment, de garder un troupeau ou un parc d'engraissement à l'abri des agents infectieux. Par exemple, on peut effectuer des tests de dépistage diagnostique sur tous les nouveaux bovins arrivant (apparemment en bonne santé) dans le troupeau, pour identifier et mettre à l'écart les sujets porteurs d'agents pathogènes contagieux, afin de réduire les risques de maladies. Pour déterminer si une telle stratégie de biosécurité est rentable, les vétérinaires doivent connaître la sensibilité et la spécificité du test de diagnostic, la prévalence des animaux porteurs, le coût du test ainsi que celui de la maladie, advenant son apparition dans le cheptel. Dans certains cas, des tests additionnels, effectués en série ou en parallèle, améliorent la rentabilité d'une stratégie de dépistage. Dans d'autres situations, le coût de ce dépistage biosécuritaire peut dépasser le coût relié à une maladie rare, mais la perturbation des rentrées d'argent qu'elle causerait pourrait inciter certains producteurs à imposer son dépistage systématique, pour prévenir toute possibilité d'infection.

Introduction

Many veterinarians express frustration when trying to determine the economic value of diagnostic testing procedures, particularly diagnostic screening of apparently healthy animals to identify carriers. To determine the economic return for diagnostic testing strategies, veterinarians need information on sensitivity and specificity of available diagnostic tests, prevalence of the condition in question in the population at large and specified sub-populations, disease dynamics such as reservoir, transmission pattern, incubation period, immune response and pathogenicity (if diagnosing an infectious disease), treatment efficacy, and negative or unintended consequences of diagnosis or treatment. Food animal veterinarians must also have data on the economic cost of the condition and the economic cost of intervention.

The most appropriate method to determine the economic value for diagnostic testing will vary depending on the condition in question, the time frame involved and how the diagnostic information will be utilized to make decisions. The most straightforward method is by utilizing a partial budget. For rare conditions or events, it may be more appropriate to determine the cost of a negative outcome and the cost of intervention and working with the client, determine his/her level of risk aversion, and together determine the value of reducing the risk of a rare event. For disease conditions with an endemic or long-term effect, and for production enhancement, multi-year enterprise or whole-farm assessment may be most appropriate. Some aspects of diagnostic testing may fall outside the ability of economic evaluations because the benefit and risk are immeasurable.

Determining Diagnostic Test Usefulness and Diagnostic Strategy

A valid question confronting veterinary practitioners is whether to use available diagnostic tests to screen a particular herd for a particular condition[4]. The input needed to arrive at a logical conclusion includes epidemiologic data about the condition or disease, diagnostic test sensitivity and specificity data, disease or condition dynamics and economic costs of the condition and its treatment.[1] Literature review and mathematic aids, such as computer spreadsheets and expert systems, are the tools used to create the necessary outputs. These outputs include post-test predictive values of diagnostic tests, economic value of testing, sensitivity of the decision to the individual inputs and the importance of individual inputs to the decision. These outputs are used to evaluate alternate diagnostic testing strategies in order to indicate the best testing strategy, and to identify the control points to be monitored for change that can trigger a re-evaluation of the decision.

Sensitivity and specificity of diagnostic tests

Sensitivity and specificity are properties of a diagnostic test that are determined by comparing the test to a "gold standard." The gold standard is considered the true diagnosis, and may be made using a variety of such information as clinical examination, expert opinion, laboratory results, or postmortem results. Sensitivity is the proportion of known positive (gold standard-positive) samples that the test in question identifies. Specificity is the proportion of known negative samples that the test in question identifies. In other words, sensitivity answers the question, "How effective is the test at identifying animals with the condition?" and specificity answers the question, "How effective is the test at identifying animals without the condition?" Because diagnostic tests (both laboratory and clinical examination tests) use an arbitrary cutoff to separate test-positive and test-negative populations, sensitivity and specificity are inversely related, and placing the cutoff is always a trade-off between the impacts of false-negative and false-positive results.[3]

Prevalence

Prevalence is the ratio of the number of cases of a condition at a given time to the population size at that time. The known or suspected prevalence is the probability of presence of the condition. Unfortunately, there is limited published, timely prevalence information for most infectious diseases of interest to veterinary medicine. Each practitioner's judgment, based on history and clinical examination of both individuals and the population, aided by available prevalence information, is often all we have to estimate disease probability.

For a test with imperfect specificity, an increasing proportion of positives will be false as prevalence decreases. At low prevalences, the majority of test positives will be false, so that for an uncommon condition, even a highly accurate test will render inaccurate results when applied to the animal population as a whole.

Post-test predictive value

The post-test predictive values of a test are determined not in the laboratory, but in the field and they tell a diagnostician if a valid test is useful. The positive predictive value is the proportion of animals with a positive test result that are actually positive, and is influenced by test specificity. The negative predictive value is the proportion of animals with a negative test result that are truly negative, and is influenced by test sensitivity. Both positive and negative predictive values of a test are affected by prevalence of the condition. As the prevalence of the condition rises, we have more animals with the condition in the population, and we have greater confidence that a positive test result is correct. With increasing prevalence, the positive predictive value of the test increases and the negative predictive value decreases, while the reverse is true as the prevalence of the condition is decreasing.

The probability that an animal that tests positive is truly positive (positive predictive value or predictive value of a positive test) is computed as:

$$PV+ = (Se \times P)/[(Se \times P)+((1-P) \times (1-Sp))]$$

The probability that an animal that tests negative is truly negative (negative predictive value or predictive value of a negative test) is computed as:

$$PV- = (1-P)/[(1-P) + ((1-Se)/(Sp))]$$

Where Se is test sensitivity, P is prevalence, and Sp is test specificity.

It is often impossible to estimate prevalence with any confidence, but one must still consider predictive value in test interpretation. When screening a herd, one often has no data to suggest that an individual animal is in a particularly high-prevalence group. In such a mode, a negative test result has a high negative predictive value and is useful in striking a rule-out off the list, but a positive test result (which is most likely a false positive) is useful only in keeping a rule-out on the active list.

Diagnostic testing strategy

The interpretation of a test result is dependent on whether the test is assisting the decision to rule out a preliminary diagnosis, rule in a preliminary diagnosis, or as a form of ruling in a preliminary diagnosis - to screen for regulatory or biosecurity reasons. This is true whether one is considering an infectious disease agent such as bovine viral diarrhea virus or a reproductive condition such as an open cow or sub-fertile bull. To rule in a preliminary diagnosis, many times it is necessary to use more than one test, either in series or in parallel. Running tests in series, where a second test is submitted only after the first test returns a positive result, is used to confirm a positive test with a low positive predictive value (low specificity or low prevalence). A two-test series is interpreted as negative if either test results in a negative response. Running two or more tests in parallel, where they are submitted simultaneously, is used to confirm a positive test with low negative predictive value (low sensitivity or high prevalence). Parallel tests are interpreted as positive if either test results in a positive response.

Determining Cost of Disease

Biology and economics intersect when veterinarians determine the cost of a negative condition. A number of tools are available to approximate the cost of a negative condition, and the biologic characteristics of the condition determine the proper economic analysis. Partial budgets are appropriate for diseases that are horizontally transmitted and immunity or other responses (death, sterility or removal from population) confine the negative effect of the disease to a short period of time; or for conditions whose negative effects are confined to a short period of time. Multi-year enterprise analyses are more appropriate to estimate the economic cost of diseases that are vertically transmitted due to an environmental source, have a chronic production-losing component, or to estimate the cost of conditions that have an impact on costs in subsequent years.

Partial budgets

Partial budgets assist in evaluating diagnostic strategies by evaluating changes in resource use and the economic effect of making one adjustment in some portion of the business.[2] The success of using partial budgets depends on their prediction accuracy, which depends on accuracy of the information and estimates they contain. Partial budgeting is based on the principle that a change, such as disease introduction, will increase some costs and decrease others, and increase some returns while decreasing others. Net effect will be the sum of positive economic effects minus the sum of negative economic effects.

When evaluating disease costs, the veterinarian and producer should collect data such as current costs of production, costs of capital, commodity prices, or other items pertinent to the consequences of disease. In addition, reasonable estimates of future prices and animal production values (weight, efficiency and carcass value) are needed. Production estimates can be obtained from several sources including published research, extension bulletins and current farm production records. Agricultural economists, USDA statisticians and futures markets provide information about the trend of prices and national production estimates.

The partial budget is ready to be developed after all pertinent data are assembled. The seven components of a partial budget are:

1) Additional returns
2) Reduced costs
3) Additional costs
4) Reduced returns
5) Total for the additional returns plus reduced costs
6) Total for the additional costs plus reduced returns
7) The net difference of 5) and 6).

Additional returns are those that occur if the disease occurs (and may be zero). Reduced costs are those not incurred as a result of the disease presence (such as reduced feed intake, hence reduced feed cost). Additional costs of disease may include treatment costs and disposal costs for dead animals. Reduced returns are those no longer received if the disease occurs (i.e. fewer or lighter animals sold). The difference between positive and negative economic effects is an estimate of the net effect of implementing the proposed diagnostic strategy. A negative difference is an estimate of the reduction in net returns if the disease occurs. The extent of the negative or positive difference, given the producer's confidence in the numbers used, impacts the final decision made. Only costs and returns that change in the event of disease occurrence should be included in the partial budget. The unit used to analyze the change may be any size (i.e. one head or the entire herd). After the analysis is performed, the result should be multiplied as necessary to show the economic impact on the entire enterprise or business.

Determining Economic Benefit of Diagnostic Strategy

Once the cost of the disease is determined, the cost effectiveness of alternate diagnostic testing strategies can be compared with a partial budget (Figure 1). In this partial budget, the post-test predictive values, test cost, cost of the negative condition, treatment cost and cost of false positives are used to calculate the return for true positives, true negatives, false positives and false negatives. The economic benefit is simply the costs for true negatives, false positives and false negatives subtracted from the return for true positives.

The value of a testing strategy, whereby all incoming animals are tested and the true-positive animals are isolated or euthanized, is the value of avoiding disease spread in the population. The cost of true negatives is essentially the cost of doing the diagnostic tests, including laboratory costs, veterinary labor and consulting costs for handling the tests, and labor for handling the animals. The cost for false positives is the cost of isolating or euthanizing an animal that was not truly infected. And, the cost of false negatives is the cost of leaving a positive animal in the herd.

Disease Diagnostic
Cost/Benefit Calculator

Single-Test Strategy	
Test Sensitivity (%)	99.00%
Test Specificity (%)	99.50%
Prevalence (%)	1.00%
Cost of diagnostic test per head ($)	$10.00
Cost of Disease per head infected	$2,000.00
Cost of treatment for test-positive animals (direct Tx for tested Dz)	$0.10
Cost of False Positive (purchase price, lost income, disposal, etc.)	$550.00

Outcome from Initial Test	
Positive Predictive Value (Initial test)	66.67%
Negative Predictive Value (Initial test)	99.99%
Value of Identifying True Positive (Initial test)	$1,989.90
Value of Identifying True Negative (Initial test)	-$10.00
Value of False Positive (Initial test)	-$560.10
Value of False Negative	-$2,010.00
Cost / Benefit of testing - Single test ($ / head)	$6.88

Details:	% of animals	If test 100,000 head	Value
True Positive	0.99%	990	$19.70
True Negative	98.51%	98,505	-$9.85
False Positive	0.50%	495	-$2.77
False Negative	0.01%	10	-$0.20
Total:	100.00%	100,000	$6.88

Figure 1. Diagnostic testing partial budget.

For conditions that are rare (low prevalence), even with an accurate test (but less than 100% specific), many of the positive test results will be false-positive, and the costs of finding true negatives (i.e. testing cost) and the cost of false-positives may be greater than the value of finding the few true-positives. In this situation, a partial budget evaluation may indicate little or no economic benefit for a testing strategy unless the cost of disease is substantial.

Because some of the relatively infrequent negative conditions of interest to veterinarians can have significant production and economic costs when present, the cost of an infrequent but significant condition can be better evaluated as an assessment of risk and cost of risk avoidance. Once the cost of the risk is quantified, the producer and veterinarian can determine the effects such an event would have on a confined period's cash flow, and can evaluate that effect with the cost of risk reduction.

Conclusions

Use of diagnostic tests for biosecurity purposes offers veterinarians a tool to reduce the cost of disease for our livestock-producing clients. However, these biologic and economic gains must be evaluated against the cost of the tests themselves and the costs of false-positive and false-negative results that occur with imperfect tests. Veterinarians should use information about test sensitivity and specificity, disease prevalence, test cost and the cost of disease to calculate the expected value of testing for biosecurity reasons.

References

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