

COST AND EFFECTIVENESS ANALYSIS OF TWO FOOT-AND-MOUTH DISEASE VACCINATION PROCEDURES

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SUMMARY

The foot-and-mouth disease (FMD) control programs so far implemented by the South American countries have established mandatory vaccination of cattle over four months of age. Such mandatory vaccination has to date been accomplished with aluminum hydroxide-saponin vaccines. Application of oil-adjuvanted vaccines has been proposed as an alternative offering longer and greater protection and permitting semi-annual vaccination (each 6 months) of cattle under two years and annual vaccination of older animals.

This study analyzes the factors bearing on the vaccination process in order to determine whether the cost of the second alternative justifies its adoption and utilization.

The total annual cost of FMD vaccination is the result of the number of vaccination stages per year, the cost per cattle vaccinated at a stage and the number of bovines to be vaccinated.

The following factors are taken into consideration in calculating the cost per bovine vaccinated at a stage: the market price of a dose of vaccine, the operational cost (both public and private sources) associated with the vaccine application, and the number of cattle to be vaccinated.

If the unit cost of vaccination per stage is considered the same for the two alternatives, then the oil-adjuvanted vaccine vaccination is undoubtedly the more feasible since, at equal cost, the oil-adjuvanted vaccines impart greater immune effectiveness.

Because oil-adjuvanted vaccines are not yet commercially available and their costs therefore unknown, different possibilities have been con-

sidered and values determined that profile the range of economically feasible solutions.

INTRODUCTION

One of the problems faced by the foot-and-mouth disease (FMD) control programs implemented in South American countries is the high cost of massive vaccination of cattle population (1). The FMD vaccine currently utilized relies on aluminum-hydroxide and saponin adjuvants; its protective effect to exposure to FMD virus lasts for a maximum of four months. The FMD control programs have therefore determined that all cattle older than four months should be necessarily vaccinated three times a year.

There is a marked concern to improve the programs' efficiency, thereby reducing their costs.

Two of the short-term changes envisioned in South America could assume considerable importance. The first, which is methodological in character, proposes the selection of disease control strategies according to the epidemiological characteristics of each region (7). A consequence of this approach would be the consolidation of the disease-free areas and their expansion at the expense of advances achieved in those occasional-occurrence areas where the risks of livestock being exposed to the virus is low. Massive vaccination as a method of controlling FMD will be initially applied in these regions. Subsequently, vaccination frequency will be gradually reduced while epidemiological surveillance and control of animals coming in from endemic areas will be intensified.

The other possibly significant change is technological in nature and aims to reduce the present scheme of three vaccinations per year. It involves the use of excellent quality vaccine to be applied in the endemic regions to provide livestock with

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a higher level of protection for a longer period of time.

With respect to this latter aspect, the Pan American Foot-and-Mouth Disease Center (PAFMDC) has in recent years developed a series of studies on an oil-coadjuvanted vaccine seeking to achieve the objective mentioned (2, 3). The problem faced is the question of whether the cost of the procedure can justify its utilization.

Analysis and assessment of this problem focus on cost and effectiveness as a means of objective decision-making when confronted with alternatives for solving the problem presented.

ALTERNATIVES UNDER STUDY

The alternatives considered in this study are two FMD vaccination schemes applied to a bovine herd (cattle population).

Alternative 1

Application of a vaccine having an aluminum-hydroxide saponin adjuvant (HV), every four months to the cattle population older than four months.

Alternative 2

Application of oil-adjuvanted vaccine (OV) with differing annual frequencies for two age groups of the cattle population (2, 3):

a) every six months for the **young** cattle (up to 24 months of age). It is estimated that this age bracket corresponds to $\alpha = 0.33$ of cattle population;

b) once a year for the **adult** cattle (older than 24 months). This group is estimated to encompass $\beta = (1 - \alpha) = 0.67$ of cattle population.

The division of young and adult animals used in this study represents a particular approach to coding the two age brackets and does not adhere strictly to physiological standards or animal husbandry practices. It is also assumed that calving occurs regularly during the entire year.

EFFECTIVENESS

The effectiveness of a vaccination procedure is measured in terms of the degree of protection

that is conferred on the cattle population when exposed to FMD virus.

Evaluations of FMD control programs in various South American countries have shown that attack rates in a systematically vaccinated population generally do not exceed 20% (4). Moreover, laboratory tests involving quality control of aluminum-hydroxide saponin adjuvanted trivalent vaccines, conducted at the PAFMDC, have yielded an 81% (171/211) $\pm 5\%$ ² protection rate in vaccinated cattle exposed to FMD virus at 30-day post vaccination (5). It has therefore been considered that the present vaccination procedure would attain 80% effectiveness when vaccines approved in quality control testing are utilized.

When submitted to quality-control tests in the same control conditions as the aluminum-hydroxide saponin vaccines, the oil-adjuvanted vaccine provides greater effectiveness: 94% (103/109) $\pm 4\%$ ² (6).

Field studies involving young cattle vaccinated with oil-adjuvanted vaccine every 6 months disclosed an effectiveness level of 80% $\pm 7\%$ ², whereas an effectiveness of 40% $\pm 7\%$ ² was noted in cattle vaccinated with aluminum-hydroxide saponin vaccine. In both cases, the effectiveness was assessed according to the procedure proposed by Gomes and Astudillo (5).

This information has served as basis for the preparation of FMD vaccination alternative 2, which contemplates vaccinating cattle up to 24 months of age with oil-adjuvanted vaccine at 6-month intervals (2, 3). From then on the livestock can be vaccinated with this vaccine once a year, since the effectiveness levels achieved with this procedure are 96% $\pm 1\%$ ² (3).

Thus the effectiveness of alternative 2 is the result of considering the effectiveness achieved with oil-adjuvanted vaccine in young and adult cattle through the respective proportions (α and β) in terms of the vaccinatable cattle population:

²95% confidence interval.

$$\begin{aligned} \text{In young cattle} &= (0.33) (0.80) = 0.2640 \\ \text{and in adult cattle} &= (0.67) (0.96) = \frac{0.6432}{0.9072} \end{aligned}$$

The overall effectiveness corresponding to alternative 2 is therefore 91%.

COST MODEL

One problem that appreciably affects the calculation of the costs of the two alternative procedures under discussion is the fact that no oil-adjuvanted FMD vaccine is yet available on the market. Vaccines produced at the PAFMDC experimental laboratory are presently the only cost reference, but cannot be considered because the laboratory's conditions differ from those of a commercial laboratory.

According to information provided by Paraguay's National Animal Health Service (SENACSA) for the third stage of vaccination in 1976, the unit cost of vaccinating a bovine with aluminum-hydroxide saponin vaccine (UCHV) reached US\$0.29 (8). When the method and coefficients proposed by Astudillo *et al.* (1) are applied to the total amount, US\$0.16 corresponds to the market cost of a vaccine dose (MCHV) and the remaining US\$0.13 correspond to the different fixed, variable, direct or indirect inputs considered in the operating cost (CVI).

The annual total cost of each FMD vaccination alternative (TCV) for a herd is defined as the product of: (a) the number of annual vaccination stages (NV); (b) the unit cost of vaccination (UCV); (c) the vaccinatable bovine population (VB).

Therefore:

$$TCV = (NV) (UCV) (VB) \quad (i)$$

In the case of alternative 1, this yields:

$$TCHV = (3) (UCHV) (VB) \quad (ii)$$

In the case of alternative 2, this yields:

$$\begin{aligned} TCOV &= (UCOV) \{ (2) (\alpha) (VB) + 1 (\beta) (VB) \} \\ &= (UCOV) \{ (2) (\alpha) (VB) + \\ &\quad [(1) (VB) - (\alpha) (VB)] \} \\ &= (UCOV) (VB) (1 + \alpha) \quad (iii) \end{aligned}$$

The TCHV varies as a function of the size of the bovine population (VB). The TCOV varies according to changes in the number of bovines to be vaccinated (VB) and also in the proportion

of young animals (α). In the latter case, if $\alpha \rightarrow 0$ the TCOV declines; if $\alpha \rightarrow 1$, the TCOV increases.

ANALYSIS OF THE PROBLEM

This section focuses on developing the study of the relationships among the components of both alternatives. Thus the conditions in which the new procedure is technically and economically feasible become apparent and enable objective decisions to be made.

1. Analysis without considering differences of effectiveness between the vaccines

The unit cost of vaccination (UCV) refers to the bovine unit for each stage of FMD vaccination during the year.

If $UCHV = UCOV$ then $TCHV > TCOV$, simply due to the lower number of vaccinations applied. However, the veracity of $UCHV = UCOV$ is unknown, especially because information on the market cost of the oil-adjuvanted FMD vaccine (MCOV) is unavailable. It should be remembered that:

$$UCOV = MCOV + CVI \quad (iv)$$

$$\text{and likewise } UCHV = MCHV + CVI \quad (v)$$

where MCV = cost of the vaccine on the market
CVI = operating cost for application.

Based on the official statistics provided by the SENACSA (8), the UCHV for that country's third stage of vaccination in 1976 reached US\$0.29; on the other hand, no data is available on the UCOV. In order to study the relationships between UCOV and UCHV, a reference assumption must be stated. In this case it is given by the following equation:

$$TCHV = TCOV \quad (vi)$$

which enables the identity of the procedures' total annual costs to be assumed.

By making substitutions on both sides of the equation according to equations (ii) and (iii), we get

$$(3) (UCHV) (VB) = (UCOV) (VB) (1 + \alpha)$$

$$\frac{UCOV}{UCHV} = \frac{3}{1 + \alpha} \quad (vii)$$

Because the proportion of young animals (α) in a cattle population to be vaccinated may fluctuate within the range

$$0 \leq \alpha \leq 1 \quad (viii)$$

given $\alpha + (1 - \alpha) = \alpha + \beta = 1$
 then the relation between the two procedures' unit costs of vaccination (UCOV/UCHV) may vary as follows:

$$1.5 \leq \frac{\text{UCOV}}{\text{UCHV}} \leq 3.0 \quad (\text{ix})$$

It can therefore be stated that if TCHV = TCOV, the unit cost of vaccination with the new alternative is from 1.5 to 3.0 times higher than the unit cost of vaccination using the present procedure. Consequently, if UCHV = UCOV, the total annual cost of vaccination with the hydroxide-saponin vaccine alternative is from 1.5 to 3.0 times the total annual cost of vaccination using the procedure proposing oil-adjuvanted vaccine.

If the relationships established in equations (iv) and (v) are substituted into equation (ix), we get

$$1.5 \leq \frac{\text{MCOV} + \text{CVI}}{\text{MCHV} + \text{CVI}} \leq 3.0$$

which enables us to isolate MCOV, the price that oil-adjuvanted vaccine would have on the market for purchase by farmers. In order to carry out this operation it is assumed that the operating costs, which are expressed in units (CVI), do not vary from one procedure to another. Therefore

$$\begin{aligned} [1.5(\text{MCHV} + \text{CVI}) - \text{CVI}] &\leq \\ \left[\frac{\text{MCOV} + \text{CVI}}{\text{MCHV} + \text{CVI}} (\text{MCHV} + \text{CVI}) - \text{CVI} \right] &\leq \\ [3.0(\text{MCHV} + \text{CVI}) - \text{CVI}] &\leq \end{aligned} \quad (\text{x})$$

Taking the Paraguayan FMD vaccination data for 1976 (8), if the operating costs assumed the estimated value of US\$0.13, it will be obtained

$$[(1.5)(\text{MCHV}) + \text{US\$0.07}] \leq \text{MCOV} <$$

$[(3.0)(\text{MCHV}) + \text{US\$0.26}]$, the range within which the unit cost of the oil-adjuvanted vaccine should fluctuate on the market (that is, the price of a dose). On taking the unit cost of the hydroxide-saponin vaccine in 1976 in Paraguay, estimated at US\$0.16 (8), equation (x) defines the following range for the market unit cost of oil-adjuvanted vaccine

$$\text{US\$0.31} < \text{MCOV} < \text{US\$0.74} \quad (\text{xi})$$

Another way of reaching this result is to consider the unit cost of vaccination for the

alternative that uses UCHV (hydroxide-saponin vaccine). According to (8), the value attained was US\$0.29 per bovine vaccinated at a stage. Keeping in mind the relations established in equations (iv), (v) and (ix), the unit cost of vaccination using the new procedure could reach the upper limit of US\$0.87. If CVI = US\$0.13 is deducted from this UCOV value, then the upper limit of MCOV should be US\$0.74.

If we establish a relationship between the values estimated for MCOV under the assumptions indicated, then the market cost of a dose of oil-adjuvanted vaccine—in relation to the cost of the same unit of presently utilized vaccine—could fluctuate over the following range:

$$1.9 \text{ times} \leq \frac{\text{MCOV}}{\text{MCHV}} \leq 4.6 \text{ times} \quad (\text{xii})$$

Among the assumptions within which these results have been prepared, attention should again turn to the assumption which establishes that TCHV = TCOV. As these results indicate, the new FMD vaccination procedure—in this case judged independently of a given vaccine effectiveness level—is economically feasible because it requires a lesser number of vaccinations per animal. It can therefore be inferred that the oil-adjuvanted vaccine could have a per-dose market cost ranging from 1.9 to 4.6 times the cost of a unit of aluminum-hydroxide saponin vaccine.

Assessment of these results and conclusions must bear in mind the conditions that have been explicitly or implicitly considered, i.e., reference neither to specific levels of vaccine effectiveness, nor to differences of effectiveness between the two procedures. Nevertheless, it is implicit that both vaccines are of good quality and would consequently be approved in any effectiveness control test.

It is clear in the foregoing relationships that application of the new procedure will make the total annual costs of vaccination higher in areas where the proportion of young animals (α) is high, such as in breeding and raising regions.

2. Analysis considering greater effectiveness with oil-adjuvanted vaccine

It is of major interest that the feasibility study of the oil-adjuvanted vaccine procedure consider

the longer duration of populational protection levels, resulting in a lesser frequency of vaccinations administered to the cattle per year. Explicit consideration should also be given to the cattle population's greater protective effectiveness at a given moment, compared with the traditional alternative. The relationship between the cost of vaccination and the immune effectiveness level of the procedures analyzed herein is determined through the unit cost of annual protection parameter (UCP), an indicator that reflects how much it costs to keep one bovine protected against FMD for one year.

According to Gomes and Astudillo (5), effectiveness in alternative 1 is taken as approximately 0.80 when aluminum-hydroxide saponin vaccine is applied. Based on this information, the respective unit cost of protection (UCHP) can be calculated through the following equation:

$$UCHP = TCHV / (0.8) (VB) \quad (xiii)$$

With equation (ii) used for the following substitutions in equation (xiii):

$$UCHP = \frac{(3) (UCHV) (VB)}{(0.8) (VB)} = 3.75 UCHV \quad (xiv)$$

According to the calculation made in the first part of this work, 0.91 is the immune effectiveness for alternative 2 which applies oil-adjuvanted vaccine. The unit cost of protection for this procedure (UCOP) is defined as:

$$UCOP = TCOV / 0.91 VB \quad (xv)$$

By making the corresponding substitution in (xv) based on equation (iii):

$$UCOP = \frac{(1 + \alpha) (UCOV) (VB)}{(0.91) (VB)} = \frac{(1 + \alpha) UCOV}{0.91} \quad (xvi)$$

given the information in equation (viii), then:

$$(1.1)(UCOV) \leq UCOP \leq (2.2) UCOV \quad (xvii)$$

Resolving equation (xiv) from the information given by SENACSA (8), according to which UCHV = US\$0.29, yields:

$$UCHP = US\$1.09 \quad (xviii)$$

One problem to resolve is to define the range of variation of UCOP by defining UCOV. But this is not directly possible because MCOV is unknown, due to the present unavailability of oil-adjuvanted FMD vaccines on the South American

vaccine market. Because this is not possible, the assumption UCOV = UCHV may be considered; the behavior of UCOP can therefore be assessed in relation to UCHP, whose value was defined in (xviii).

Under the assumption that UCOV = UCHV, and following through with equation (xvii):

$$(1.1) \frac{(UCOV)}{(3.75)(UCHV)} \leq \frac{UCOP}{UCHP} \leq (2.2) \frac{(UCOV)}{(3.75)(UCHV)}$$

$$0.29 \leq \frac{UCOP}{UCHP} \leq 0.59$$

$$(0.29) (UCHP) \leq UCOP \leq (0.59) (UCHP) \quad (xix)$$

This result leads to the statement that if the unit cost of vaccination per stage were equal for both the procedures, the annual unit cost of protection for the alternative proposing oil-adjuvanted vaccine (UCOP) would be from 41% to 71% lower than the UCHP.

The required substitution in equation (xix) yields

$$US\$0.32 \leq UCOP \leq US\$0.64 \quad (xx)$$

which represents the value range within which the annual cost of protection for bovines under alternative 2 could fluctuate provided the established suppositions are taken into consideration.

The situation occurring when it is assumed that UCOP = UCHP should be analyzed using the same approach as applied to the problem in section "a". Thus

$$(3.75) (UCHV) = \frac{(1 + \alpha) UCOV}{0.91} \quad (xxi)$$

through substitutions in the equation based on equations (xiv) and (xvi).

The equation can then be worked out to yield:

$$\frac{UCOV}{UCHV} = \frac{3.41}{(1 + \alpha)} \quad (xxii)$$

with $0 \leq \alpha \leq 1$, then the UCOV/UCHV ratio can range as follows:

$$1.71 \leq \frac{UCOV}{UCHV} \leq 3.41 \quad (xxiii)$$

through operations similar to those made in the preceding section, MCOV can be isolated and its range of variation defined as follows:

$$\frac{[(1.71)(MCHV) + (0.71)(CVI)]}{[(3.41)(MCHV) + (2.41)(CVI)]} \leq MCOV \leq \quad (xxiv)$$

in a general way, this expresses the range of variation of the unit cost of the oil-adjuvanted vaccine on the market (MCOV), and now takes into account the fact that the two procedures' effectiveness is not the same, the greater one being that which corresponds to the alternative utilizing oil-adjuvanted vaccine.

By using the Paraguayan data (8) and making the substitutions required in equation (xxiv), we get:

$$US\$0.37 \leq MCOV \leq US\$0.86 \quad (xxv)$$

It can be observed that the market-cost range of a dose of oil-adjuvanted vaccine, when this vaccine's greater effectiveness is considered, has increased by approximately 18% as compared to the limits ascertained when a difference of immune effectiveness between the two procedures was disregarded (equation xi).

Moreover, if this unit-cost range of oil-adjuvanted vaccine on the market is related to the situation of the known market cost of a dose of hydroxide saponin vaccine (8), the following occurs:

$$2.3 \text{ times} \leq \frac{MCOV}{MCHV} \leq 5.4 \text{ times} \quad (xxvi)$$

which makes this statement verifiable only if the supposition UCHP = UCOP is fulfilled, considering greater effectiveness for oil-adjuvanted vaccine (0.91 versus 0.80) and using the costs estimated for the 1976 FMD vaccinations in Paraguay (8).

CONCLUSIONS

The annual total cost of FMD vaccination for alternative 1, using aluminum-hydroxide saponin vaccine, depends on the number of animals to be vaccinated and the cost of vaccinating one bovine at one stage. The same kind of cost for alternative 2, which employs oil-adjuvanted vaccine, is a function of (a) the number of bovines to be vaccinated, (b) the cost of vaccinating one bovine at one stage, and (c) the proportion of young animals in the population. The unit cost of vaccination at a stage depends on the cost of a vaccine dose on the

market and on the operating cost of applying the vaccine.

The latter cost, expressed in units, is identical for both procedures. Because oil-adjuvanted vaccine is not yet available on the market, a study of the cost relationships must take vaccination under alternative 1 as reference. Assuming that UCHV = UCOV, it is understood that TCHV > TCOV; the new procedure therefore becomes economically feasible because even though the entire bovine population to be vaccinated may be young (α), the annual total cost of vaccination would be one-third less than what would be achieved with the currently used procedure. On the other hand, if it is assumed that TCHV = TCOV, and differences of effectiveness between the two procedures are disregarded, then the oil-adjuvanted vaccine procedure is economically viable within a range whose limit is MCOV = 4.6 MCHV. These results can be attained by applying the costing methodology proposed by Astudillo *et al.* (1) and utilizing the data on vaccination costs in Paraguay in 1976 (8).

The immune effectiveness of the oil-adjuvanted vaccine procedure is 0.91, versus 0.80 for the hydroxide saponin vaccine procedure. Considering this difference in effectiveness, the cost study should refer to the annual cost of protecting a bovine against FMD (UCP). If it is assumed that UCOV = UCHV, then the UCOP turns out to be always lower than UCHP. On the other hand, if it is supposed that the annual costs of protecting a bovine are equal for both alternatives (UCOP = UCHP), then the new FMD vaccination scheme is economically feasible over the UCV range whose limit is UCOV = 3.41 UCHV. If the assessment is referred to the unit cost of a dose of oil-adjuvanted vaccine on the retail market, the scheme is feasible up to the point at which MCOV = 5.4 MCHV, when the Paraguayan data (8) and the methodology proposed in a previous study (1) are applied.

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