Simple Method for Rough Determination of the Cost–Benefit Balance Point of Immunization Programmes

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The planning of health activities, including those aimed at control of communicable diseases, is a complex matter. Finance is one of the most important constraints that force health administrators to utilize the limited resources available as effectively as possible. To this end the priorities should first be established and then reviewed from a cost–benefit standpoint to ascertain the most economical control measures. In developing countries, with their many needs and restricted resources, selection of the most profitable measures is particularly important. The use of complex computing and of mathematical models (Cvjetanović et al., 1971) for this purpose is frequently out of the reach of health administrators. This is why simple aid in the planning of control measures is required.

Acute infectious endemic diseases are relatively easy to study without the use of complex computing techniques. We shall, therefore, limit this presentation to acute communicable diseases of bacterial origin against which there are effective vaccines and that occur in endemic form in developing countries. Other types of communicable disease for which vaccines are available could be treated in a similar way. Due attention should be paid to the particular epidemic behaviour of such infections and therefore methods devised for acute bacterial infections should be modified accordingly.

Methods

Collection of essential information. The following information should be available for each specific disease and the factors related to its control:

(1) incidence of cases (if possible, their distribution by sex and age groups, ethnic and social structure, geographical areas, etc.);

(2) cost of treatment per case (if possible, classified by the severity of the cases and by therapeutic institution);

(3) cost of immunization per individual per year (including manpower and vaccine cost); and

(4) effectiveness of vaccine in preventing the disease and duration of protection.

The data for items (1), (2), and (3) should be collected and assessed locally. Information on the effectiveness of the vaccine and the duration of immunity (4) is obtained from the scientific evidence presented by studies carried out using that type of vaccine. Laboratory testing of vaccines and evaluation of their potency are necessary.

All this information should be as accurate as possible so that averages can be calculated for each country, area, and population group for specific diseases. For diseases for which there are combined vaccines (DPT, TAB, etc.) the cost cannot be pooled and the averages taken, since each vaccine component differs in effectiveness and each disease varies in its incidence.

In our approach to the evaluation of costs and benefits, we have considered as input, the overall cost of vaccination campaigns (manpower, transport, vaccines, etc.) and as benefit, the savings made through vaccination on cases prevented, expressed as the cost of treating such cases. We have not added savings on wages, as a large proportion of the population in developing countries (children and housewives) would not be engaged in gainful activities.

The present method applies essentially to developing countries in which the health authorities have to provide nearly the total cost of immunization campaigns, together with the cost of treatment. The simple technique for cost–benefit evaluation developed in this paper should therefore provide an indication to departments of health on the costs and benefits of immunization programmes.

Determination of the cost–benefit balance point of vaccination. The calculations below for the preparation of a simple nomogram have been made on the basis of one mass immunization of the population group [3] against a certain disease and of the

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[3] The population group is defined as the group actually vaccinated. The vaccination coverage is therefore 100%.

costs of treatment and vaccination applicable to developing countries. Typhoid fever, tetanus, and cholera were selected because, among other reasons, it is interesting to compare the results of this method with those obtained from more advanced mathematical models. The following parameters are used:

P = population
C_t = cost of treating one case
C_v = cost of vaccinating one individual
E_v = vaccine effectiveness
i = incidence of cases per 10 000 population

The vaccine effectiveness is defined as the proportional reduction in the original incidence of the disease due to vaccination.

The ranges of parameters shown in Table 1 are supposed to cover practically all values actually encountered.

Table 1. Ranges for parametric values

Disease	Annual incidence [a] (per 10 000 population)	Cost of case treatment (in US $)	Mean cost of one vaccination per annum [b] (in US $)	Vaccine effectiveness [c]
cholera	1–1 000	11– 100	0.1 –0.2	0.25–0.75
typhoid	1– 100	20– 500	0.02–0.04	0.60–0.90
tetanus	1– 100	20–1 000	0.01–0.05	0.75–0.95

[a] For cholera the incidence is per epidemic period.
[b] For cholera the cost is per epidemic period. For typhoid the cost of one vaccination has been divided by 5 and for tetanus by 10, the duration of effect being taken as 5 and 10 years, respectively.
[c] Mean annual effectiveness for typhoid and tetanus.

The following calculations are on an annual basis for typhoid fever and tetanus and per epidemic period for cholera.

The total cost of treatment when the population is not vaccinated is:

$$C_t \times \frac{i \times P}{10\,000}$$

The total cost of vaccination is:

$$C_v \times P$$

The total cost of treatment when the population is vaccinated is:

$$C_t \times \frac{i \times P}{10\,000} \times (1 - E_v)$$

The critical balance point between the cost of treatment saved by preventive measures and the cost of the vaccination programme is reached when:

$$C_t \times \frac{i \times P}{10\,000} = C_v \times P + C_t \times \frac{i \times P}{10\,000} \times (1 - E_v) \quad (1)$$

This equation can be simplified as follows:

$$C_t \times \frac{i \times P}{10\,000} \times E_v = C_v \times P \quad (2)$$

and, hence,

$$C_t = 10\,000 \times \frac{C_v}{E_v} \times \frac{1}{i}$$

Calling R the ratio $\frac{C_v}{E_v}$, equation (2) becomes:

$$C_t = 10\,000 \times \frac{R}{i} \quad (3)$$

The mathematical relationships between C_v, E_v, i, and C_t are presented graphically in the nomograms discussed below.

Nomogram for cost–benefit balance determination. The nomogram for determining the cost–benefit balance of vaccination, presented in Fig. 1, is based on formula (3). The scale for the incidence of the disease concerned is given on the abscissa (logarithmic scale) and covers the full range envisaged in Table 1 (from 1 case to 1 000 cases per 10 000 population). Similarly, the logarithmic scale for the cost of treatment per case is shown on the ordinate for values ranging from 10 to 1 000 US dollars (see Table 1). The minus 45°-slope lines across the nomogram represent the value of R, defined as the ratio of the vaccination cost of one individual over the mean vaccination effectiveness. These lines show a balance or indifference; they divide the nomogram into two areas; the lower left portion corresponds to loss and the upper right portion to gain in terms of money.

The level of disease incidence and treatment cost for a specific population group can easily be plotted on the nomogram. The location of the point so determined with respect to the relevant indifference line will give the position of the immunization programme in terms of financial loss or gain. A point falling in the lower left field corresponds to loss, while

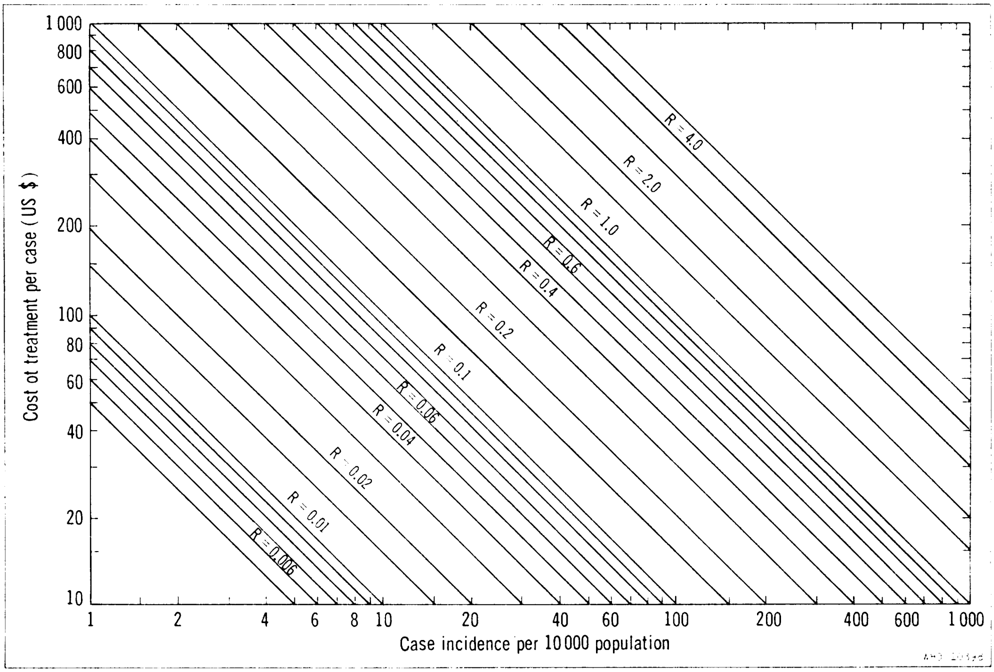

Fig. 1. Nomogram for determining the cost-benefit balance of an immunization programme.

a point falling in the upper right field corresponds to gain. In addition, the distance from the point to the indifference line reflects the magnitude of the loss or gain.

The determination of the value of *R*, which defines the indifference line, is facilitated by means of the nomogram given in Fig. 2. It suffices to plot the cost of vaccinating one individual on the left scale and the vaccination effectiveness on the right scale of this nomogram, and to draw a straight line through these two points: the corresponding *R* value can be read at the intersection of this line with the middle scale.

The correct numerical estimation of the parameters is of primary importance. The average effectiveness of the vaccine and the duration of the protective effect is established from scientific evidence (e.g., mean reduction of 80% in annual incidence of typhoid cases over 5 years).

The average cost of immunizing an individual should be divided by the number of years of protection in order to obtain the cost of protection per year, at a certain level of effectiveness. If the protection is only for 6 months the cost of individual immunization should be multiplied by 2, unless the incidence of the disease is seasonal, as with cholera, and protection for 6 months covers the epidemic season of each year. Immunization in such cases must be performed at the proper time of year to be effective.

There may be several vaccines available with different rates of effectiveness and cost. Furthermore, there may be several schemes of immunization using the same vaccine (e.g., one dose or two) giving different durations and degrees of protection at different costs. The cost–benefit relationship of all these combinations can be calculated from the nomogram.

Nomograms similar to the one for typhoid fever, tetanus, and cholera shown in Fig. 1 can be prepared for other endemic infections of bacterial origin.

Examples of use. (1) In a given population group the usual seasonal cholera incidence rate is 150 cases per 10 000 population and the cost of treatment of 1 case is 25 US dollars. These 2 parametric values define point A on Fig. 3. It is planned to immunize the population with a vaccine of 60% effectiveness (E_v = 0.60). The cost of the vaccination campaign will correspond to 15 US cents per individual vaccinated (C_v = 0.15). *R* (the ratio C_v/E_v) is therefore equal to 0.25. The corresponding indifference line

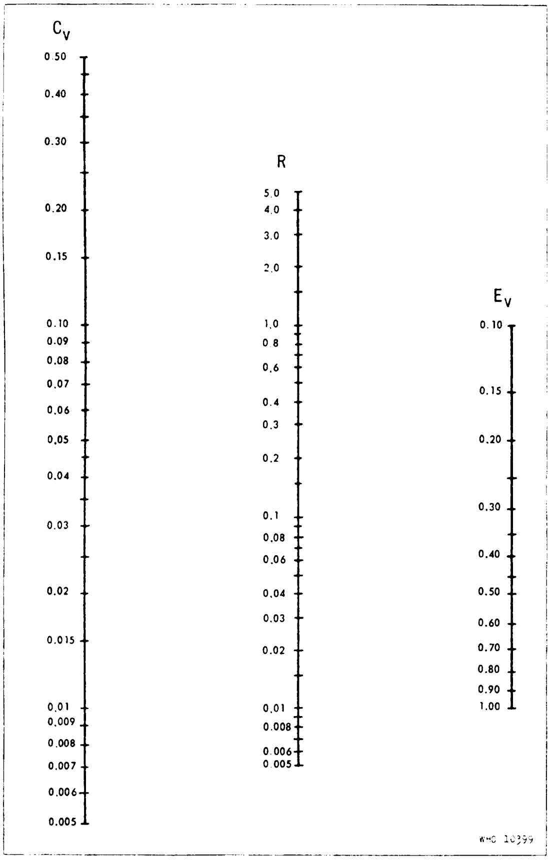

Fig. 2. Nomogram for calculating the ratio of vaccination cost to vaccination effectiveness: C_v = cost of vaccinating one individual (in US $); E_v = vaccine effectiveness; $R = C_v/E_v$.

is called L_1 on Fig. 3. It can be seen that point A falls in the upper right field of the nomogram (Fig. 3), which means that a financial gain is expected from the immunization campaign. It can also be noted that if the cost of treatment per case were less than US$17 or if the incidence were less than 100 cases per 10 000 population, point A would fall in the nomogram area corresponding to an economic loss.

(2) The annual incidence of typhoid is 6 cases per 10 000 population in a certain community. The treatment of a case costs on the average US$65. These two values are the co-ordinates of point B on Fig. 3. Assuming that the cost of 1 individual vaccination is 20 US cents, the mean annual value of C_v will be US$0.04 (see Table 1). It is further assumed that the mean annual effectiveness of the vaccine is 80%. Entering on the nomogram of Fig. 2 the data points $C_v = 0.04$ and $E_v = 0.80$ gives $R = 0.05$, which in turn defines the indifference line L_2 on Fig. 3. It is seen that mass immunization under the present conditions will lead to a loss in terms of money. A benefit might result from the vaccination programme if the cost of treatment were higher than US$85 or, alternatively, if the incidence were higher than 8 per 10 000.

(3) In order to demonstrate the uses of such nomograms, we present data obtained from different countries in recent years, in relation to tetanus and typhoid fever.

The effectiveness of tetanus vaccine is considered to be 95% for 10 years, while that of typhoid is taken as 75% for 5 years. Since the cost of tetanus vaccination is rather high in Dakar (US$0.5 per dose) and that of typhoid vaccination much lower (US$0.2 per dose), it appears that the ratio (R) for both is the same 0.053 (see the line L_3 in Fig. 4).

Fig. 4, which is self-explanatory, shows data concerning tetanus in Dakar separately for the general population and for newborn babies. In Dakar, the average cost of the treatment of tetanus (per case) is US$230, and the cost of immunization per person per year is US$0.05. The incidence of tetanus is high in the general population (4.2 per 10 000), but it is much higher in newborn babies (15 per 10 000). From the nomogram, it is clear that, while immunization of both the general population and of newborn babies is economically beneficial, a programme to immunize pregnant mothers—to protect the newborn—would be far more beneficial than immunizing the whole population, and therefore deserves priority.

Fig. 4 also shows data concerning typhoid fever in several countries. In some, immunization gives a clear benefit, while in others it does not. In Yugoslavia, for example, where the incidence is rather low but the cost of treatment very high, the benefit of mass immunization is questionable. In Western Samoa, immunization is beneficial economically because the incidence is high, although the cost of treatment is lower than in Yugoslavia. The data for Mexico and Ceylon show that no economic benefit would result from immunization because, although the cost of treatment is low, the incidence is also low. However, the data for these two countries deserve closer study to evaluate the real position as far as the cost–benefit balance of antityphoid immunization is concerned.

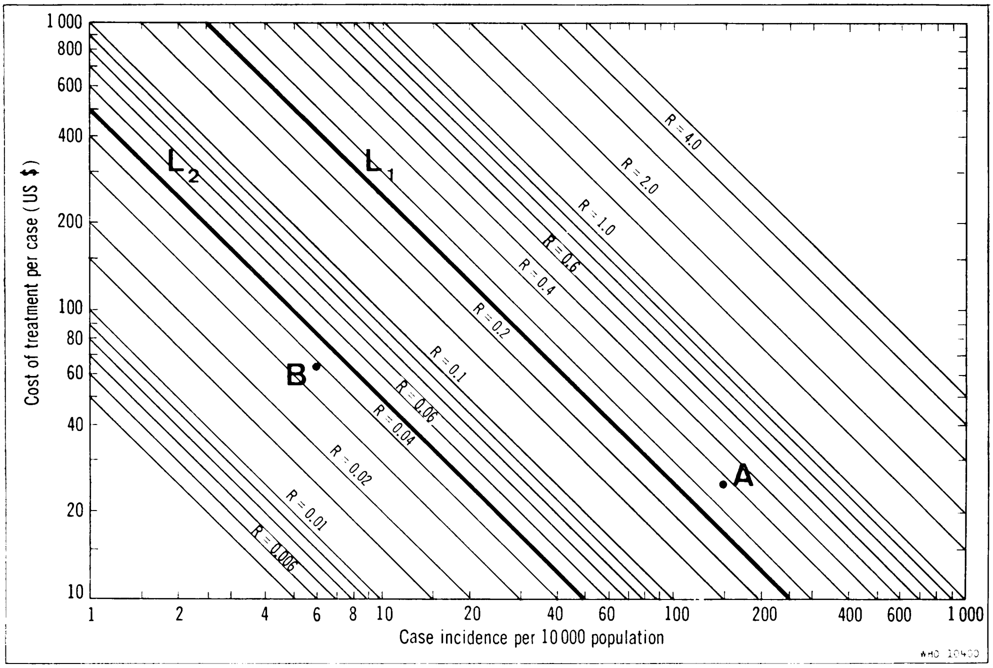

Fig. 3. Nomogram for determining the cost-benefit balance of an immunization programme: theoretical examples of use.

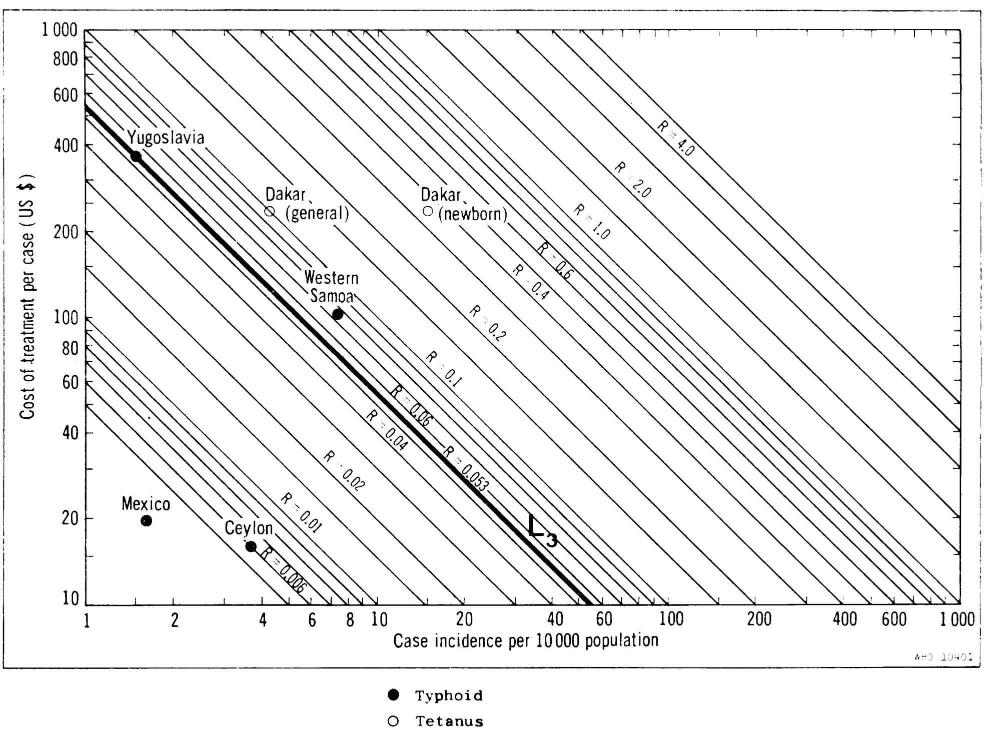

Fig. 4. Nomogram for determining the cost-benefit balance of an immunization programme against typhoid or tetanus: actual examples of use.

Discussion and Conclusions

It is advisable, for diseases that attack equally both sexes and all ages and social strata, to utilize a yearly average of incidence in the total population. For infections affecting childhood only, the incidence in children of a susceptible age should be taken into account. For example, in tetanus of the newborn, the incidence per 1 000 births should be the basis of the calculations. Two points should be indicated in nomograms for tetanus: one for tetanus in the general population and the other for tetanus in the newborn. If, for example, in pertussis or diphtheria, the incidence in specific age groups were plotted on the nomogram the curve might cross the cost–benefit balance line. In this case vaccination of the age groups on one side of the line would bring direct financial benefit, whereas vaccination of those on the other side of the line would not.

The financial benefit of immunization is higher when the incidence and/or the cost of treatment is higher. It is interesting to note that, as the general state of health and standards of living improve, the incidence of most (particularly endemic) bacterial infections declines. However, the financial benefit of immunization does not decline proportionately, since treatment becomes more expensive. This has been observed particularly in typhoid fever and in tetanus. At very low incidence rates there is no longer any financial benefit, but when that stage is reached the community is usually sufficiently wealthy to provide the necessary means to fight infection.

This rather over-simplified and rough method of cost–benefit balance determination was developed to provide a simple technique for those who do not have the facilities for complex work on the planning of health programmes. The method described has many imperfections and is far from accurate. It is not a substitute for the utilization of more accurate mathematical models, but it may be useful for planning communicable disease control programmes in the absence of better facilities. The accuracy of the method may be improved by introducing more detailed data and by drawing more appropriate nomograms for specific diseases and situations. The method described does not give guidance on cost-effectiveness; for this, mathematical models similar to the one we constructed for typhoid (Cvjetanović, Grab & Uemura, 1971) may be used.

The nomograms described in the present paper do not help the planner to predict the effect of a control measure over long periods and thus are not suitable for long-term planning. The results of long-terms vaccination campaigns cannot be predicted without the use of mathematical models. The use of the present method should be limited to evaluation of cost–benefit aspects of mass immunization campaigns against various acute endemic diseases, particularly in developing countries.

REFERENCES

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