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12. Mathematical modelling: a key to control of infectious diseases in man and animals

McLean AR, Anderson RM. Epidemiol Infect 1988; **100**: 419–442

AN APPRECIATION BY PETER MORGAN-CAPNER

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Predicting the impact of infectious diseases on the well-being of the community is a cornerstone of identifying effective prevention, control and support. One only has to reflect on the last few years in the United Kingdom to see the impact mathematical modelling has had on public and government, with controversy around the likely numbers of sufferers from new-variant Creutzfeld–Jakob disease, human immunodeficiency virus, and continuing debate as to whether to use vaccine to support control of foot-and-mouth disease. Over the last 20–25 years, *Epidemiology and Infection*, and before it the *Journal of Hygiene*, have published many of the sentinel papers in the mathematical modelling of infectious disease, both in humans and animals. The discipline has advanced from relatively simple analyses to the most complex assessments whose underlying mathematics and statistics almost certainly exceed the comprehension of all but a few microbiologists and public health specialists. The depth of the analysis does not obscure the key messages, however, for the epidemiology of infectious disease and its control, and a Special Article in the journal in 1988 overviewed its contribution [1].

In 1988, McLean and Anderson published their prediction of the impact of mass vaccination on the transmission dynamics of measles in developing countries [2]. Uncontrolled measles has a devastating effect on the health of children, with even now some one million deaths a year in developing countries. Yet we have had effective live attenuated vaccines available since the early 1960s, and successful eradication in much of the developed world. Predicting how to use vaccine optimally to eradicate measles in the developing world presents problems not seen with such modelling in the developed world. For instance, the high mortality rates and high population growth have a significant impact on virus transmission. McLean and Anderson concluded from their analyses that there was no single optimum age to immunize children in developing countries, that a temporary phase of low incidence would follow mass vaccination, but recurrent epidemics will appear later, and that a one-stage programme aimed at young children is of greater benefit than two-stage programmes. A key parameter to be calculated in such analyses is the basic reproductive rate of infection (R_0) – ‘the average number of new cases that would be generated if one infectious individual were introduced into a wholly susceptible population’ [3]. If a vaccination strategy were to ensure R_0 is less than 1, eradication is achievable. Calculating R_0 is dependent on having the appropriate data. To provide the basic data to enable mathematical modelling to be meaningful requires information on the epidemiology of the infection in the community being studied. In a previous paper, McLean and Anderson reviewed available information on measles in developing countries [4]. Data included duration of protection from maternally derived antibodies, age distribution of infection, age-stratified serological profiles, measles fatality rates, and fertility/mortality age profile.

It is not only in developing countries that mathematic modelling has led to major vaccine initiatives. In 1994, the United Kingdom had a mass measles/rubella vaccine campaign aimed at children aged 5–16 years. This campaign was carried out to avert an anticipated epidemic in older children and younger adults. This was presaged by modelling the age-stratified measles antibody profile (‘seroepidemiology’) of the population, and deducing that susceptibility was building in the target population as a consequence of failure to achieve the necessary high levels of immunization with mumps, measles and rubella vaccine since its introduction in the United Kingdom in 1988, whilst endemic measles had been reduced to the levels where exposure was unlikely [5, 6]. This build-up of susceptibles was becoming sufficient to support a major epidemic, as indeed happened in Scotland in 1993.

These studies have confirmed the importance in having high-quality seroepidemiology information available: robust age-stratified serological information on exposure and immunity of the community based on validated techniques. Such information, and the resultant conclusions on epidemiology and control, have now been presented in the journal for a wide range of human viral infections, but particularly measles, rubella, mumps and varicella-zoster [7–18], bacterial infections such as whooping cough [19–23], and parasitic infections [24, 25]. Studies also include infections in animals [26–28], including prion diseases [29], and from many parts of the world. International collaborative studies have been performed [30], and are now being reported which compare the efficacy of the different strategies for vaccine use in Europe and beyond [9, 12, 14, 23]. Mathematical modelling is an essential part of understanding the epidemiology of infectious disease, and hence its control.

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