Critical Issues in Determining Feasibility of Eradication

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5

Political and Social Determinants of Disease Eradication

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Abstract

Eradication of disease is a major social achievement. To date, six attempts have been made to eradicate diseases in which humans are the primary or sole host, but only one has been successful. Success depends on very high levels of participation, beyond the levels predicted if individual community members act rationally in a self-interested way. Because near-universal participation is a condition of the achievement of eradication, a global eradication initiative can be held to ransom by a single country or small political groups. It is not always in the interests of a country to participate in an eradication initiative, particularly if there are pressing health needs in other areas. Game theory provides a useful way of understanding these processes. To achieve disease eradication, an international system of diplomatic and financial incentives and enforcements will need to be developed.

Introduction

The eradication of an important disease is a pinnacle of collective human achievement, let alone of public health. The ability to free all future generations across the globe from the threat of death and disability from a disease ranks as one of the greatest contributions that can be made by social effort. Disease eradication brings large, multiple, and long-lasting benefits, improving both quantity and quality of life, bringing economic benefit, and political credit to those who directed the effort. The eradication of smallpox, for instance, has been responsible for a major improvement in health in nearly every country, with economic gain due to a vastly reduced need for control measures and a complete end to the costs of treating and caring for people with smallpox. The eradication of smallpox conferred enormous political legitimacy on the

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World Health Organization and other agencies which sponsored and directed the program. Indeed, the success of this effort has driven the search for other eradicable diseases and the development of proposals to initiate further disease eradication programs.

Eradication

As a concept, disease eradication appears to have first originated with Jenner, when he wrote in 1801 (Fenner et al. 1988:259):

> …it now becomes too manifest to admit of controversy, that the annihilation of the Small Pox, the most dreadful scourge of the human species, must be the final result of this practice.

However, it was only in the 20th century that serious attempts were made to eradicate infectious diseases from humans (Aylward et al. 2000a; Taylor 2009). Six diseases have been targeted: yellow fever (1915–1977), yaws (1954–1967), malaria (1955–1969), smallpox (1955–1980), polio (1988–continuing), and dracunculiasis (1986–continuing). To date, only one of these six diseases, smallpox, has been eradicated.

Many attempts have been made to define disease eradication. A workshop on "Global Disease Elimination and Eradication as Public Health Strategies" in Atlanta in 1998 reviewed several definitions and concluded that eradication was the "[p]ermanent reduction to zero of the worldwide incidence of infection caused by a specific agent as the result of deliberate efforts; intervention measures are no longer needed" (Dowdle 1998). This definition echoes the conclusions reached in 1997 at another workshop on the "Eradication of Infectious Diseases" (Ottesen et al. 1998) and has broad currency in the field.

Thus defined, eradication essentially rests on the proposition that complete and permanent removal of the risk of acquiring disease is both necessary and sufficient. It implies global reach, or there would be some remaining risk arising from some geographical areas. However, without absolute and permanent extinction of the infectious agent, this condition does not hold, and neither does the corollary, that intervention measures are not required. If risk persists at any level, then control measures of some kind are still required, though they may be minor, especially in comparison with the Herculean effort needed to achieve eradication of a disease. The situation of smallpox illustrates this point: in 1978, after eradication, there was an outbreak of smallpox, including one death, sourced from a laboratory (Fenner et al. 1988) because this aspect of control was not adequate. Stocks of viable smallpox virus still exist, and stringent control must be, and is, maintained over them, while surveillance for smallpox continues. Once the eradication of wild poliovirus has been achieved, the need for continuing control measures will be a considerable and larger problem; there will be a need for a stringent laboratory containment

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regime, since it is possible to manufacture poliovirus in the laboratory from its constituent parts (Cello et al. 2002), and this ability is now irrevocably present.

For these reasons, it is unlikely that it will ever be possible to abandon all control measures for an "eradicated" disease. Since it is impossible to remove risk entirely, I shall define eradication as the reduction of incidence of a disease to zero cases per unit time through deliberate efforts, allowing the reduction of control measures to a level that is both low and the minimum possible.

There are two consequences of this argument: Control measures must be maintained in perpetuity, so costs must be viewed as infinite. Also, organizational and international arrangements under some kind of global public health agreement need to be established and maintained indefinitely.

The Feasibility of Eradication

Conventionally, the feasibility of eradication of a disease has been considered to be determined by biological and social and political criteria. For each candidate disease, criteria have been defined by the International Task Force on Disease Eradication (MMWR 1993; Hinman and Hopkins 1998) as:

1. Biological criteria
    a. Epidemiological vulnerability
    b. Effective practical interventions likely to achieve eradication
    c. Demonstrated feasibility
2. Social and political criteria
    d. A broad social perception of the importance of the disease
    e. A reasonable projected cost
    f. Synergy with other health system activities
    g. Necessity for eradication rather than control

These criteria are commonly accepted, but they underemphasize the importance of the social and political criteria (Aylward et al. 2000a; Shiffman 2006; Bhattacharya and Dasgupta 2009; Taylor 2009). Due to its absolute nature, eradication requires universal engagement of countries (Barrett 2004) and generally very high engagement of populations within countries.

The degree of social and national engagement required depends on the endemicity and infectivity of the disease. It is easier to eradicate a disease with very limited geographical or social spread and easier to eradicate a disease of low infectivity. Eradication of endemic disease is more difficult, because there are more infectives that are spread over a greater geographical area (Barrett 2004). For highly infectious diseases, the requirements for mobilization of countries and their populations are very high indeed, and there are major risks for failure if universal engagement is not achieved. Polio and smallpox have roughly the same degree of infectivity (Anderson and May 1991:70, 88); however, polio was endemic in 125 countries at the beginning of the Global Polio Eradication

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Initiative in 1988, whereas smallpox was present in only 59 countries (Barrett and Hoel 2007) at the beginning of the smallpox eradication program in 1958. Smallpox was an ideal candidate for eradication, and its eradication has proved easier than that of polio.

For a vaccine-preventable disease, the degree of social engagement required to eradicate a disease can be modeled. To achieve eradication of a vaccine-preventable disease, the number of persons in the population susceptible to the disease must be below a threshold, which is determined by the infectivity of the disease in the community. For highly infectious diseases this threshold is itself rather low, and while not everyone needs to be immunized, a very high proportion of the population does need to participate in the immunization program. Individuals, communities, and nations assess their willingness to participate against a number of criteria, and eradication of disease may not be of value to them. Because near-universal participation is needed, there is great scope for gaming, and social groupings, and indeed nations, may use their power of veto to demand concessions before they will participate in the eradication initiative. This problem is magnified if the effectiveness of the vaccine is low, or if several doses are required, or the disease has several different immunotypes.

Eradication is an absolute concept and has been referred to as "extreme" public health (Barrett and Hoel 2003); it is a great gamble (Barrett 2009). As a public health strategy, attempts at eradication have a mixed history: three of the six attempts (yellow fever, yaws, malaria) failed, while two (polio and dracunculiasis) are still in progress and one (smallpox) has been successful (Taylor 2009). The polio eradication program was successful in 1999 in eradicating type 2 poliovirus, one of three serotypes of polio (Barrett 2004). Eradication as a strategy is vulnerable to failure at many points.

Rationale for Eradication

Humanitarian arguments feature very prominently in the reasons advanced in support of eradication iniatives. These arguments note the improvement in health that can be made by freeing the world from target diseases. The resolution of the World Health Assembly in 1988, which committed the World Health Organization to the eradication of polio, makes no mention of economics, either in terms of costs or benefits (World Health Assembly 1988). Its rationale appears to be purely humanitarian; however, it does recognize the importance of politics in reaching the goal. The resolution on the eradication of smallpox, adopted in 1958, argued the humanitarian case, but also stated the Assembly's view that the costs of eradication would be less than the costs of control, and that successful eradication would make expenditures on smallpox control and treatment redundant (Fenner et al. 1988:368).

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Social and Political Determinants of Eradication

I shall describe the factors that affect the outcome of an eradication program as "determinants," in that these factors interact among themselves to influence the outcome, and no single determinant completely predicts the outcome. I shall categorize the social and political determinants of eradication as being broadly economic as well as social and political. I shall discuss the economic considerations only briefly, as part of the setting for the social determinants.

Economic Considerations

Eradication of a disease can be considered in economic terms as an investment, where an expenditure in the present reaps dividends into the future (Barrett and Hoel 2007). There are often diminishing returns on health expenditure, but for disease eradication this is not true. As control improves, there are diminishing returns, but when eradication is achieved there are very great returns indeed. For smallpox, the dividend was enormous. A one-time investment made for smallpox eradication in 1967 of USD 100 million saved about USD 1.35 billion per year, which, assuming a 3% discount rate, resulted in a benefit/cost ratio of ~150/1. The benefit/cost ratio for the incremental cost of eradicating polio in 1967 was even larger: ~450/1. The benefit to the United States alone was USD 5 billion (Barrett 2004; Barrett and Hoel 2007). Barrett and Hoel (2007) describe this as "an astonishingly good deal" for the world. Countries can be strongly motivated to participate in eradication by the promises of a great return on such investments and, more critically, de-motivated when the returns on investment are low or, in the case of failure, negative.

The Utility of Eradication

Economically, eradication is always better than continued efforts and expenditure on high-level control. If eradication is feasible then it is always to be preferred, and altering course to change the objective from eradication to control is not economically optimal (Thompson and Duintjer Tebbens 2007; Barrett and Hoel 2007). Eradication requires greater effort in the short run, but returns a bigger dividend over the long term; for control, this situation is reversed (Barrett 2004). For polio, this means that the world should be willing to pay yet more to achieve eradication. If we return to a situation of low control, the epidemiology will revert to the situation in the 1980s, but with a bigger world population. This constitutes a very strong economic and public health case for eradication now (Thompson and Duintjer Tebbens 2007).

The returns from investment in a disease eradication initiative over the long term are very large; however, they accrue into the future, and their valuation depends on countries' and people's time consistency of preferences. It is difficult for communities and countries to value the far distant future in the same

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way as the present, and this becomes particularly important in political processes, which are generally characterized by short time horizons.

The economic benefits and costs of disease eradication are not uniformly distributed over populations or countries. Countries with a high burden of disease may benefit more, but the cost structure of the health care system will also influence policymakers' views. To take the example of polio, the return to the world as a whole on investment in eradication has been found to be high (Khan and Ehreth 2003; Duintjer Tebbens et al. 2011). However, there are differences between high- and lower- and middle-income countries. If polio immunization were discontinued, eradication would be a good investment for high-income countries. Most of these countries, however, have made policy decisions to continue polio vaccination after eradication for other reasons, and thus the return will not include savings due to cessation of immunization (Barrett and Hoel 2007). For countries proposing to cease polio immunization after eradication, eradication becomes economically optimal if lifetime welfare costs of paralytic polio exceed USD 60 to USD 250. Treatment costs in low-income countries are about USD 420, and Barrett and Hoel (2007) conclude that eradication is the preferred strategy.

Competing Priorities

Eradication may be a worthwhile goal for any country, but the proposal cannot be considered in a vacuum since there are always competing proposals. Eradication may be a good investment in the long run, but it may not be the best alternative in the present. For many countries, eradication of a disease that can be well controlled by immunization may be a low priority when placed alongside the burden of other diseases. This is a current problem for polio eradication. For many countries in Africa, for instance, polio is not a high priority in terms of reducing the burden of disease.

Social and Political Engagement

Public health is, by definition, a collective enterprise and is therefore, of necessity, political. Public health programs, and especially large, high-risk proposals like eradication, attract attention from a range of political actors including international organizations (both diplomatic and nongovernment), nation-states, and political groupings within nation-states (Taylor 2009). Disease eradication programs, especially those that use immunization to achieve these ends, are "deeply social and political phenomena" (Bhattacharya and Dasgupta 2009). Because high coverage is needed, it is impossible to conduct an immunization program without paying due consideration to the social and political context within which it occurs. For disease eradication to happen, a threshold minimum of the population must be removed from risk, and for vaccine-preventable diseases this means the population must be immune. Epidemiological theory

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describes a minimum susceptible population size needed to sustain continued transmission, and this is always a very small proportion of the global population. For all practical purposes disease eradication "relies on absolute commitment among all engaged parties" (Taylor 2009); there must be very high social commitment to eradication within a country, and disease eradication cannot be achieved if even one small country does not participate in the program. This creates a major diplomatic challenge. It is difficult to organize consensus among nations, and difficult to organize consensus within nations, since, though the costs are very evident, no single group by itself benefits enough from eradication to campaign for it (Farchy 2005). This is a not uncommon problem in international relations, and there is a history of both successes and failures. Universal agreements on smallpox and containment of atmospheric ozone depletion have been achieved (Barrett 2006), but agreement has eluded international negotiators for other universal projects, such as nuclear disarmament and targets for reduction in emissions of carbon dioxide.

The Politics of Eradication

Lessons from smallpox eradication that can assist other eradication initiatives include the need for long-term, high-level political commitment (Fenner et al. 1988:1349) and the understanding that "societal and political considerations ultimately determine success" (Aylward et al. 2000a:1515). It is often said that if political commitment is obtained, disease control and eradication initiatives will be strengthened and immunization coverage will increase. However, it is difficult to describe exactly what "political will" entails in this context (Gauri and Khaleghian 2002), and this argument does not sufficiently recognize all the other factors that determine the performance of an eradication program.

Disease eradication is a very large strategic gamble (Barrett 2009), and risk of failure is a major political problem. Countries fear for sunk costs if the program is ultimately unsuccessful. These costs are incurred up to the point of acceptance of failure and are not recoverable; because disease control will have to be maintained, this leads to a loss of political legitimacy (Farchy 2005; Barrett 2006, 2009). Failure may have dire political consequences for governments and the international organizations that have sponsored the unsuccessful eradication attempt. Countries will not participate unless confident of success, and the benefit conferred by failure is small or zero.

Community Participation in Immunization Programs

Immunization programs that target the entire population depend on reliable demand for vaccination and effective supply. This is immediately a sociopolitical argument, as participation depends on the perceptions of disease and risk held by individuals in the community, and competing priorities (Taylor 2009). Eradication of vaccine-preventable diseases raises the stakes, requiring

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high, though not universal, immunization coverage. Directly transmitted communicable diseases can only be spread to persons who are susceptible to the disease. This is the rationale for immunization, since it reduces, often to very low levels, the probability of transmitting disease from an infective to a vaccinated individual. If the infective person makes contact with only susceptible persons, the degree of transmission of the disease will depend on the properties of the disease in that community. If the infective person makes contact with only vaccinated persons, who are therefore not susceptible, transmission does not occur. If there are both vaccinated and unvaccinated persons in the community, the sustainability of transmission depends on the properties of the disease in the community and on the average number of contacts made with unvaccinated persons. For a large population, a threshold proportion of effectively immunized persons can be derived. Mathematically this is given by:

$$v^* \geq 1 - \frac{1}{R_0}, \tag{5.1}$$

where v^* is the proportion effectively immunized and R_0 is the average number of secondary cases due to a single infective in a completely susceptible population (Smith 1964). Thus it is not, in principle, necessary to obtain universal immunity to eradicate a disease, and it is possible to accommodate a limited degree of nonparticipation.

Estimates of the threshold "herd" immunity required to eradicate various diseases have been made. The range for most of the potentially eradicable diseases is between 70% and 95% (Anderson and May 1991:88). However, a number of factors must modify this conclusion. Vaccines are not perfectly effective, many vaccines require multiple doses for efficacy, and several diseases have multiple immunotypes, each of which requires threshold coverage for eradication. For practical purposes it is necessary to engage nearly the entire population of a country in this effort.

Individuals in a completely "rational" community would participate in an immunization program up to the level where the perceived benefits for each individual outweigh the perceived risks. The principal benefits are protection from disease, whereas the risks are the adverse effects of the vaccine. A community behaving in this manner would participate to the point where the disutility of adverse effects is just balanced by the utility of protection (Fine and Clarkson 1986). However, protection (or risk of disease) is afforded not only by an individual's own acceptance of a vaccine, it is also determined by uptake of the vaccine throughout the rest of the community. The incidence of the disease is dependent on immunization coverage, which is in turn dependent on the sum of individuals' decisions to accept vaccination. Decisions of an individual would therefore depend in part on the decisions made by other community members (Bauch et al. 2003). Game theory was developed to investigate such eventualities and one can describe a "vaccination game." Under this theory, a

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game reaches a stable point at a Nash equilibrium, when all players have adopted the best strategy available, given the strategies adopted by other players. The behavior of real populations can be modeled, and in general observed behavior follows convergently stable Nash equilibria (Bauch and Earn 2004). In a convergently stable Nash equilibrium, the strategies players adopt converge to a single strategy, irrespective of strategies adopted by other players. For the vaccination game, the relative risk of adverse effects of vaccination is defined as $r \equiv \frac{r_v}{r_i}$, the risk due to the vaccine (r_v) divided by the risk due to infection (r_i). Persons who perceive that $r > 1$ (i.e., the vaccine is more risky than taking one's chances with the disease) would not participate in the vaccination program, whereas persons perceiving $0 < r < 1$ would see benefit in vaccination and would participate. On the assumption that the behavior is "rational," Bauch and Earn show that the proportion of the community taking up vaccination under a convergently stable Nash equilibrium is given by P^* where

$$P^* = 1 - \frac{1}{R_0(1-r)} < 1 - \frac{1}{R_0}. \tag{5.2}$$

R_0 is again the average number of secondary cases attributable to a single infective in a completely susceptible population. Thus, under these assumptions, a "rational" community would never participate in an immunization program to the extent necessary to eradicate a disease (Bauch and Earn 2004; Farchy 2005).

Further insights may be gained from game theory into the effects of adverse publicity. It is not at all uncommon for the media to propagate scare stories about the alleged adverse effects of vaccines, with consequent, sometimes disastrous, loss of public confidence in the immunization program. On the basis of their analysis, Bauch and Earn expect that the community would be more likely to refuse immunization for highly infectious diseases, compared with diseases of lower transmissibility.

Furthermore, the impact of vaccine scares and education programs to counter them would be asymmetrical. Vaccine scares would lead to rapid reductions in vaccine uptake, but public education campaigns on the value of immunization designed to offset scare stories would produce slower increases in uptake, because increasing uptake by the community as a whole would reduce an individual's incentive to participate (Bauch and Earn 2004). Both of these effects seem to occur in practice.

The first consequence of this analysis is that to achieve sufficient immunization coverage for eradication to be successful, community members have to participate beyond the extent determined by "rational" self interest. The decision to participate may entail a positive valuation of the health of others in addition to one's own, and this may include other members of the present community, or for future members, particularly one's descendants. In addition, education and other campaigns designed to mitigate the effects of scare

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stories are critical, and can often take time. Thus consistency and persistence are required.

A possible strategy for overcoming community nonparticipation in a program is to make participation compulsory (Lahariya 2007). Immunization is quasi-compulsory in many countries, where school entry laws require a certificate of immunization (or in some countries a certificate of exemption). Compulsion, even forcible compulsion, has been described in some places during the smallpox eradication program (Greenough 1995; Bhattacharya and Dasgupta 2009).

In practice, eradication of a disease cannot be achieved without engagement and participation of the entire population; therefore, eradication programs require a greater focus than is usually given to marginalized groups (Taylor 2009). Participation of hard-to-reach subpopulations becomes a critical part of eradication initiatives and necessitates the development of novel ways to engage with these communities that differ from the approaches of more routine health services. For example, uptake of polio vaccine among the Moslem population in northern India has been low in the recent past compared with the Hindu population, and the eradication program has attempted to engage this community by relabeling it as "underserved," a language that avoids religion as a potential barrier to participation (Taylor 2009).

There is a conflict between the interests of the community as a whole and the individuals within it (Fine and Clarkson 1986; Taylor 2009). Generally, public health staff tend to adopt a technical-scientific paradigm, and consider the social and political requirements of program operation to be of secondary importance. This leads to an attitude that tolerates a subversion of rights for the "greater good" (Lahariya 2007; Taylor 2009). This is sometimes reinforced by the fact that many public health staff are government employees and operate in an environment that uses regulation extensively to achieve public health ends. Eradication of a disease relies on universal commitment, yet a community's perception of a focus on a single disease, with consequent scaling back of emphasis on other concerns, may result in disengagement. The community responds to different diseases in different ways, owing to their different natural histories and different means of treatment and control. The effort put into polio control, for example, is perceived by many in the community, and even by many in the public health community, as being disproportionate to the risk it poses (Gersovitz and Hammer 2003; Taylor 2009).

Scientifically trained public health staff (especially Westerners) often interpret nonparticipation in immunization programs as being religious in nature. Although religious belief may play a role, this interpretation is usually an oversimplification. Local political leaders often use immunization as a wedge, holding the program hostage to other concerns (Bhattacharya and Dasgupta 2009). Essentially, this strategy works because of the value differences between local people and program managers and advocates.

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Participation of a population in an eradication initiative is determined by a complex mix of factors. Participation of "rationally" behaving individuals will never be sufficient to eradicate a disease; some other motivation must be brought to bear. This may be altruism, a sense of commitment to society or one's descendants, or compulsion. Different strategies will be more or less effective in different contexts. These considerations then raise major ethical issues that need to be addressed by the eradication program.

Program Management

Disease eradication requires an enormous, global effort. It is a high-risk proposition, as any one of very many factors could cause the entire enterprise to fail. Strong program management is therefore an essential condition for success. Surprisingly, however, there is a dearth of high-quality evidence on the impact of management on the effectiveness of immunization programs. A search of the literature by Ryman et al. (2008) revealed 11,500 papers published between 1975 and 2004. Of these, only 25 met quality criteria. Their results focused on strategies to bring immunization services closer to the community, communication to increase demand for immunization, changing practices at fixed sites, and using more innovative management practices, all of which resulted in increase in uptake and community engagement (Ryman et al. 2008).

A World Bank study examined predictors of immunization service performance at national level, reviewing published data to construct a model of predictors of national immunization performance (Gauri and Khaleghian 2002). The broad findings were that:

- Global policy significantly affected immunization coverage, with the Universal Childhood Immunization initiative, for example, being most likely responsible for a major increase in coverage in most countries.
- Involvement with international agencies, such as UNICEF or revolving funds, affected coverage positively but delayed uptake of new vaccines.
- Democratic governments were associated with lower immunization coverage, but not in low-income countries.
- Supply-side factors, such as quality of a country's institutions, affected coverage but several demand-side factors did not. Institutional quality was measured using an index available to the World Bank, and demand-side factors included national income, literacy, access to mass media, female participation in the labor force, and previous experience of disease outbreaks.

Gauri and Khaleghian (2002) emphasize that, in their opinion, this does not provide support for the establishment and support of autocratic regimes. However, the study does indicate that international support and broad indicators of management quality are associated with higher coverage, and these have been major foci of activity in the operation and management of eradication activities.

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Eradication is impossible without international coordination, and failure of management of eradication initiatives on the ground has been considered to be a key cause in lack of progress in eradication. Several countries have suffered setbacks in their eradication programs, because of poor-quality leadership and management.

Eradication depends on elimination from all areas, including the area with the least favorable conditions (Barrett 2004). Often there are issues of conflicts of competence and responsibility. National policy may be set by national governments but it is implemented by provincial, state, regional, or local governments, all of which may have their own agendas. In many countries the relations between all these levels of government and the other actors, such as voluntary and nongovernment organizations, are complex. "There is a lot going on, and it easily ends up a jumble" (Gersovitz and Hammer 2003). Ensuring long-lasting agreement and commitment to high standards of program management and performance is critical in all areas.

International Diplomacy

An eradication program depends on active participation by all nations; even one country failing to eliminate provides a source of infection for all other countries (Farchy 2005). No nation is so small that the contribution its population makes to the epidemiology of a disease can be ignored in an eradication initiative. This poses a diplomatic challenge. The behavior of disease agents is indifferent to the political orientation of any country's government, so that the international arrangements must incorporate all governments, both *de facto* and *de jure*, including those who may not recognize each other or even be at war with each other. These arrangements must then be maintained in perpetuity, because, as I have argued above, some level of control effort will be required indefinitely.

Game theory provides a framework to consider the actions of countries. The choices available to any country at any stage of disease eradication are made by countries independently, but the optimal choice for each depends on the actions of others (Thompson and Duintjer Tebbens 2008a). In the case of eradication, the game may be characterized as a "prisoner's dilemma." Here, benefits and costs from eradication are not the same for all players, and players can choose to either cooperate or defect. For some players, the net costs and benefits for cooperation are less than the net costs and benefits for not cooperating. For disease eradication this means that countries either participate or not in the eradication program, and it turns out that the "rational" response is not to participate (Leyton-Brown and Shoham 2008). If all countries receive the same benefit, the game is a "coordination game," where there are no conflicting interests, and the optimal strategy for all players is to coordinate their strategies (Barrett 2004; Barrett and Hoel 2007).

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The optimal choice for an individual country may not be optimal for the world as a whole, and thus a mechanism must be found to reach a globally optimal outcome while minimizing the costs (economic, social, and political) for each individual country. In traditional diplomacy, this entails some degree of enforcement. Although a limited degree of nonparticipation within countries in the immunization program can be tolerated, nonparticipation during post-eradication control (e.g., by establishing regimes for laboratory security) cannot be accommodated at all. Because there is a requirement for universal participation, there are incentives for uninterested nations to hold the program to ransom. In addition, nations are not monolithic; they are made up of competing political forces, and there is an incentive for political forces competing against the government to behave in similar ways within nations. This happens wherever security or lack of political legitimacy is an impediment to immunization and eradication programs, and occurs in many countries. Obvious examples affecting polio eradication are Afghanistan, Pakistan, and the cessation of the program in northern Nigeria in 2003–2004.

An eradication initiative also assumes that countries value the health of future generations, even if discounted. The political cycle, even with very long-term governments, is far shorter than this time horizon, and it is unlikely that health benefits beyond 50–100 years come into serious political consideration. Further, public health is not usually a field where governments feel strong political pressure.

International cooperation will be required indefinitely after eradication has been achieved. Post-eradication management is an insurance problem, and thus all countries will have some incentive to protect against the risk of disease recurrence, but may do so at different levels. Collaboration among countries to insure against reintroduction or escape of an eradicated disease agent will almost certainly be cheaper (Thompson and Duintjer Tebbens 2008a).

Nation-states have an interest in encouraging other countries to improve the control of communicable disease (Gainotti et al. 2008), and international mechanisms, notably the International Health Regulations, have been established to achieve this end. International surveillance of disease in the post-eradication environment is similar to testing individuals for disease. Individuals often do not wish to know their disease status, or they may conceal it, and knowledge of disease status affects behavior in varying ways (Gersovitz and Hammer 2003). Infected individuals may not necessarily behave in ways that minimize transmission; infected people with pessimistic expectations may engage in risky behavior (Auld 2003). Likewise, countries may behave in very similar ways.

Global Coordination

A mechanism for global coordination is required to ensure universal engagement with an eradication initiative. This has to work with the complexities of international organizations, national and regional governments, as well as with

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global and national nongovernment organizations and foundations and a wide variety of bilateral and multilateral international arrangements (Bhattacharya and Dasgupta 2009). The history of disease eradication to date has been sponsorship by an international organization and delivery by nation-states, with a consequent potential for conflict (Smith et al. 2004; Taylor 2009). As a diplomatic organization, the World Health Organization has to give primacy to nation-states, but where the authority of the state is weak, the capacity to deliver an eradication program may be problematic. Compared with the era of the smallpox eradication program, there are now many more international actors. There are more nation-states, often with an increasing number of powerful regional political entities as well as powerful nongovernment organizations. For example, in the past, global immunization policy was by and large determined by the WHO, but now the World Bank, the Bill & Melinda Gates Foundation, the Global Alliance for Vaccines and Immunization, and Rotary International all influence policy.

Availability of donor funding for communicable diseases control programs, including eradication initiatives, may be analyzed in terms of recipient need, provider interest, or global policy frameworks (Shiffman 2006). Donor funding is poorly related to burden of disease in recipient countries and often reflects perceptions of burden in donor countries (Shiffman 2006).

There are incentives for international cooperation (Thompson and Duintjer Tebbens 2008a), but experience and game theory demonstrate that some degree of enforcement may be required (Barrett 2004). International law has been important in communicable disease control, and the International Health Regulations were developed as one means of achieving cooperation (Lazcano-Ponce et al. 2005; Gainotti et al. 2008).

A partial solution to this may be diplomatic and financial. It is possible to exert diplomatic pressure for eradication initiatives, and the WHO itself has attempted this in Nigeria. Countries can be supported financially to eradicate disease, if the priority for the country is lower than the priority for aid donors.

Conclusions

Disease eradication presents unique benefits and novel challenges. It is a high-stakes game, demanding universal participation over a prolonged period, in an environment where the mechanisms to ensure participation are weak. Yet eradication has been achieved on one occasion, and smallpox has been removed as a global threat. In addition, large areas of the world have eliminated polio, measles, rabies, dracunculiasis, lymphatic filariasis, and even malaria.

Disease eradication cannot be achieved without a vision for the future. If a community takes only its present self-interest into account, participation in eradication initiatives will never be sufficient to reach this goal. The investment case for eradication is on behalf of future generations, and advocacy

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needs to focus on this. To be successful, it is necessary to create the conditions that ensure that there are future generations, through encouraging peace and sustaining the environment. Mechanisms must be found to establish and maintain agreement to eradication programs among participants whose interests diverge sufficiently to cause deep political conflict and even open warfare. This, inevitably, will be a mix of incentives and disincentives. Many countries have far more pressing priorities than disease eradication, and some means must be found to allow support for both these priorities and eradication initiatives. It would seem that there should be a principle that those who receive the greatest benefit should contribute most to the costs. However, it also seems necessary to have a mechanism of enforcement.

These considerations apply at all levels. There is a need for international leadership, in a context where leadership is dependent on the willing agreement of all nations. There is a need for national and social leadership, to submerge other differences of social opinion in agreement on disease eradication. Eradication initiatives are critically dependent on the participation of the most marginalized groups. This provides an unprecedented opportunity for those groups to apply political pressure to achieve their objectives and, correspondingly, a means to incorporate these groups into broader society.

The political and social criteria for eradication override all others. While eradication of a disease may be technically feasible, agreement, organization, and funding all need to be established and maintained. This cannot be done outside politics. Despite these difficulties, it is little short of astonishing that disease eradication has been achieved and is feasible for a number of other diseases.

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