Bioterrorism in Canada: An economic assessment of prevention and postattack response

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R St John, B Finlay, C Blair. Bioterrorism in Canada: An economic assessment of prevention and postattack response. Can J Infect Dis 2001;12(5):275-284.

The present paper calculates the human and economic consequences of a bioterrorist attack on Canadian soil using aerosolized *Bacillus anthracis* and *Clostridium botulinum*. The study assumed that 100,000 people in a Canadian suburban neighbourhood were exposed over a 2 h period to an infectious dose of one of the agents. Using an epidemic curve based on the epidemiology and management of anthrax and botulinum poisoning, the costs of intervention and treatment after an attack were compared with the costs of preparedness before a bioterrorist attack. The results show that an investment in planning and preparedness to manage the consequences of an attack can reduce morbidity, mortality and economic costs. The sooner that an intervention program is instituted, the more significant are the health and economic benefits. The greatest benefits were realized when postattack intervention was initiated before day 3 after the event. The economic impact of a bioterrorist attack in Canada could range from $6.4 billion/100,000 exposed to *B anthracis* to $8.6 billion/100,000 exposed in an attack using *C botulinum*. Without the benefit of an effective consequence management program, predicted deaths totalled 32,875 from anthrax and 30,000 from botulinum toxin. Rapid implementation of a postattack prophylaxis program that includes the stockpiling of antibiotics, vaccines and antitoxins; training of first responders in the diagnosis, handling and treatment of pathogens; and the general enhancement of Canada's response capability would reduce both human and economic losses.

Key Words: *Actuarially fair premium; Anthrax; Bioterrorism; Botulinum toxin; Economic consequences*

Bioterrorisme au Canada : évaluation économique de la prévention et de la capacité d'intervention après une attaque

RÉSUMÉ : Le présent article a pour objet les conséquences humaines et économiques d'une attaque bioterroriste au Canada par la projection de *Bacillus anthracis* et de *Clostridium botulinum* en aérosol. Nous avons supposé que 100 000 personnes vivant en banlieue avaient été exposées durant deux heures à l'un des deux agents infectieux. Nous avons comparé, à partir d'une courbe de l'épidémiologie et du traitement de l'anthrax et du botulisme, les coûts d'intervention et de traitement après une attaque à ceux de l'état de préparation avant une attaque bioterroriste. Les résultats montrent qu'investir de l'argent dans la planification et l'état de préparation afin de gérer les conséquences d'une attaque peut réduire la morbidité, la mortalité et les coûts. Plus un programme d'intervention est mis en œuvre rapidement, plus les bienfaits pour la santé et l'économie sont grands. Les gains les plus importants sont réalisés lorsque l'intervention est amorcée avant le troisième jour après une attaque. Le coût d'une attaque bioterroriste au Canada pourrait varier de 6 400 000 000 $/100 000 habitants exposés à *B. anthracis* à 8 600 000 000 $/100 000 habitants exposés à *Clostridium botulinum*. Sans les avantages d'un programme efficace de gestion des conséquences, le nombre total de morts pourrait s'élever à 32 875 pour l'anthrax et à 30 000 pour le botulisme. Aussi croyons-nous que la mise en œuvre rapide d'un programme de prophylaxie après une attaque, comprenant la constitution de réserves d'antibiotiques, de vaccins et d'antitoxines, la formation des premiers répondants en matière de diagnostic, de manipulation et de traitement des agents pathogènes et une amélioration générale de la capacité d'intervention du Canada, permettrait de réduire les pertes humaines et économiques.

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Received for publication January 11, 2000. Accepted July 5, 2000

In its 1998 *World Health Report*, the World Health Organization (WHO) reported that infectious and parasitic diseases caused over 17 million of the 52 million estimated deaths worldwide (1). Naturally occurring emerging and re-emerging infectious diseases have drawn considerable attention in the scientific community. However, a relatively recent biological accident in Russia involving anthrax and the release of sarin gas in a Tokyo subway have dramatized the threat posed by the deliberate release of highly dangerous pathogens and toxins. According to another WHO report released in 1970 and currently under revision, a deliberate attack on an urban centre releasing 50 kg of dried anthrax in an aerosolized form would affect an area far in excess of 20 km^2, resulting in tens to hundreds of thousands of deaths (2).

In the April to June 1997 issue of the Centers for Disease Control and Prevention (CDC) journal *Emerging Infectious Diseases*, Kaufmann et al (3) published a study detailing the economic impact of a hypothetical bioterrorist attack against a suburb of a major city in the United States. Their study assumed that 100,000 people were exposed in the target area. The authors analyzed the economic impact of an aerosolized release of the biological agents *Bacillus anthracis*, *Brucella melitensis* and *Francisella tularensis*. They compared the benefits of systematic intervention with the costs of increased disease incidence. The CDC study revealed that the economic impact of a bioterrorist incident can range from an estimated CDN$477.7 million/100,000 persons exposed (brucellosis scenario) to CDN$26.2 billion/100,000 persons exposed (anthrax scenario). The authors concluded that the rapid implementation of a postattack prophylaxis program is the single most important means of reducing excess morbidity and mortality and that there are sound economic justifications for initiating preparedness measures.

In May 1998, the Global Surveillance and Field Epidemiology (formerly the Office of Special Health Initiatives), Centre for Emergency Preparedness and Response (formerly the Laboratory Centre for Disease Control), Health Canada (Ottawa, Ontario) began similar research into prevention and postattack intervention programs in the event of a bioterrorist incident on Canadian soil. Our study substitutes Canadian data in the CDC model to derive a base cost estimate for a theoretical biological dispersion of *B anthracis*. In addition, we substituted a second biological agent, botulinum toxin, in place of the other pathogens studied by the CDC.

Recent reports that national governments (4) and terrorist groups (5) have stockpiled botulism toxin have increased levels of concern regarding preparedness for a deliberate attack with this agent. It is estimated that as little as 1 g of aerosolized botulism toxin has the potential to kill at least 1.5 million people, and modern techniques of aerosolization via tactical ballistic missiles or aeronautical spraying may be capable of disseminating up to 60% of this dosage to a target population (6).

The huge human and economic costs that could arise from the use of such weapons justify the need for prerelease domestic preparedness. Although we chose to base this study on a single massive bioterrorist dispersion, a more likely scenario may involve a single or a series of smaller orchestrated attacks in various locations. Such attacks would not only be more feasible from a dispersion perspective, but would also generate major problems related to response coordination and the treatment of victims.

TABLE 1
Case fatality rate (%) after anthrax and botulism exposure by day

Day	Anthrax	Botulism
0	85	60
1	80	60
2	70	46
3	50	30
4	50	30
5	50	30
6	50	30
7	70	30

DATA AND METHODS

The model chosen was a large attack on a civilian population in a suburban setting using a large scale dispersion of the neurotoxin produced by the anaerobic bacterium *Clostridium botulinum* or the dispersion of *B anthracis* spores.

Epidemiology: For each agent, an epidemiological outbreak curve was constructed using the assumptions that follow.

Anthrax: The study model assumed a nonmilitary attack on the suburb of a major city with 100,000 persons exposed in the target area. The attack was made by generating an aerosol of *B anthracis* spores along a line perpendicular to the direction of the prevailing wind. It was assumed that all meteorological conditions including thermal stability, relative humidity, wind direction and speed were optimal, and that the aerosol cloud passed over the target area over the course of a 2 h period, ie, exposure of the population lasted 2 h.

It was assumed that, when inhaled, the infectious $dose_{50}$ (ID_{50}) was 20,000 spores. The rate of physical decay for airborne particles 5 μm or less in diameter was estimated to be negligible for *B anthracis* spores. Viability and virulence were not lost in the aerosol. Persons exposed to the *B anthracis* cloud at any point in the 2 h transit time inhaled one ID_{50} dose. Assuming that 100,000 persons were exposed in the target area, only one-half or 50,000 persons received an infectious dose of the anthrax spores.

The mortality rate for anthrax by day after exposure is summarized in Table 1. Case fatality rates were also assumed to vary by the day after exposure that symptoms were first noted. Case fatality rates were high for persons who presented for care on day 1, based on the assumption that such cases were initially exposed to very heavy innocula and antibiotic treatment would prove less effective. The case fatality rate was estimated to be 85% for patients with symptoms on day 1; 80% for those with symptoms on day 2; 70% for those with symptoms on day 3; 50% for those with symptoms on days 4, 5 and 6; and 70% for those with symptoms on and after day 7. The increased death rate in persons with an incubation period of

seven or more days was based on the assumption that diagnosis was delayed with a concomitant delay in initiating therapy.

This study did not consider many of the longer term effects of an attack with *B anthracis*. For instance, the immediate environment would remain contaminated indefinitely. Air dispersion of spores would also be expected to contaminate localities far distant from the area of immediate attack. These considerations could elevate the overall number of casualties and costs of treatment.

Botulism: Similar to anthrax, the impact of a theoretical bioterrorist attack on a suburb of a major city was calculated. It was assumed that 100,000 persons were exposed for 2 h, with one-half or 50,000 persons receiving an infectious dose. The attack was made by generating an aerosol of botulinum toxin along a line across the direction of the prevailing wind under optimal meteorological conditions.

The lethal dose$_{50}$ (LD_{50}) for botulinum toxin by inhalation was assumed to be 3.0 ng/kg (7). For the purposes of this study, and in the absence of any data to define a dose response curve, it was assumed that the ID_{50} delivered during the incident was sufficient to result in a 60% case fatality rate for patients not adequately treated with ventilatory assistance and the trivalent antitoxin (personal communication, Connaught Laboratories' Immunization Service). Similar to anthrax, the rate of physical decay for airborne particles 5 μm or less in diameter was estimated to be negligible for botulinum toxin, and viability and virulence were not lost.

The Canadian fatality rate for untreated botulism (contracted through ingestion) before the introduction of the trivalent equine antitoxin was 58% (8). According to unclassified North Atlantic Treaty Organization sources (9), the fatality rate for untreated botulism before 1950 was 60%. Both numbers reflect fatality rates for patients treated with neither the antitoxin nor ventilatory assistance. For the purposes of the present study, it was assumed that sufficient quantities of the trivalent antitoxin would not be available until 48 h after the initial exposure. According to Connaught Laboratories, the fatality rate for patients receiving hospitalized care and ventilatory assistance without the benefit of the antitoxin is 46%. Inhalation botulism patients diagnosed accurately and treated with the antitoxin while receiving mechanical ventilation had a reduced fatality rate of 30% (estimate based on unclassified United States Army Medical Research Institute for Infectious Diseases research into inhalational botulism and on Connaught Laboratories' Vaccine Information Service). Thus, fatality rates fluctuated according to the day of onset of symptoms and the likelihood of medical response. The model assumed that stockpiles of drugs and, more importantly, ventilators were available and could be moved rapidly to points of need.

The mortality rate for inhalation botulism by day after exposure is also summarized in Table 1. As noted above, the case fatality rates also varied according to the estimated level of preparedness of responders. Fatality rates for those exhibiting symptoms within the first 24 h was 60%; for day 1, 60%; for day 2 46%; and for day 3 onwards, when supplies of both antitoxin and ventilators were assured, 30%.

Economic costs: Economic costs associated with each event were calculated using data from multiple sources. The technical details for the calculation of the present value of hospitalization, costs of posthospitalization care and the costs of outpatient visits can be found in the Technical Annex.

When the costs of hospitalization and outpatient visits were calculated, it was assumed that only persons with symptoms (ie, case patients) would use medical facilities, ie, emergency rooms, hospital clinics and inpatient facilities. The remainder of the exposed, potentially exposed and so-called 'worried well' populations would receive only postexposure prophylaxis in other settings, eg, private physician offices, community clinics, schools, pharmacies, etc.

The costs of mortality were calculated using the human capital approach and were represented by the current monetary value of future productivity lost due to premature mortality. Details are also included in the Technical Annex.

The costs of an intervention were calculated according to the following formula:

$$\text{Cost of intervention} = (\text{cost of drugs used}) \times ([\text{number of people exposed} \times \text{multiplication factor}] - \text{number killed} - \text{number hospitalized} - \text{number of persons who require outpatient visits})$$

Details for the calculation of the costs for the components of this formula can also be found in the Technical Annex.

Economic cost of preparedness: The economic calculations for an intervention after an attack include several assumptions that do not necessarily reflect reality. First, it was assumed that the stockpiles of drugs, vaccines, antitoxins and, most importantly, ventilators would be available, and could be moved rapidly to points of need. Second, it was assumed that civilian, military and other organizations would be in place and be able to identify the agent rapidly, dispense drugs, treat patients and keep order within the population. Finally, it was assumed that the probability of an attack was very low and arbitrarily assigned a probability of once/100 years or 0.01. The cost of these preparedness activities can be calculated if they are seen as a form of insurance, the goal of which is to 'purchase' the maximum net savings in terms of reduced morbidity, mortality and economic costs through preparedness to manage the consequences of an attack. The so-called 'actuarially fair premium' for the 'insurance' can be defined as follows:

$$\text{Actuarially fair premium} = \text{probability of attack} \times \text{value of avoidable loss}$$

The term 'avoidable loss' incorporates the concept that, even if a postexposure program were to be implemented on the day of the release (day 0), some deaths, hospitalizations and outpatient visits would be unavoidable.

A range of minimum and maximum values of avoidable loss was derived from the net savings calculations. The values reflect differences in effectiveness of the various pro-

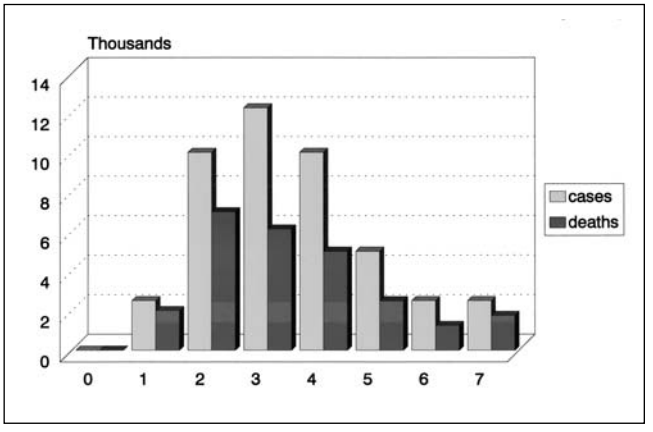

Figure 1) *Number of anthrax cases and deaths by day*

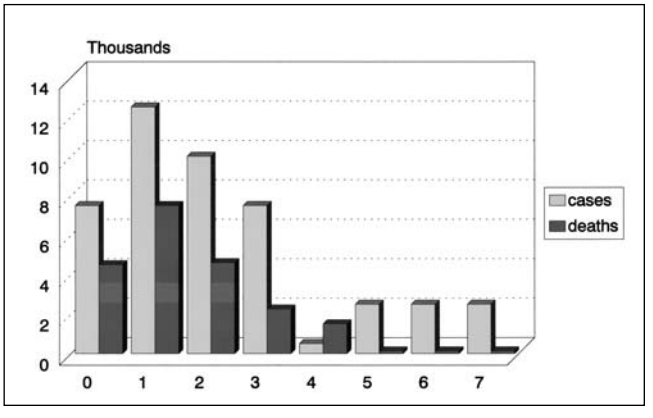

Figure 2) *Number of botulism cases and deaths by day*

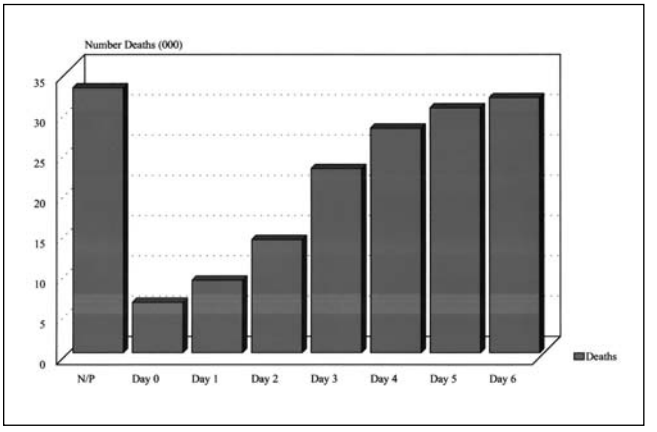

Figure 3) *Deaths following an anthrax intervention program initiated on the indicated postattack day. N/P No intervention program*

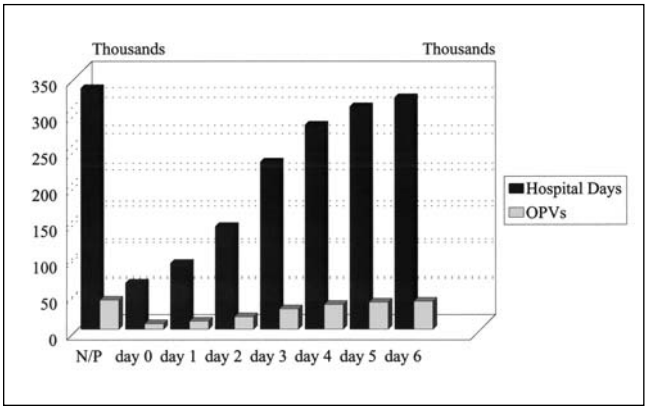

Figure 4) *Outpatient visits (OPVs) and hospital days following an anthrax intervention program initiated on the indicated postattack day. N/P No intervention program*

TABLE 2
Total cases, deaths, hospitalizations and cost after anthrax and botulixm exposure by day

	Anthrax	Botulism
Total cases	50,000	50,000
Total deaths	32,875	30,000
Total days of hospitalization	332,500	4,275,000
Total cost	$6.5 billion	$8.6 billion

phylaxis regimens, the reduced impact of delayed prophylaxis on illness and death, and the two discount rates used to calculate the present value of earnings lost because of death.

RESULTS

Assuming that 100,000 persons were exposed to either *B anthracis* or *C botulinum*, high rates of morbidity and mortality would result. Figure 1 shows the epidemic curve for an outbreak of pulmonary anthrax. Assuming no postexposure prophylaxis program is initiated, 50,000 cases of inhalation anthrax would result in 332,500 person hospital days and 32,875 deaths. Figure 2 reveals the epidemic curve for botulism. Due to the rapid onset of illness after exposure to botulism, cases are expected on day 0, with a more rapid increase in incidence in the early phases of the outbreak. In the event of an efficient dispersion of botulinum toxin resulting in the infection of 50,000 persons, and in the absence of a rapid response with both mechanical ventilation and sufficient doses of antitoxin, 4,275,000 hospital days could be expected along with 30,000 deaths. These data and associated costs are summarized in Table 2.

In the absence of an immunized population and a very limited supply of vaccine, anthrax morbidity and mortality prevention would be highly dependent on the availability of large supplies of commonly available antibiotics, eg, doxycycline. Figures 3 and 4 summarize the number of deaths, outpatient visits and hospital days expected, respectively, if an anthrax intervention program could be initiated on the day indicated after the release of the agent. For example, if the program for distribution, utilization and effectiveness of the chosen antibiotic was assumed to be 90% and the program could be implemented on day 0, ie, immediately, then only 6250 deaths would occur along with 7300 outpatient visits and 63,700 person hospital days.

Implementation of a prevention program at a later time, eg, after day 2 or day 3, results in much greater adverse

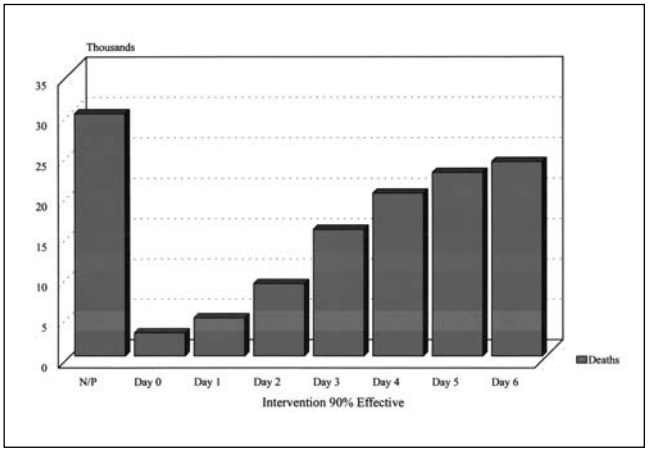

Figure 5) *Deaths following a botulism intervention programme initiated on the indicated postattack day. N/P No intervention program*

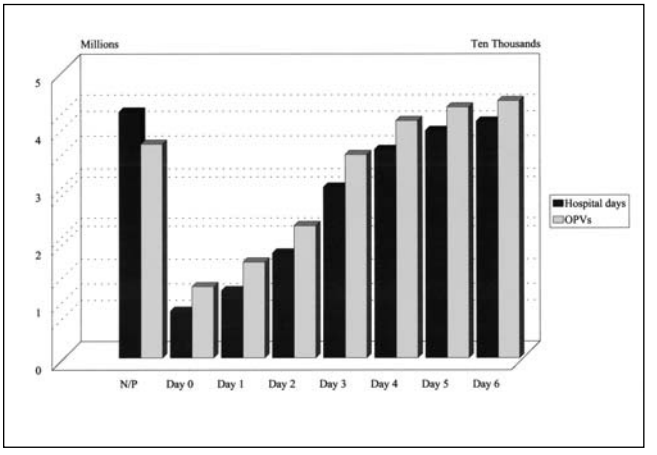

Figure 6) *Outpatient visits (OPVs) and hospital days following a botulism intervention programme initiated on the indicated postattack day. N/P No intervention program*

effects. No program at all results in astronomical losses. Figures 5 and 6 present similar data for a botulism intervention program. However, because of the difference in morbidity compared with anthrax, hospitalization days are measured in millions of days with a very high cost.

Table 3 shows the results of using an actuarially fair premium approach. Delaying a prophylaxis program for anthrax, a disease with a short incubation period and a high death rate, increases the risk for loss on a semilogarithmic scale. Arithmetic increases in response time buy disproportionate increases in benefit (prevented losses). The potential for reducing loss is great because an attack is assumed, thus increasing the actuarially fair premium available to prepare for and implement a rapid response. Thus, for a given likelihood of an anthrax event (once/100 years), the increase in investment to be able to respond on day 0 instead of day 6 is very large, eg, from $1.0 million on day 6 (minimum loss estimate) to $54.5 million on day 0 (maximum loss estimate). The required investment for botulism is much greater (see Technical Annex).

TABLE 3
Maximum amount yearly insurance (premium in millions) by an actuarially fair premium approach

Anthrax	Probability (1/100)
Day 6	1
Day 0	54.5

DISCUSSION

The threat of a biological terrorist event with a dangerous pathogen and its insidious impact are among the most dangerous, yet least understood, threats to civil society today. Although human pathogens are often lumped together with nuclear explosives and lethal chemicals as potential weapons of mass destruction, there is an obvious, fundamentally important difference: pathogens are alive, weapons are not. The use of a manufactured weapon, such as a bomb, is a singular event, ie, an explosion; the consequences are limited in time. Most of the damage occurs immediately. The use of a pathogen, by contrast, is an extended process whose scope and timing cannot be precisely controlled.

Anthrax is often considered the most likely pathogen to be used in a bioterrorist attack. Botulinum toxin is perhaps more difficult to deliver in an appropriately dispersed form. If a rapid response can be instituted, the costs in both human life and economic terms can be greatly reduced. With both anthrax and botulinum poisoning, incubation periods are short, and interventions must occur before day 3 after exposure to prevent the maximum number of deaths, hospital days and outpatient visits. Instituting interventions up to six days after exposure will still result in some benefits, although many fewer compared with earlier intervention.

The economic impact of a bioterrorist attack on Canadian soil can range from $6.5 billion/100,000 people exposed in the *B anthracis* scenario to $8.6 billion/100,000 people exposed in the botulism scenario. Exact costs are difficult to calculate. Under the assumptions made in this model, these costs are minimum estimates based on the consistent use of low estimates for all factors affecting costs. Moreover, other factors, such as a higher projected morbidity or mortality rate, physical and psychological illnesses, decontamination costs, disruptions in commerce and travel, and a lower than projected effectiveness of intervention programs, would have inflated the costs associated with a bioterrorist incident dramatically.

The rapid implementation of a prophylaxis program is essential in reducing morbidity, mortality and the economic costs associated with a bioterrorist attack. Although the savings achieved by initiating a prophylaxis program on any given day after exposure ranges widely, delays in initiating the program for both agents markedly reduce savings. In fact, delay in starting a prophylaxis program is the single most important factor resulting in increased losses. For anthrax, if an intervention could be instituted on day 0 rather than day 6 (postdispersion), over 25,000 lives could be saved, assuming a 90% rate of effectiveness and a 90%

TABLE 4
Costs of hospitalization and output patient visits (OPVs) following a bioterrorist attack

	Anthrax		Botulinum toxin	
	Base	Upper	Base	Upper
Hospitalized patient				
Days in hospital (n)	7	7	90	180
Drugs used	D/C	D/C+V	A	A
Cost of drugs ($)*	0.66/10.02	0.66/10.02+12.18	703	703
Cost per day ($)†	613	810	613	810
Lost productivity ($/day)	69.50	69.50	69.50	69.50
Follow-up OPVs (n)	2	2	1	1
Cost first OPV ($)‡	24.80	48.20	24.80	48.20
Cost follow-up OPVs ($)§	83.16	106.56	16.25	24.80
OPV laboratory ($)¶	58.36	58.36	58.36	58.36
OPV x-ray costs ($)**	5.30	8.80	nil	nil
Lost productivity ($/OPV)††	17.38	17.38	17.38	17.38
Total costs ($)	4,945.87	6,417.40	61,499.61	158,580.40
Average costs/day ($/day)	706.55	107.57	683.33	881.00
Nonhospitalized Patient				
Number of OPVs	7	7	7	7
Cost first OPV ($)‡‡	24.80	48.20	24.80	48.20
Cost follow-up OPVs ($)§§	16.25	24.80	16.25	24.80
Lost productivity ($/OPV)††	17.38	17.38	17.38	17.38
Laboratory costs ($)	58.36	58.36	58.36	58.36
X-ray costs ($)¶¶	20.25	30.71	N/A	N/A
Drugs used	D/C	D/C+V	A	A
Cost of drugs ($)***	0.66/10.02	0.66/10.02+12.18	703	703
Total cost of drugs ($)	18.48/264.60	55.02/301.14	703	703
Total costs ($)	362.46	753.00	1,216.72	1,563.43
Average costs/day ($/day)	46.64	107.57	173.82	223.35

**Projected intervention program for anthrax was either a 28-day course of oral ciprofloxacin or doxycycline (assumed to be 90% effective) or a 28-day course of oral ciprofloxacin or doxycycline plus three doses of the human anthrax vaccine (assumed to be 95% effective); for botulism, projected intervention was assumed to be a single dose of the trivalent equine antitoxin (assumed to be 90% effective), with the assumption that 80% of reported cases require mechanical ventilation. Upper estimates operate under the assumption that 25% of victims would require a second dose after exhibiting continued signs of deterioration. †Hospital costs for 1993 to 1994 fiscal year (12); upper estimates were drawn from total operating expenses per patient day for the province of Alberta. ‡First OPV based on the cost of a single intermediate visit to a general practitioner; subsequent visits based on the cost of a single minor assessment by a general practitioner; upper estimates based on a single general assessment. §Follow-up OPVs for hospitalized patients included two laboratory test sets for anthrax patients; for Botulism victims, base and upper follow-up OPV costs rated as OHIP A001 and A007. ¶For a more detailed enumeration of laboratory tests, please refer to "Cost of Post-Hospitalization" in the text of the article. **X-ray charges calculated for a single film procedure including only professional costs associated with the procedure; x-ray costs associated with botulism were presumed to be negligible once the toxin is identified and as such, while early diagnoses would likely involve at least one set of tests, extra charges have not been included in this study. ††Productivity lost due to an OPV was assumed to be one-quarter of an unspecified day's value (13). ‡‡First OPV based upon the cost of a single minor assessment by a general practitioner; upper estimates costed at that of a general assessment. §§Follow-up OPVs costed as a minor assessment with upper estimates ranked as intermediate assessments. ¶¶X-ray charges calculated for a single film procedure including all billable technical and professional costs, and for a two view diagnostic radiology procedure; x-ray costs associated with botulism were presumed to be negligible once the toxin is identified and as such, while early diagnoses would likely involve at least one set of tests, extra charges have not been included. ***For anthrax victims, projected intervention program was either a 28-day course of oral ciprofloxacin or doxycycline (assumed to be 90% effective) or a 28-day course of oral ciprofloxacin or doxycycline plus three doses of the human anthrax vaccine (assumed to be 95% effective); for victims of an attack with botulinum toxin, projected intervention was a single dose of the trivalent antitoxin (assumed to be 90% effective); it was also assumed that 25% of all victims would require a second dose after exhibiting continued signs of deterioration. A Trivalent Equine Antitoxin; C Ciprofloxacin; D Doxycycline; N/A Not applicable; V Anthrax vaccine*

compliance rate. For botulism, assuming the same time before intervention, rate of effectiveness and compliance rate, upwards of 28,000 lives would be spared as a result of the rapid implementation of mass inoculations with the antitoxin. This observation was supported by the analysis of the actuarially fair premium for preparedness. Reduction in preventable loss due to early intervention had a significant impact on the amount of an actuarially fair premium.

The maximum amount of the annual actuarially fair premium varies directly with the desired speed of postattack response, ie, the faster the desired response, the greater the required premium. As with the CDC study, the calculated amount of actuarially fair premium, however, should be considered a lower bound estimate. A higher estimate (called the certainty equivalent) can also be calculated; however, this requires the determination of a social welfare function, which is beyond the scope of this study.

Depending on the level of protection that can be achieved, the annual actuarially fair premium in an anthrax scenario would be $1.0 million to $54.5 million, and in a botulism scenario would be $20.5 million to $96.1 million. The lower premium would be justifiable for measures that would allow

TABLE 5
Costs of prophylaxis program following a bioterrorist incident in Canada

	Anthrax	Botulinum toxin
Lower estimates		
Effectiveness (%)	90	90
Drugs used	D or C	A
Cost of drugs ($)	0.66 or 10.02	703
Number of visits	4	1
Visit to drug dispensing site ($)*	8.51	8.51
Total cost/person ($)	52.52 or 298.64	711.51
Minimum number of participants	493,754	493,442
Total estimated costs ($)	25,931,960 or 147,452,006	351,088,917
Maximum number participants	1,468,456	1,466,082
Total estimated costs ($)	77,123,309 or 394,486,019	1,043,132,003
Upper estimates		
Effectiveness (%)	95	95
Drugs used	D+V or C+V	A
Cost of drugs	0.66+12.18 or 10.02+12.18	703
Number of visits	4	1
Visit to drug dispensing site ($)*	8.51	8.51
Total cost/person ($)	89.06 or 335.18	711.51
Minimum number of participants†	493,754	493,442
Total estimated costs ($)	43,973,731 or 165,496,465	351,088,917
Maximum number of participants‡	1,468,456	1,466,082
Total estimated costs ($)	130,780,691 or 492,197,082	1,043,132,003

**Cost of visit to drug dispensing site calculated as the cost of a mini assessment at $8.51; †Estimate assumed that the prophylaxis program was initiated on postattack day 6, that the prophylaxis program had a 90% effectiveness level and that the multiplication factor for unnecessary prophylaxis given to unexposed persons (the so-called 'worried well') was 5; ‡Estimate assumed that the prophylaxis program was initiated on postattack day 0 (day of the release), that the prophylaxis programme had a 95% level of effectiveness and that the multiplication for unnecessary prophylaxis given to unexposed persons (the so-called 'worried well') was 15. A Trivalent Equine Antitoxin; C Ciprofloxacin; D Doxycycline; V Anthrax Vaccine*

for the mounting of an intervention program within six days of the attack. The higher premium would be justifiable for measures that could allow for immediate intervention if an attack occurred.

This study assumes that the release of the pathogen occurs under ideal conditions. No adjustments were made to account for meteorological factors that would increase or decrease the dispersion of the agent, or adversely affect its inactivation in the environment. Optimal temperature and humidity are assumed. As a result, the number of victims under more realistic conditions may be lower than estimates in the present report. However, even if more realistic conditions yielded 50% of the present report's cases and deaths, the costs remain catastrophic for Canadian society.

The state of the atmosphere plays such an important role in the behaviour of aerosol clouds that it is a major factor in determining the outcome of an attack – the effect of which could be considerably reduced or almost nullified if the atmosphere was very unstable, or very serious if it was in a state of pronounced and prolonged stability. The model used in this study could benefit from the addition of dispersion models to examine the effects of different meteorological factors.

This model, designed by the CDC and modified for the Canadian context, provides an economic rationale for preparedness and planning measures to increase the civilian capability to respond rapidly in the event of a bioterrorist incident.

TECHNICAL ANNEX

Economic methodology – ***Net savings:*** To analyze the net savings resulting from public health intervention in response to an anthrax or botulism outbreak, the following formula was used:

Net savings = (number of deaths averted × present value of expected future earnings) + (number of days of hospitalization averted × cost of hospitalization) + (number of outpatient visits [OPVs] averted × cost of outpatient visits) – cost of intervention

When the costs of hospitalization and OPVs were calculated, the study assumed that only persons with symptoms (ie, case patients) would use medical facilities, eg, emergency rooms and inpatient facilities. The remainder of the exposed, potentially exposed and so-called 'worried well' would receive only postexposure prophylaxis in other settings, eg, private physician offices, community clinics, schools, pharmacies, etc, on an outpatient basis.

Present value of expected future earnings: Calculations of the present value of expected future earnings used in the CDC study were drawn from Haddix et al (10). The present value of expected future earnings was calculated, at a 3% and a 5% discount rate, to be US$790,440 and US$544,160, respectively, using the 'human capital approach'. Based on a study published in 1997 by Health Canada (11), the authors also used this approach to estimate the production losses attrib-

TABLE 6
Costs* (millions of dollars) of a bioterrorist attack with no postexposure prophylaxis programme

	Anthrax	Botulinum toxin
Direct costs		
Medical base estimates†		
Hospital	211.8	2,624.1
Outpatient visit	2.1	1.5
Medical upper estimates‡		
Hospital	281.7	3,469.2
OPV	4.8	1.7
Lost productivity		
Illness§		
Hospital	23.1	297.1
OPV	0.8	0.2
Death		
3% discount	6,180.1	5,639.6
5% discount	5,069.9	4,626.6
Total costs:		
Base estimates		
3% discount	6,417.2	8,562.3
5% discount	5,307.0	7,549.3
Upper estimates		
3% discount	6,489.8	9,407.8
5% ciscount	5,379.6	8,394.7

**Assuming 100,000 exposed; †Medical costs are the costs of hospitalization (which include follow-up outpatient visits [OPVs]) and outpatient visits (Table 1); ‡Upper estimates calculated with the data in Table 1; §Lost productivity due to illness is the value of time spent in hospital during outpatient visits (Table 1)*

utable to premature mortality. The corresponding values expressed in Canadian dollars for the present value of expected future earnings using the same discount rates were $187,989 and $154,220, respectively. Our approach differs from Haddix et al (10) in several ways. The authors calculated the 'value of a human life' using the expected lifetime earnings of the entire population instead of just the productive portion of the population. The authors also used average annual earnings for all earners (including seasonal and part-time workers), rather than full-year, full-time workers to provide a more accurate estimate of future earnings. Finally, the authors extended productivity to persons aged 85 years and older instead of just to persons aged up to 75 years. The authors feel these adjustments are reasonable because intent was to delineate the impact of a bioterrorist assault on the Canadian population within current Canadian economic realities for valuation of human life and potential life earnings.

Costs: Table 4 summarizes base and upper limit costs for hospital days, drugs used, lost productivity, follow-up outpatient visits, outpatient laboratory costs and lost productivity due to time spent in outpatient visits. Detailed assumptions, costs and sources of data are available from the authors.

Cost of prophylaxis intervention: After an attack, the only direct public health intervention available is prophylaxis with antibiotics or vaccines. As with the CDC study, the costs of an intervention were expressed using the following formula:

Cost of intervention = (cost of drugs used) × ([number of people exposed × multiplication factor] – number killed – number hospitalized – number of persons who require outpatient visits)

The intervention costs per person depend directly on the costs of the antimicrobial agents and vaccines used in a prophylaxis program (Table 5). The authors derived both lower and upper estimates for the efficacy of prophylactic regimens and their costs, including dispensing costs. The authors accounted for the fact that more people would receive prophylactic antitoxin than were actually exposed because of general anxiety and uncertainty about the boundaries of the attack, the timing of the attack and the time that it would take nonresidents to travel through the attack area. Three different multiplication factors (5, 10 and 15) were used to construct alternative cost-of-intervention scenarios that take into account persons who were not at risk but participated in the prophylaxis program – the so-called 'worried well'. Thus, if 100,000 people were exposed, the study assumed that the maximum number of persons seeking prophylaxis was 500,000, 1,000,000 or 1,500,000. Additional details are available from the authors.

Costs of a bioterrorist attack with no postexposure prophylaxis program: The costs (in millions of dollars) of a bioterrorist attack with no postexposure prophylaxis program are summarized in Table 6.

Economic analysis of preparedness: The analyses outlined above consider only the economics of an intervention after an attack and include several assumptions:

- First, it was assumed that the stockpiles of drugs, vaccines, antitoxins and, most importantly, ventilators would be available and could be rapidly moved to points of need.

TABLE 7
Maximum annual actuarially fair premium – Anthrax

Day postattack*	Preventable loss ($ millions)	Actuarially fair premium ($ millions) Probability of attack 0.01
Maximum loss estimate†		
Day 0	5,444.7	54.5
Day 1	4,896.4	49.0
Day 2	3,857.5	38.6
Day 3	2,039.6	20.4
Day 4	1,000.7	10.0
Day 5	481.3	4.8
Day 6	221.6	2.2
Minimum loss estimate‡		
Day 0	4,191.1	41.9
Day 1	3,750.0	37.5
Day 2	2,938.6	29.4
Day 3	1,518.7	15.2
Day 4	707.5	7.1
Day 5	301.8	3.2
Day 6	99.0	1.0

**Number of days from attack to effective initiation of prophylaxis; †Preventable loss (maximum) occurs with the doxycycline-anthrax vaccine combined prophylaxis regimen and a multiplication factor of 5 for unnecessary prophylaxis; ‡Preventable loss (minimum) occurs with the ciprofloxacin regimen and a multiplication factor of 15 for unnecessary prophylaxis*

TABLE 8
Maximum annual actuarially fair premium – Botulinum toxin

Day postattack*	Preventable loss ($ millions)	Actuarially fair premium ($ millions) Probability of attack 0.01
Maximum loss estimate†		
Day 0	9,650.0	96.1
Day 1	9,059.8	90.6
Day 2	7,821.1	78.2
Day 3	5,781.5	57.8
Day 4	4,498.1	45.0
Day 5	3,796.3	38.0
Day 6	3,436.3	34.4
Minimum loss estimate‡		
Day 0	7,550.4	75.5
Day 1	7,022.3	70.2
Day 2	5,926.7	59.3
Day 3	4,114.4	41.1
Day 4	2,982.6	29.8
Day 5	2,366.6	23.7
Day 6	2,051.6	20.5

**Number of days from attack to effective initiation of prophylaxis; †Preventable loss (maximum) occurs with a discount rate of 3% and a multiplication factor of 5 for unnecessary prophylaxis; ‡Preventable loss (minimum) occurs with a discount rate of 5% and a multiplication factor of 15 for unnecessary prophylaxis*

- Second, it was assumed that civil, military and other organizations would be in place and have the capability to identify the agent rapidly, dispense drugs, treat patients and keep order within the population.
- Third, the authors considered that a bioterrorist event of this magnitude would be a low probability or rare event. It was arbitrarily assigned a value of once/100 years.

The cost of these prerequisite activities can be calculated if they are seen as a form of insurance, the goal of which is to 'purchase' the maximum net savings through preparedness to manage the consequences of an attack. The so-called 'actuarially fair premium' for the 'insurance' can be defined as follows:

$$\text{Actuarially fair premium} = \text{the probability of an attack} \times \text{value of avoidable loss}$$

The term 'avoidable loss' refers to the fact that, even if a postexposure program were to be implemented on the day of the release (day 0), some deaths, hospitalizations and outpatient visits would be unavoidable.

A range of minimum and maximum values (Tables 7 and 8) of avoidable loss was derived from the net savings calculations. The values reflect differences in effectiveness of the various prophylaxis regimens, the reduced impact of delayed prophylaxis on illness and death, and the two discount rates used to calculate the present value of earnings lost because of death.

ACKNOWLEDGEMENTS: The authors are greatly indebted to Dr MI Meltzer, as well as to Drs AF Kaufmann and GP Schmid, Centers for Disease Control and Prevention, Atlanta, Georgia, for their valuable technical advice and assistance in providing the basic model that was adapted to Canadian data. We are also indebted to Mrs Rachel Moore, Centre for Emergency Preparedness and Response, Health Canada, Ottawa, Ontario, for technical assistance in calculating the economic burden associated with a terrorist attack. Drs Alan Meltzer and Martin Tepper, Centre for Emergency Preparedness and Response, Health Canada, provided advice and assistance in editing this paper.

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