MODELING THE COSTS OF HOSPITAL-ACQUIRED INFECTIONS IN NEW ZEALAND

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ABSTRACT

OBJECTIVE: To model the economic costs of hospital-acquired infections (HAIs) in New Zealand, by type of HAI.

DESIGN: Monte Carlo simulation model.

SETTING: Auckland District Health Board Hospitals (DHBH), the largest publicly funded hospital group in New Zealand supplying secondary and tertiary services. Costs are also estimated for predicted HAIs in admissions to all hospitals in New Zealand.

PATIENTS: All adults admitted to general medical and general surgical services.

METHOD: Data on the number of cases of HAI were combined with data on the estimated prolongation of hospital stay due to HAI to produce an estimate of the number of bed days attributable to HAI. A cost per bed day value was applied to provide an estimate of the economic cost. Costs were estimated for predicted infections of the urinary tract, surgical wounds, the lower and upper respiratory tracts, the bloodstream, and other sites, and for cases of multiple sites of infection. Sensitivity analyses were undertaken for input variables.

RESULTS: The estimated costs of predicted HAIs in medical and surgical admissions to Auckland DHBH were $10.12 (US $4.56) million and $8.64 (US $3.90) million, respectively. They were $51.35 (US $23.16) million and $85.26 (US $38.47) million, respectively, for medical and surgical admissions to all hospitals in New Zealand.

CONCLUSIONS: The method used produces results that are less precise than those of a specifically designed study using primary data collection, but has been applied at a lower cost. The estimated cost of HAIs is substantial, but only a proportion of infections can be avoided. Further work is required to identify the most cost-effective strategies for the prevention of HAI (*Infect Control Hosp Epidemiol* 2003;24:214-223).

Studies of the economic cost of hospital-acquired infection have been undertaken in the United States,[1-15] England,[16-21] Germany,[22,23] Denmark,[24] Spain,[25,26] China,[27] Israel,[28] and France.[29] The findings illustrate the impact of the disease on the acute and the community healthcare sectors, patients, caregivers, and the wider economy. These data have been used to raise the profile of hospital-acquired infection among policy makers[30] and, if appropriately derived, they proxy the value of the potential economic benefits that result from programs that prevent hospital-acquired infection.[31]

Although the prevalence of hospital-acquired infections in New Zealand hospitals and estimates of the cumulative incidence have been reported,[32,33] no estimates of the economic cost of these infections have been published. The purpose of this article is to model the cost attributable to hospital-acquired infections occurring among adult patients admitted to the general medical and surgical services of Auckland District Health Board Hospitals for calendar year 1999 and patients admitted to all hospitals in New Zealand for the 1998–1999 financial year.

The cost analysis includes only hospital costs because recent work has shown that 93.4% of the total costs of hospital-acquired infection fall on the hospital sector[34] and assessing the remaining costs, those that fall on primary and community care services and the patients themselves, would involve extensive additional data collection and analysis. The method uses data gathered from the routine surveillance of hospital-acquired infection in Auckland District Health Board Hospitals,[32] estimates of the cumulative incidence derived from these data,[33] and findings from the published literature.

METHODS

Setting

Auckland District Health Board Hospitals comprises four separate hospitals. Auckland Hospital has 560 beds and

provides emergency, acute, and elective general medical and surgical services, as well as major hematology, oncology, and liver transplant services. Green Lane Hospital has 197 beds and provides otorhinolaryngology, cardiology, respiratory medicine, and cardiothoracic surgery services, including heart and lung transplants. National Women's Hospital provides maternity and neonatal intensive care services, and Starship Hospital is a specialist pediatrics hospital; admissions to the National Women's and Starship hospitals were excluded from this study.

In 1999, there were 32,179 medical and 24,899 surgical admissions for Auckland and Green Lane hospitals with an average length of stay of 4.7 and 5.2 days, respectively. Existing infection control services include four dedicated infection control practitioners and a service coordinator. They are supported by infectious disease physicians or microbiologists, who supply 1 day per week to the service (0.2 full-time equivalent). The approximate cost of these services, including staff time, expenses, overhead, and education, is $450,000 (US $203,032) per year. In addition to the routine infection control activities, point-prevalence surveys are performed twice a year by two-person teams consisting of a physician and an infection control practitioner.[32,33] All patients except pediatric cases in Starship Hospital are included.

Overview of the Method

Data on the predicted number of cases of hospital-acquired infection were combined with data on the estimated prolongation of stay due to hospital-acquired infection. This produced an estimate of the number of bed days attributable to hospital-acquired infection. Valuations of the opportunity cost of the resources used to supply a bed day were applied to derive a monetary estimate of the opportunity cost of hospital-acquired infection. This method is detailed in Table 1.

The patient population is all adults admitted to general medical and surgical services and cost estimates are derived for the following single sites of hospital-acquired infection: surgical wound (SW), lower and upper respiratory tracts (CHEST), urinary tract (UT), bloodstream (BS), and other sites (OTHER). Cost estimates are also derived for patients with more than one site of hospital-acquired infection (MULTI).

Data Sources

Estimates of the cumulative incidence of hospital-acquired infection in medical and surgical admissions to Auckland District Health Board Hospitals are presented in Table 2.[33] These rates, and the values for the 95% confidence intervals, were applied to the 32,179 medical and 24,899 surgical admissions to Auckland District Health Board Hospitals and to the 162,879 medical and 245,130 surgical admissions to all acute hospitals in New Zealand in 1999 to derive an estimate of the "most likely," "low," and "high" number of cases of hospital-acquired infection. The results of this are presented in Table 2 and provide the information required for category A of Table 1.

TABLE 1
OVERVIEW OF THE METHOD USED TO DETERMINE THE COST OF HOSPITAL-ACQUIRED INFECTION IN NEW ZEALAND

A	Number of cases of hospital-acquired infection (with estimates of likely variation)
B	Additional bed days per case (with estimates of likely variation)
C	Opportunity cost per bed days (point estimate)
	Cost of hospital-acquired infection = A*B*C

To determine estimates of the likely prolongation of length of stay due to hospital-acquired infection, the published literature was reviewed. An electronic search was made of the MEDLINE database.[35] Searches were made for the subject heading "cross infection" and then the subheading "economics"; this search yielded 418 articles. These results were combined with the results of a further search of the key word(s) "length of stay"; this yielded 106 articles. These abstracts were reviewed and all articles that included a specific investigation of the prolongation of hospital stay due to hospital-acquired infection were retrieved. Foreign language articles that did not report the results in the English abstract were discarded. Articles that reported results only by pathogen and not by site or specialty were discarded. The reference lists of the remaining articles were reviewed so that any further relevant articles might be identified. The following information was extracted from the final set of articles: site of hospital-acquired infection studied; patient group studied; number of patients with hospital-acquired infection included in the analysis; study design; year of publication; country in which the study was undertaken; and prolongation of hospital stay due to hospital-acquired infection. The results of this process are presented in the Appendix. Studies published before 1980 were excluded to reduce bias arising from changes to length of stay, treatment regimens, and clinical practice that would inevitably have occurred over time.

The values of the prolongation of length of stay derived from the literature were applied to the model as follows: values reported for "all admissions" were used to indicate the likely prolongation of length stay for the predicted cases of hospital-acquired infection in medical admissions in the model; values reported for "surgical patients" were used for the predicted cases of hospital-acquired infection in surgical admissions in the model; and, because no values were reported in the literature for CHEST, BS, and OTHER in "surgical patients," the values for "all admissions" were applied. The number of values for the estimated prolongation of hospital stays for each type of hospital-acquired infection was insufficient to allow any useful inferences to be made about the nature of the probability distribution. Instead, the "low," "median," and "high" values for prolongation of hospital stay due to hospital-acquired infection were used for each type of hospital-acquired infection. These data, and the references to the articles from which

TABLE 2
THE VALUES USED FOR THE INPUT VARIABLES USED IN THE SIMULATION MODEL

Type of Hospital-Acquired Infection	Incidence, %[33] (CI_95)		Likely No. of Cases of Hospital-Acquired Infection, High and Low Estimates				Median Value for Prolongation of Length of Stay, Low and High Values			
			ADHB Hospitals		All NZ Hospitals					
	Medical	Surgical	Medical*	Surgical†	Medical‡	Surgical‡	Medical	References	Surgical	References
UT	1.40 (1.14% to 1.67%)	2.54 (2.27% to 2.81%)	452, 366 and 538	633, 566 and 700	2,288, 1,853 and 2,723	6,228, 5,567 and 6,888	1.00, 0.50 and 5.10	1, 3, 18	4.70, 3.60 and 5.10	2, 17, 26
SW	0.51 (0.12% to 0.91%)	2.31 (1.96% to 2.66%)	166, 37 and 294	575, 488 and 662	838, 188 and 1,488	5,660, 4,803 and 6,518	7.5, 4.00 and 11.00	1, 3, 18, 23, 25	12.00, 5.70 and 12.90	2, 5, 17, 24, 47
CHEST	1.04 (0.56% to 1.51%)	1.00 (0.62% to 1.37%)	333, 181 and 486	248, 155 and 342	1,687, 915 and 2,459	2,446, 1,527 and 3,364	6.50, 3.70 and 8.70	1, 3, 9, 18	6.50, 3.70 and 8.70	1, 3, 9, 18
BS	1.77 (1.54% to 2.01%)	0.48 (0.11% to 0.85%)	571, 496 and 645	120, 27 and 213	2,890, 2,512 and 3,267	1,179, 265 and 2,093	4.00, 0.00 and 12.00	1, 10, 18	4.00, 0.00 and 12.00	1, 10, 18
OTHER	1.00 (0.70% to 1.30%)	0.88 (0.58% to 1.19%)	321, 224 and 418	220, 145 and 296	1,625, 1,134 and 2,116	2,168, 1,424 and 2,912	2.5, 0.00 and 12.40	1, 18	2.5, 0.00 and 12.40	1, 18
MULTI	0.99 (0.55% to 1.43%)	0.61 (0.19% to 1.03%)	318, 178 and 459	152, 48 and 256	1,611, 899 and 2,322	1,500, 475 and 2,524	29.10‖	18	25.00, 18.00 and 26.20	2, 17, 48

ADHB = Auckland District Health Board; NZ = New Zealand; UT = urinary tract; SW = surgical wound; CHEST = chest; BS = bloodstream; OTHER = other site; MULTI = multiple sites; CI_95 = 95% confidence interval.
*Based on 32,179 admissions to medical services during the calendar year 1999.
†Based on 24,899 admissions to surgical services during the calendar year 1999.
‡Based on 162,879 admissions to medical services during the financial year 1998–1999.
§Based on 245,130 admissions to surgical services during the financial year 1998–1999.
‖Point estimate because only one study reported results for MULTI in medical patients.

they were drawn, are presented in Table 2 and provide the information required for category B in Table 1.

The corporate accounts department of the study hospital derived the cost of the resources used to supply a bed day. The operating costs of the organization reflect the market prices paid for the labor, consumables, and utilities and include a valuation for the use of capital infrastructure. The estimated 1999 cost per bed day for medical and surgical admissions was $557 (US $251). In addition, a low value of $279 (US $126), 50% of the estimate, and a high value of $836 (US $377), 150% of the estimate, were used in the modeling. This provides the information required for category C in Table 1.

Data Analysis

To model the effect of uncertainty around the input variables on the outcome variable, cost of hospital-acquired infection, Monte Carlo simulation was applied using risk assessment software.[35] This technique combines the uncertainties around the input variables and produces a range of output values that reflect these uncertainties. To run these models, assumptions are required about the probability distribution of values for the input variable.

Uncertainty for the number of cases was described by the "low," "likely," and "high" values for number of cases. These three data points were triangulated, based on the assumption that the "likely" value had a greater probability of occurring than did the "high" and "low" values, which had the same probability of occurring, and used as the starting point for the simulation. Uncertainty for the prolongation of length of stay was based on the results from the review of the literature (Appendix). The "low," "median," and "high" estimates for each site of hospital-acquired infection, and for multiple sites, were assumed to reflect the "low," "likely," and "high" values, triangulated as above and used as the starting point for the simulation. Because the cost per bed day data were calculated from known local data, point estimates of cost were used in the model. However, to allow different scenarios to be examined, the model was simulated for "low," "estimated," and "high" values of the cost of a bed day.

Because the direction of causation in the model was unambiguous, a sensitivity analysis was conducted by a multivariate stepwise regression in which the sampled input variable values were regressed against output values, leading to a coefficient of sensitivity for each input variable. This coefficient is an estimate of the independent change in the output variable due to a unit change in the input variable.

RESULTS

The values for the input variables used in the simulation models for medical and surgical patients are presented in Table 2. The results of the simulation model for admissions to Auckland District Health Board Hospitals are presented in Table 3.

The total costs for predicted infections in medical patients assuming $279 (US $126) per bed day, $557 (US

TABLE 3

MEAN COST OF HOSPITAL-ACQUIRED INFECTION IN ADMISSIONS TO AUCKLAND DISTRICT HEALTH BOARD HOSPITALS: RESULTS OF SIMULATION MODELS FOR THE THREE DIFFERENT VALUES OF A BED DAY

Hospital-Acquired Infection	Low Value of Bed Day (Range)		Estimated Value for Bed Day (Range)		High Value for Bed Day (Range)	
	Medical	Surgical	Medical	Surgical	Medical	Surgical
UT						
NZ$	273,964 (94,081 to 547,831)	789,046 (649,062 to 907,446)	548,967 (179,555 to 1,123,388)	1,572,834 (1,325,539 to 1,821,362)	834,917 (281,167 to 1,692,315)	2,363,826 (1,973,031 to 2,727,774)
US$	123,608 (42,448 to 247,172)	356,004 (292,846 to 409,424)	247,685 (81,012 to 506,854)	709,637 (598,061 to 821,768)	376,701 (126,858 to 763,545)	1,066,519 (890,199 to 1,230,726)
SW						
NZ$	349,833 (131,351 to 638,268)	1,608,821 (1,055,381 to 2,078,332)	710,456 (253,310 to 1,228,640)	3,249,936 (2,123,207 to 4,192,093)	1,033,967 (378,005 to 1,871,999)	4,907,425 (3,200,530 to 6,270,669)
US$	157,839 (59,263 to 287,976)	725,873 (476,170 to 937,709)	320,546 (114,289 to 554,342)	1,466,317 (957,956 to 1,891,403)	466,509 (170,550 to 844,615)	2,214,149 (1,444,026 to 2,829,222)
CHEST						
NZ$	586,248 (333,090 to 883,542)	432,645 (259,769 to 646,311)	1,191,409 (658,980 to 1,808,564)	882,000 (520,693 to 1,281,427)	1,757,516 (996,935 to 2,694,121)	1,304,541 (782,406 to 1,915,580)
US$	264,505 (150,285 to 398,639)	195,202 (117,203 to 291,605)	537,544 (297,321 to 815,994)	397,944 (234,928 to 578,159)	792,962 (449,800 to 1,215,543)	588,587 (353,009 to 864,278)
BS						
NZ$	840,700 (198,417 to 1,649,030)	173,353 (25,637 to 443,088)	1,673,121 (374,954 to 3,233,980)	355,965 (58,221 to 823,227)	2,543,310 (520,512 to 4,982,466)	539,124 (91,429 to 1,266,393)
US$	379,310 (89,522 to 744,015)	78,214 (11,567 to 199,914)	754,884 (169,173 to 1,459,118)	160,605 (26,268 to 371,427)	1,147,499 (234,846 to 2,248,006)	243,244 (41,251 to 571,376)
OTHER						
NZ$	450,642 (75,404 to 986,137)	298,431 (51,773 to 711,850)	852,287 (149,457 to 1,930,430)	615,556 (100,795 to 1,349,892)	1,324,365 (237,297 to 2,953,250)	916,210 (169,533 to 2,057,015)
US$	203,322 (34,021 to 444,929)	134,647 (23,359 to 321,175)	384,538 (67,433 to 870,978)	277,729 (45,477 to 609,049)	597,532 (107,065 to 1,332,458)	413,379 (76,490 to 928,091)
MULTI						
NZ$	2,596,854 (1,687,451 to 3,465,328)	994,837 (457,536 to 1,527,699)	5,152,621 (3,413,563 to 6,956,884)	1,969,899 (958,471 to 3,015,736)	7,724,299 (5,107,130 to 10,353,960)	2,897,134 (1,346,798 to 4,540,990)
US$	1,171,658 (761,350 to 1,563,499)	448,854 (206,433 to 689,272)	2,324,777 (1,540,143 to 3,138,831)	888,786 (432,446 to 1,360,650)	3,485,076 (2,304,252 to 4,671,535)	1,307,139 (607,653 to 2,048,820)

NZ$ = New Zealand dollars; US$ = United States dollars; UT = urinary tract; SW = surgical wound; CHEST = chest; BS = bloodstream; OTHER = other site; MULTI = multiple sites.

$251) per bed, and $836 (US $377) per bed day were $5,098,242 (US $2,300,186), $10,128,861 (US $4,569,862), and $15,218,374 (US $6,866,110), respectively. The total costs for predicted infections in surgical patients assuming $279 (US $126) per bed day, $557 (US $251) per bed, and $836 (US $377) per bed day were $4,297,132 (US $1,938,747), $8,646,190 (US $3,900,922), and $12,928,261 (US $5,832,874), respectively.

The results of the simulation model for admissions to all hospitals in New Zealand are presented in Table 4.

The total costs for predicted infections in medical patients assuming $279 (US $126) per bed day, $557 (US $251) per bed, and $836 (US $377) per bed day were $25.63 (US $11.56) million, $51.35 (US $23.16) million, and $77.15 (US $34.81) million, respectively. The total costs for predicted infections in surgical patients assuming $279 (US $126) per bed day, $557 (US $251) per bed, and $836 (US

$377) per bed day were $42.53 (US $19.18) million, $85.26 (US $38.47) million, and $127.05 (US $57.32) million, respectively.

In medical admissions, BS was the most expensive single site of hospital-acquired infection, followed by CHEST, OTHER, SW, and UT. Patients with multiple sites of hospital-acquired infection imposed greater costs than did patients with any single site of hospital-acquired infection. In surgical admissions, SW was the most expensive single site of hospital-acquired infection, followed by UT, CHEST, OTHER, and BS. Patients with multiple sites of hospital-acquired infection incurred costs that were lower than those of patients with SW but higher than those of patients with UT.

The results of the sensitivity analysis are presented in Table 5.

Cost outcomes, with the exception of SW and

TABLE 4

MEAN COST OF HOSPITAL-ACQUIRED INFECTIONS IN ADMISSIONS TO ALL HOSPITALS IN NEW ZEALAND: RESULTS OF SIMULATION MODELS FOR THE THREE DIFFERENT VALUES OF A BED DAY

Hospital-Acquired Infection	Low Value of Bed Day (Range)		Estimated Value for Bed Day (Range)		High Value for Bed Day (Range)	
	Medical	Surgical	Medical	Surgical	Medical	Surgical
UT						
NZ$	1,403 (462 to 2,853)	7,720 (6,461 to 8,873)	2,816 (959 to 5,881)	15,562 (12,940 to 17,971)	4,174 (1,380 to 8,508)	23,286 (19,465 to 26,691)
US$	633 (208 to 1,287)	3,483 (2,915 to 4,004)	1,271 (433 to 2,653)	7,021 (5,838 to 8,108)	1,883 (623 to 3,839)	10,506 (8,782 to 12,042)
SW						
NZ$	1,773 (579 to 3,048)	16,249 (10,531 to 20,709)	3,489 (1,203 to 6,290)	32,134 (21,112 to 41,260)	5,355 (1,978 to 9,404)	47,691 (31,214 to 62,337)
US$	800 (261 to 1,375)	7,331 (4,751 to 9,343)	1,574 (543 to 2,838)	14,498 (9,525 to 18,616)	2,416 (893 to 4,243)	21,517 (14,083 to 28,125)
CHEST						
NZ$	2,942 (1,637 to 4,478)	4,291 (2,497 to 6,219)	5,992 (3,374 to 9,068)	8,555 (5,138 to 12,376)	8,882 (4,730 to 13,526)	13,040 (7,770 to 18,960)
US$	1,327 (738 to 2,020)	1,936 (1,127 to 2,806)	2,704 (1,522 to 4,091)	3,860 (2,318 to 5,584)	4,008 (2,134 to 6,103)	5,883 (3,506 to 8,555)
BS						
NZ$	4,325 (844 to 8,524)	1,722 (247 to 4,247)	8,438 (1,702 to 16,789)	3,500 (583 to 8,374)	12,806 (2,028 to 25,280)	5,269 (617 to 12,601)
US$	1,951 (381 to 3,846)	777 (112 to 1,916)	3,807 (768 to 7,575)	1,579 (263 to 3,778)	5,778 (915 to 11,406)	2,377 (279 to 5,685)
OTHER						
NZ$	2,182 (382 to 5,042)	2,967 (448 to 6,395)	4,549 (811 to 9,708)	6,057 (902 to 12,961)	6,529 (1,199 to 14,271)	8,824 (1,452 to 19,628)
US$	985 (172 to 2,275)	1,339 (202 to 2,885)	2,052 (366 to 4,380)	2,733 (407 to 5,848)	2,946 (541 to 6,439)	3,981 (655 to 8,856)
MULTI						
NZ$	13,007 (8,483 to 17,574)	9,584 (4,521 to 14,962)	26,068 (17,138 to 35,064)	19,460 (9,157 to 30,739)	39,408 (26,370 to 52,231)	28,945 (13,564 to 46,698)
US$	5,868 (3,827 to 7,929)	4,324 (2,040 to 6,751)	11,761 (7,732 to 15,820)	8,780 (4,132 to 13,869)	17,780 (11,898 to 23,566)	13,060 (6,120 to 21,069)

NZ$ = New Zealand dollars; US$ United States dollars; UT = urinary tract; SW = surgical wound; CHEST = chest; BS = bloodstream; OTHER = other site; MULTI = multiple sites.

CHEST in medical patients and MULTI in surgical patients, were more sensitive to changes in "prolongation of length of stay" than to changes in the "estimated number of cases."

DISCUSSION

In the estimation of the local and national costs of hospital-acquired infection, assumptions were made about the values of the number of cases of hospital-acquired infection, the prolongation of the length of stay, and the economic cost of a bed day.

Values for the number of cases of hospital-acquired infection were derived from estimates of the cumulative incidence of hospital-acquired infection in Auckland District Health Board Hospitals and were reported elsewhere.[33] These were found to be comparable to other reported rates,[33] and the method used to derive them[36] has been validated by others.[37,38] The total admissions to which these rates were applied, to derive an estimate of the number of cases of hospital-acquired infection, were retrieved from reliable data sources and were assumed to be accurate. It is likely that the estimates of the number of cases are a reasonable approximation to the true values. For the purpose of the simulation modeling, it was assumed that the "most likely" value had a greater probability of occurring than the "low" and "high" values, which had the same probability of occurring. Because these values were derived from the means and 95% confidence intervals from the predicted cumulative incidence rates,[33] this assumption is likely to be appropriate.

The assumptions used to determine the prolongation of length of stay are vulnerable to some bias. First, the

extent to which the results derived from the literature reflect the patient groups included here was not assessed. In particular, values for "all admissions" were used to reflect the prolongation of hospital stay for all predicted cases of hospital-acquired infection in medical patients and for predicted cases of CHEST, BS, and OTHER in surgical patients. Had more specific estimates been available, then these would have been used. Second, the studies used to derive these values employed competing methods for the attribution of additional length of stay to hospital-acquired infection. These methods have been reviewed and found to produce different results when applied to the same patient population.[39-42] Third, these studies were conducted in different countries and time periods with patients admitted to a range of medical and surgical services. Clinical practice would vary and baseline lengths of stay have certainly changed during the time period in which the studies were conducted. To reduce bias from changes over time, studies whose results were published before 1980 were excluded. Despite these shortcomings, New Zealand is an industrialized country with a gross national product, healthcare system, and life expectancy comparable to those of the countries in which the studies were conducted. We argue that the broad picture of prolongation of hospital stay that emerges from the literature review is transferable to the broad picture in New Zealand, given the caveats already discussed. We also present a range of results that reflect 95% confidence intervals.

Values for the prolongation of hospital stay due to hospital-acquired infection derived from the literature were treated in the same manner as the number of cases, with the low, median, and high values triangulated for the purpose of the simulation modeling. Nothing could be inferred about the underlying probability distribution of this variable. If more data points were available, goodness of fit tests could have been conducted to determine the nature of the probability distribution. In the absence of this, the approach taken, which used the median and the range of values, was assumed to be optimal.

As a result of variation in both the number of cases and the prolongation of length of stay, the range of results, which reflects 95% confidence intervals, around the mean cost estimates is wide. Further uncertainty is associated with the estimates of cost for all hospitals in New Zealand, because it was assumed that the cumulative incidence rates derived from the data collection at Auckland District Health Board Hospitals were representative of the rates for the rest of the country.

The method used is an alternative to a specifically designed study with primary data collection. Indeed, to produce the number of results included here by this route would require many years of work and many thousands of research dollars. There appears to be a tradeoff between the precision of results and the research costs.

The valuations of the cost of a bed day are likely to be more robust than the input variables already discussed. They were derived by the administration of Auckland District Health Board Hospitals and reflect local input

TABLE 5
RESULTS OF THE SENSITIVITY ANALYSIS: THE EFFECT OF A 1% CHANGE IN INPUT VARIABLES ON COST OUTCOMES*

Cost Outcome	Effect of a 1% Change in Prolongation of Length of Stay on Cost Outcome	Effect of a 1% Change in Estimated No. of Cases on Cost Outcome
Cost of UTI in medical	0.98%	0.17%
Cost of SWI in medical	0.50%	0.84%
Cost of CHEST in medical	0.66%	0.74%
Cost of BSI in medical	0.99%	0.11%
Cost of OTHER in medical	0.97%	0.22%
Cost of UTI in surgical	0.85%	0.52%
Cost of SWI in surgical	0.93%	0.37%
Cost of CHEST in surgical	0.71%	0.68%
Cost of BSI in surgical	0.81%	0.53%
Cost of OTHER in surgical	0.96%	0.25%
Cost of MULTI in surgical	0.27%	0.96%

UTI = urinary tract infection; SWI = surgical wound infection; CHEST = chest infection; BSI = bloodstream infection; OTHER = other site of infection; MULTI = multiple sites of infection. *Sensitivity analysis was not possible on MULTI in medical patients because only a point estimate was available for the input variables.

prices and hospital throughput. However, they were not derived explicitly for the purpose of economic analysis, but reflect a monetary valuation of the resources used to supply the bed days. These are subject to certain assumptions about the allocation of jointly used resources, the validity of which has not been tested. A key question is whether these resources have an opportunity cost in their existing use. If they could be re-deployed without cost to supply services to other patients, who have the capacity to benefit and an effective demand, then strong arguments could be made that the resources tied up with the consequences of hospital infection have a marginal economic opportunity cost.

If a proportion of these infections were avoided, the benefits would not accrue as cash savings to the budget statements of the hospital. Instead, bed days would become available sooner for patients who might otherwise be waiting for access to hospital services. This could cause an increase in the costs of the hospital, because patients tend to cost more during the early part of their hospital stay.[43] However, throughput would most likely increase, driving down the average cost per case as a result of an increase in production efficiency. These are reasonably complex issues, but the key message is that there are likely to be marginal opportunity costs associated with the prolongation of the hospital stay due to hospital-acquired infection because other patients could enjoy benefits if they accessed the bed days sooner and the values presented here are an approximation of those benefits. Also, costs are expressed only in terms of the additional length of stay and not other components of the cost of hospital care. This assumption is

supported by a recent comprehensive study of the additional costs of hospital-acquired infection that found that 88% of the additional costs were due to the effects of additional length of stay.[34]

Although these results have face validity, one in particular warrants discussion. The estimated costs of UT infection are much greater for surgical compared with medical admissions. The reason is that the median value for prolongation of length of stay for UT infection in medical patients is only 1 day, compared with 4.7 days for surgical patients (Table 2). These may not be accurate and the reader is encouraged to pay attention to the range of results presented.

The costs reported here are substantial, with the estimates of the total cost of all sites of hospital-acquired infection in all patients admitted to Auckland District Health Board Hospitals close to $19 (US $8.5) million and $137 (US $62) million for all admissions to New Zealand hospitals for calendar year 1999. However, these costs are based on only surgical and medical admissions, which constitute 89% of adult admissions to all hospitals in New Zealand and 72% of adult admissions to Auckland District Health Board Hospitals. The remaining admissions are maternity and intensive care patients, for whom the costs of hospital-acquired infection could potentially be great. Also, pediatric admissions were excluded; hospital-acquired infection in this group could also impose significant costs. The costs reported here are likely to understate the total cost.

Only a proportion of hospital-acquired infections are avoidable. An analysis conducted on data collected for the Study of the Efficacy of Nosocomial Infection Control (SENIC) performed in the United States in the 1970s suggested that up to 32% of hospital-acquired infections could be avoided.[44] More recent estimates from the United Kingdom put the figure at 15%.[45] In addition, given that infection control activities have a cost themselves, there must be some comparison of these costs with the economic benefits likely to accrue. From an economist's perspective, the rate of hospital-acquired infection to be tolerated is where the marginal costs of prevention programs are equal with the marginal benefits. This is the point that minimizes the sum of the cost of hospital-acquired infection and the cost of the prevention program.[46]

Work on the cost-effectiveness of prevention programs using either prospective data collection or the modeling of existing data should be a priority for researchers in the area of infection control. A crude analysis of the results presented here suggests that if 10% of hospital-acquired infections could be avoided, economic benefits to the value of $1.9 (US $0.85) million would accrue to Auckland District Health Board Hospitals and $13.7 (US $6.2) million would accrue nationally. If this could be achieved at a cost lower than the available economic benefits, these programs should be pursued.

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APPENDIX

RESULTS OF A LITERATURE REVIEW TO DETERMINE ESTIMATES OF THE LIKELY ADDITIONAL LENGTH OF STAY ASSOCIATED WITH A CASE OF URINARY TRACT INFECTION

Reference	Patients Studied	No. of Hospital-Acquired Infections Included in Analysis	Country	Additional Length of Stay (d)
Plowman et al.,[18] 2001	All admissions	107	England*	5.1
Haley et al.,[1] 1981	All admissions	70	United States[†]	1
Haley et al.,[1] 1981	All admissions	17	United States[†]	0.5
Scheckler,[3] 1980	All admissions	38	United States[†]	0.6
Haley et al.,[1] 1981	All admissions	90	United States[†]	2
Medina et al.,[26] 1997	General surgery	33	Spain	4.7
Rubinstein et al.,[2] 1982	General surgery and orthopedics	30	United States	5.1
Coello et al.,[17] 1993	General surgery, orthopedics, and gynecology	36	England	3.6

All studies used matched control subjects for attribution of additional length of stay to hospital-acquired infection, except where * indicates that a cohort study with regression modeling was used and [†] indicates that the concurrent method or physician review was used.

RESULTS OF A LITERATURE REVIEW TO DETERMINE ESTIMATES OF THE LIKELY ADDITIONAL LENGTH OF STAY ASSOCIATED WITH MULTIPLE SITES OF HOSPITAL-ACQUIRED INFECTION

Reference	Patients Studied	No. of Hospital-Acquired Infections Included in Analysis	Country	Additional Length of Stay (d)
Plowman et al.,[18] 2001	All admissions	57	England*	29.1
Li et al.,[48] 1990	Cardiac surgery	43	China	25
Rubinstein et al.,[2] 1982	General surgery and orthopedics	8	United States	18
Coello et al.,[17] 1993	General surgery, orthopedics, and gynecology	9	England	26.2

All studies used matched control subjects for attribution of additional length of stay to hospital-acquired infection, except where * indicates that a cohort study with regression modeling was used.

RESULTS OF A LITERATURE REVIEW TO DETERMINE ESTIMATES OF THE LIKELY ADDITIONAL LENGTH OF STAY ASSOCIATED WITH A CASE OF CHEST INFECTION

Reference	Patients Studied	No. of Hospital-Acquired Infections Included in Analysis	Country	Additional Length of Stay (d)
Plowman et al.,[18] 2001	All admissions	48	England*	8.4
Freeman et al.,[9] 1979	All admissions‡	27	United States	8.7
Scheckler,[3] 1980	All admissions	10	Untied States	3.7
Haley et al.,[1] 1981	All admissions	29	United States†	6
Haley et al.,[1] 1981	All admissions	36	United States†	7
Haley et al.,[1] 1981	All admissions	10	United States†	6
Kappstein et al.,[47] 1992	Intensive care‡	34	Germany	10.13

All studies used matched control subjects for attribution of additional length of stay to hospital-acquired infection, except where * indicates that a cohort study with regression modeling was used, † indicates that the concurrent method or physician review was used, and ‡ indicates that the estimate was not used in modeling presented in this article.

RESULTS OF A LITERATURE REVIEW TO DETERMINE ESTIMATES OF THE LIKELY ADDITIONAL LENGTH OF STAY ASSOCIATED WITH A CASE OF SURGICAL WOUND INFECTION

Reference	Patients Studied	No. of Hospital-Acquired Infections Included in Analysis	Country	Additional Length of Stay (d)
Plowman et al.,[18] 2001	All admissions	38	England*	7.1
Schafer,[23] 1987	All admissions	168	Germany	11
Pena et al.,[25] 1996	All admissions	63	Spain	10
Haley et al.,[1] 1981	All admissions	67	United States†	8
Haley et al.,[1] 1981	All admissions	31	United States†	7
Haley et al.,[1] 1981	All admissions	16	United States†	4
Scheckler,[3] 1980	All admissions	16	United States†	7.5
Kappstein et al.,[47] 1992	Cardiac surgery‡	22	Germany	12.2
Poulsen et al.,[24] 1994	General surgery	291	Denmark	5.7
Lowenthal,[19] 1962	General surgery‡,§	177	England	7.3
Clarke,[16] 1957	General surgery‡,§	107	England‡	5
Simchen & Sacks,[28] 1975	General surgery‡	94	Israel	17
Sperry & Craddock,[6] 1968	General surgery‡	235	United States	15.2
Thoburn et al.,[7] 1968	General surgery‡,§	178	United States‡	14.1 to 26.3
Fekerty,[4] 1965	General surgery‡	143	United States	18
Kirkland et al.,[5] 1999	General surgery	255	United States	12
Green & Wenzel,[49] 1977	General surgery‡	51	United States	6
Rubinstein et al.,[2] 1982	General surgery and orthopedics	19	United States	12.9
Coello et al.,[17] 1993	General surgery, orthopedics, and gynecology	12	England	10.2
Mugford et al.,[20] 1989	Maternity–cesarean sections only‡	41	England‖	2.1
Davies & Cottingham,[21] 1979	Orthopedics‡	29	England	17

All studies used matched control subjects for attribution of additional length of stay to hospital-acquired infection, except where * indicates that a cohort study with regression modeling was used, † indicates that the concurrent method or physician review was used, ‡ indicates that the estimate was not used in modeling presented in this article, § indicates no matching, and ‖ indicates that the study used a retrospective review of 58 controlled trials.

RESULTS OF A LITERATURE REVIEW TO DETERMINE ESTIMATES OF THE LIKELY ADDITIONAL LENGTH OF STAY ASSOCIATED WITH A CASE OF BLOODSTREAM INFECTION

Reference	Patients Studied	No. of Hospital-Acquired Infections Included in Analysis	Country	Additional Length of Stay (d)
Plowman et al.,[18] 2001	All admissions	4	England*	4
Haley et al.,[1] 1981	All admissions	5	United States[†]	8
Haley et al.,[1] 1981	All admissions	2	United States[†]	0
Haley et al.,[1] 1981	All admissions	1	United States[†]	12
Rose et al.,[12] 1977	All admissions	124	United States	32
Spengler & Greenough,[14] 1978	All admissions	435	United States	14
Abramson & Sexton,[10] 1999	All admissions (including ICU MSSA)	19	United States	4
Abramson & Sexton,[10] 1999	All admissions (including ICU MRSA)[‡]	19	United States	12
Digiovine et al.,[11] 1999	Intensive care[‡]	68	United States	7
Pittet et al.,[13] 1994	Surgical intensive care[‡]	86	United States	14

ICU = intensive care unit; MSSA = methicillin-susceptible *Staphylococcus aureus*; MRSA = methicillin-resistant *S. aureus*.
All studies used matched control subjects for attribution of additional length of stay to hospital-acquired infection, except where * indicates that a cohort study with regression modeling was used, [†] indicates that the concurrent method or physician review was used, and [‡] indicates that the estimate was not used in modeling presented in this article.

RESULTS OF A LITERATURE REVIEW TO DETERMINE ESTIMATES OF THE LIKELY ADDITIONAL LENGTH OF STAY ASSOCIATED WITH OTHER SITES OF INFECTION

Reference	Patients Studied	No. of Hospital-Acquired Infections Included in Analysis	Country	Additional Length of Stay (d)
Haley et al.,[1] 1981	All admissions	20	United States[†]	2.5
Haley et al.,[1] 1981	All admissions	2	United States[†]	0
Scheckler,[15] 1978	All admissions[‡]	11	United States[†]	5.7
Scheckler,[3] 1980	All admissions	15	United States[†]	7
Plowman et al.,[18] 2001	All admissions	30	England *	12.4

All studies used matched control subjects for attribution of additional length of stay to hospital-acquired infection, except where * indicates that a cohort study with regression modeling was used, [†] indicates that the concurrent method or physician review was used, and [‡] indicates that the estimate was not used in modeling presented in this article.