



BMJ Open Modelling the costs and consequences of reducing healthcare-associated infections by improving hand hygiene in an average hospital in England

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ABSTRACT

Objective To assess the potential clinical and economic impact of introducing an electronic audit and feedback system into current practice to improve hand hygiene compliance in a hypothetical general hospital in England, to reduce the incidence of healthcare-associated infections (HCAIs).

Methods Decision analysis estimated the impact of introducing an electronic audit and feedback system into current practice to improve hand hygiene compliance among front-line healthcare practitioners (HCPs).

Results The model assumed 4.7% of adult inpatients (ie, ≥ 18 years of age) and 1.72% of front-line HCPs acquire a HCAI in current practice. The model estimated that if use of the electronic audit and feedback system could lead to a reduction in the incidence of HCAIs of between 5% and 25%, then the annual number of HCAIs avoided could range between 184 and 921 infections per hospital and HCAI-related mortality could range between 6 and 31 deaths per annum per hospital. Additionally, up to 86 days of absence among front-line HCPs could be avoided and up to 7794 hospital bed days could be released for alternative use. Accordingly, the total annual hospital cost attributable to HCAIs could be reduced by between 3% and 23%, depending on the effectiveness of the electronic audit and feedback system. If introduction of the electronic audit and feedback system into current practice could lead to a reduction in the incidence of HCAIs by at least 15%, it would have a ≥ 0.75 probability of affording the National Health Service (NHS) a cost-effective intervention.

Conclusion If the introduction of the electronic audit and feedback system into current practice in a hypothetical general hospital in England can improve hand hygiene compliance among front-line HCPs leading to a reduction in the incidence of HCAIs by $\geq 15\%$, it would potentially afford the NHS a cost-effective intervention.

INTRODUCTION

Healthcare-associated infections (HCAIs) are those occurring in a healthcare setting that were not present prior to a patient entering that care setting.¹ HCAIs can develop either as a direct result of healthcare interventions or from being in contact with a healthcare setting.² The epidemiological evidence indicates that hand-mediated transmission is a

Strengths and limitations of this study

- This is the first published study to evaluate the potential clinical and economic impact of reducing the incidence of healthcare-associated infections (HCAIs) in a hypothetical general hospital in England.
- This was a modelling study based on disparate sources of published evidence.
- The costs and consequences of introducing an electronic audit and feedback system into current practice to improve hand hygiene compliance among front-line healthcare professionals (HCPs) in an average general hospital in England were estimated from a model depicting the pathways and associated management of adult inpatients and front-line HCPs who acquire a HCAI in the hospital environment over a period of 1 year.
- The relationship between HCPs improving compliance with hand hygiene and reducing the background incidence of HCAIs is uncertain.
- The model does not consider HCPs' adaptation to the electronic audit and feedback system and subsequent decline in compliance nor does it distinguish between different types of pathogens causing HCAIs and the definition of HCAI would appear to vary between clinicians.

major contributing factor in the acquisition and spread of infection in hospitals, and such transmission can occur directly via hands, or indirectly via an environmental source (eg, commodes, wash bowls, blood pressure monitors, mobile phones).^{3,4} HCAIs can be caused by a range of pathogens including methicillin-resistant *Staphylococcus aureus* (MRSA), methicillin-sensitive *Staphylococcus aureus*, *Clostridium difficile* (*C. difficile*) and *Escherichia coli* (*E. coli*).⁵ Antibiotics are the mainstay of HCAI management,⁶ although their use can increase the likelihood of infection from drug-resistant organisms and *C. difficile*.^{6,7}

HCAIs pose a serious risk to patients, healthcare practitioners (HCPs) and visitors in a healthcare setting. Within a general

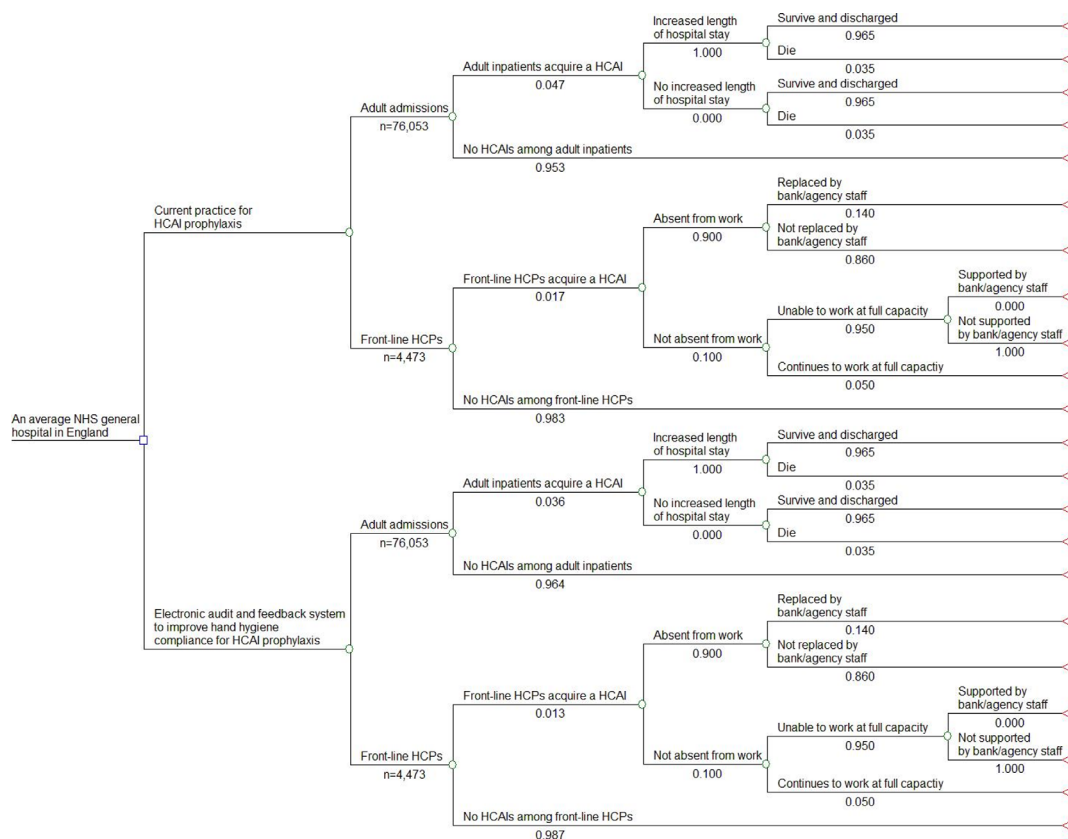


Figure 1 Decision model depicting the management of HCAs in an average NHS general hospital. The number below each branch depicts the probability of following a particular pathway, and is based on a 25% reduction in the incidence of HCAs following the introduction of an electronic audit and feedback system into current practice to improve hand hygiene compliance among front-line HCPs. HCAI, healthcare-associated infection; HCP, healthcare practitioner; NHS, National Health Service.

hospital, HCAs are more likely to occur among patients who become vulnerable to infection due to several factors, such as extended and inappropriate use of invasive devices and antibiotics, undergoing a high-risk and sophisticated procedure, being immunocompromised and other severe underlying conditions.⁸ Inadequate infection control expertise and insufficient hygiene levels can also be contributing factors.⁸

Public Health England monitors the epidemiology of certain HCAs through routine surveillance programmes, and also advises on how to prevent and control infection in establishments, such as hospitals.⁹ All National Health Service (NHS) hospitals must have an infection prevention service in place. Evidence-based guidelines for preventing HCAs in NHS hospitals in England state that HCPs need to apply standard infection control precautions to the care of all patients.¹⁰ The guidelines also affirm that one aspect of infection control is the consistent adherence to a hygiene protocol comprising: hospital environmental hygiene; hand hygiene; use of personal protective equipment; safe use and disposal of sharps; and principles of asepsis.¹⁰

These guidelines specify that a hand hygiene protocol requires HCPs to decontaminate their hands: (1) immediately before each episode of direct patient contact or care, including clean/aseptic procedures; (2) immediately after each episode of direct patient contact or care;

(3) immediately after contact with body fluids, mucous membranes and non-intact skin; (4) immediately after other activities or contact with objects and equipment in the immediate patient environment that may result in the hands becoming contaminated; and (5) immediately after the removal of gloves.¹⁰ This hand hygiene protocol is consistent with the World Health Organization's (WHO) 'My 5 Moments of Hand Hygiene'.¹¹

Audit with performance feedback is an important component of the WHO's hand hygiene guidelines⁴ and is undertaken routinely in many high and low income countries. Audit with feedback can improve the uptake of healthcare interventions generally¹² and is an important component of many hand hygiene interventions.¹³ High levels of hand hygiene adherence are frequently overestimated¹⁴ as a result of the Hawthorne effect¹⁵ and other sources of bias.¹⁴ Awareness of being watched encourages HCPs to cleanse their hands more often^{14 16 17} while audit periods are typically brief (15–20 min) giving an incomplete picture of usual practice, especially if intricate procedures with high risk of hand contamination are postponed until the audit is over.¹⁷

There have been numerous systematic reviews assessing the risks and impact of HCAs (too many to quote) in both high and low income countries. In particular, two systematic reviews explored the effectiveness of automated hand hygiene monitoring systems, and both

included electronic devices. Both reviews concluded that such systems may be of benefit, but acknowledged that the primary studies were poorly controlled (pre/post test designs) and both recommended an economic analysis.^{18,19} There is minimal published evidence on the association between HCAs and hand hygiene,¹³ so it is hard to quantify the effect of improving hand hygiene on the rate of acquiring HCAs. However, one study in Geneva between 1994 and 1998 saw hand hygiene compliance increase from 48% to 66%, resulting in a reduction in the annual HCAI prevalence, from 16.9% in 1994 to 9.9% in 1998.²⁰ Against this background, this study considers the potential cost-effectiveness of reducing the incidence of HCAs by varying amounts following the introduction of a 'hand hygiene electronic audit and feedback system' into current practice to improve hand hygiene compliance among front-line HCPs in a hypothetical general hospital in England.

METHODS

Study design

This was a modelling study which estimated the potential clinical and economic impact of reducing the incidence of HCAs in a hypothetical general hospital in England, by improving compliance with hand hygiene protocols among front-line HCPs.

Patient and public involvement

Patients and members of the public were not directly involved in this study.

Data sources

A systematic literature review was performed by searching PubMed, the Kings Fund, House of Commons library, NHS digital (Hospital Episode Statistics, workforce statistics and bed occupancy data) and the Office for National Statistics for relevant publications on HCAs published between January 2008 and June 2018. The search focused on epidemiology, clinical and health outcomes, management, resource use, costs and productivity and the search strings used to identify publications contained terms such as: 'Hospital acquired infection' OR 'Nosocomial infection' OR 'Healthcare associated infection' OR 'HAI' OR 'HCAI' AND 'epidemiology' OR 'prevalence' OR 'incidence' OR 'mortality' OR 'Cost' OR 'Cost-effectiveness'. The search was limited to publications in the English language and only studies concerning humans. If multiple sets of the same data were found over the 10 year period then the most recent published data set was used. Manual searches were also performed based on citations in the published articles and suggestions from the clinical co-authors.

The searches yielded 1104 different publications, of which 905 were excluded because of duplication or lack of relevance generating 199 publications to review in full. Of the 199 publications which were reviewed, a further 100 were excluded as they did not meet the study criteria. This left 99 articles for data extraction of which 44 contained relevant data which were used to inform this modelling study.

Health economic modelling

A decision model was constructed depicting the pathways and associated management of adult inpatients and front-line HCPs who acquire a HCAI in the hospital environment over a period of 1 year (figure 1). The model considers the costs and consequences of current practice compared with introducing an electronic audit and feedback system to improve hand hygiene compliance among front-line HCPs in an average general hospital in England. The model considers the impact of these two strategies on HCAI prophylaxis among both adult inpatients and front-line HCPs.

Healthcare resource use

The model incorporated the following assumptions (table 1):

- ▶ In an average year in an average NHS hospital in England, there would be 76 053 adult admissions,²¹ 510 adult inpatient beds²² and 4473 front-line HCPs.²³
- ▶ 4.7% of adult inpatients would acquire a HCAI.²⁴
- ▶ 3.5% of patients who acquire a HCAI would die from their infection.²⁵
- ▶ 1.72% of front-line HCPs would acquire a HCAI (an estimated mean from two different sources).^{26,27}
- ▶ Every adult inpatient who acquires a HCAI would have an increased length of stay.
- ▶ Once an adult inpatient acquires a HCAI, 90% would remain on the ward to which they were admitted, 10% would be isolated²⁸ and 0.04% would be transferred into intensive care (ICU).^{21,29,30}
- ▶ Patients would remain on the ward or in an isolation unit for a mean of 9.1 days.²⁹
- ▶ Patients who are transferred to ICU would remain there for a mean of 4.0 days before returning to the ward.³⁰

Healthcare resource use and corresponding costs pertaining to bed occupancy and outpatient visits are detailed in tables 1 and 2. The daily cost of bed occupancy at 2016/2017 prices (table 2) was applied to the additional length of hospital stay to estimate the cost of hospital stay attributable to HCAs. The costs of diagnostic tests, prescribed medication and clinician time were assumed to be included in the daily cost of hospital stay.

HCPs absenteeism from work

According to the clinical authors, it is NHS Hospital Trust policy that HCPs who develop an infection should not attend work. The model assumed that 90% of front-line HCPs who acquire a HCAI would not attend work for a mean of 5 days, while the other 10% would attend.

The cost of front-line HCPs being absent from work due to HCAs comprises the cost of replacing HCPs who acquire a HCAI with either bank or agency staff (table 2). The cost of replacing front-line HCPs with bank staff was calculated using a weighted average of the cost per day per staff type weighted by the proportion of the different types/grades of front-line staff that work in NHS hospitals in England.²³ The cost of agency staff was assumed to be

**Table 1** Model inputs

Parameter	Value	Source
Probabilities		
Probability of patients acquiring a HCAI	0.047	24
Probability of patients dying as a result of a HCAI	0.035	25
Probability of HCPs acquiring a HCAI	0.017	26 27
Probability of HCPs being absent from work due to acquiring a HCAI	0.900	(Assumption)
Probability of absent HCPs being replaced by agency or bank staff	0.140	53
Probability of HCPs not being absent from work but unable to work at full capacity	0.950	(Assumption)
Probability of HCPs not being absent from work and being supported by bank or agency staff	0.000	(Assumption)
Probability of adult inpatients having increased length of hospital stay as a result of a HCAI	1.000	(Assumption)
Probability of HCPs being admitted into hospital as a result of acquiring a HCAI	0.001	(Assumption)
Probability of being placed in isolation following a HCAI	0.100	28
Probability of being transferred to an ICU as a result of a HCAI	0.0004	21 29 30
Probability of remaining on a ward after acquiring a HCAI	0.900	(Calculation)
Probability of a follow-up hospital outpatient appointment	0.310	29 54 55
Resource use		
Probable additional number of bed days as a result of a HCAI	9.100	29
Number of follow-up hospital outpatient appointments	0.800	56
Average number of days spent in critical care	3.970	30
Length of time HCPs are off work and replaced by agency staff (days)	5.000	(Assumption)

HCAI, healthcare-associated infection; HCP, healthcare practitioner; ICU, intensive care unit.

the maximum 55% above the daily cost of NHS employees, excluding any administrative fees.³¹ The model assumed that 14% of absent HCPs would be replaced by agency or bank staff, of which 70% would be bank staff and the other 30% would be agency staff.

Hand hygiene electronic audit and feedback system

The model assumed the electronic audit and feedback system comprises a technology (such as 'Tork Vision Hand Hygiene') which monitors compliance with hand hygiene practices according to the WHO's five moments for hand hygiene (ie, moments 1, 4 and 5).¹¹ This is accomplished by tracking HCPs' movements with high

precision in real time and by combining their use of hand sanitisers (USAGE events) with their physical movements in relation to patients' beds (OPPORTUNITY events). The compliance results are fed back to the HCPs both at a group and individual level. The system incorporates the use of antennae mounted in the ceilings in hospital wards, tags worn by HCPs and hand hygiene product dispenser tags that record dispensing actions.

One feasibility study showed that the electronic audit and feedback system led to a 20% increase in compliance with hand hygiene practices (ie, cleaning hands before patient contact, cleaning hands after patient contact and cleaning hands after contact with patient surroundings (WHO's Hand Hygiene moments 1, 4 and 5)).³² The base case model assumes that introducing the electronic audit and feedback system into current practice to improve compliance with hand hygiene protocols would lead to a reduction in the incidence of HCAs by 25%. However, the effect of reducing the incidence of HCAs by 20%, 15%, 10% and 5% has also been evaluated. The model assumes that the electronic audit and feedback system would cost an average hospital in England £1.50 per inpatient bed per day.

Model outputs

The model outputs for an average NHS hospital with 76 053 adult admissions,²¹ 510 adult inpatient beds²² and 4473 front-line HCPs²³ were:

- The annual number of HCAs avoided.

Table 2 Hospital resource costs at 2016/2017 prices

Resource	Cost (£)	Source
General ward cost per bed day	586.59	57
General ward cost per excess bed day	351.00	57
Isolation ward cost per day	586.00	57
ICU cost per day	1621.16	57
Hospital outpatient cost per visit	201.00	57
NHS bank staff per day	286.19	58
Agency staff per day	443.59	31

ICU, intensive care unit; NHS, National Health Service.

- ▶ The annual number of HCAI-related patient deaths avoided.
- ▶ The annual number of HCAI-related days of avoided absence by HCPs.
- ▶ The annual number of HCAI-related occupied bed days.
- ▶ The total annual hospital cost attributable to HCAs comprising:
 - The annual cost of patient management.
 - The annual cost of HCP management.
 - The annual cost of agency staff.
 - The annual cost of the electronic audit and feedback system to improve hand hygiene compliance.

Economic evaluation

The cost-effectiveness of introducing the electronic audit and feedback system into current practice was calculated by dividing the cost difference between the two hand hygiene strategies by the difference in health outcomes of the two strategies. If use of the electronic audit and feedback system leads to an improvement in outcome for less cost, it was considered a dominant (cost-effective) strategy.

The cost–benefit (return on investment) of introducing the electronic audit and feedback system into current practice was also calculated by dividing the net financial benefit of the strategy by the cost of implementing the electronic audit and feedback system.

Sensitivity analysis

Probabilistic sensitivity analysis was undertaken to evaluate uncertainty within the model by applying a distribution to all the model inputs. A beta distribution was assigned to the probabilities and a gamma distribution to resource use and costs, by assuming a 10% SE around the mean values. This enabled the generation of 10 000 iterations of the model by randomly selecting a value from all the different inputs simultaneously. The outputs from these iterations was a distribution of costs and outcomes over 1 year for each strategy. The analysis also estimated the probability of implementing the electronic audit and feedback system to improve hand hygiene compliance among front-line HCPs being cost-effective when compared with current practice.

Deterministic sensitivity analysis was also performed to examine the effect of individually decreasing and increasing by 25% the value of each of the key model inputs and assumptions.

RESULTS

HCAI-related outcomes

The base case model estimated that in an average NHS hospital with 76 053 adult admissions per annum,²¹ 510 adult inpatient beds²² and 4473 front-line HCPs²³ there are 3683 HCAs per annum. Introduction of the electronic audit and feedback system into current practice was estimated to potentially reduce this to 2762 HCAs per annum (table 3). The model also estimated that

there are 126 HCAI-related patient deaths per annum in an average NHS hospital and this could potentially be reduced to 95 deaths following introduction of the electronic audit and feedback system into current practice. Hence, introduction of the electronic audit and feedback system into current practice could potentially lead to the avoidance of 921 HCAs and 31 HCAI-related patient deaths and free-up 7794 hospital bed days for alternative use, equivalent to 4% of the annual number of hospital bed days. Additionally, 86 days of front-line HCPs being absent from work could be avoided (table 3). These estimates can vary according to the percentage reduction in HCAs following introduction of the electronic audit and feedback system into current practice (table 3).

HCAI-related hospital costs

The base case model estimated that an average NHS general hospital with 76 053 adult admissions per annum,²¹ 510 adult inpatient beds²² and 4473 front-line HCPs²³ incurs an annual cost of £11.9 million attributable to HCAs, of which >99% is attributable to patient management (table 4). This could potentially be reduced by 23% (£2.7 million) following introduction of the electronic audit and feedback system into current practice (table 4). These estimates can vary according to the percentage reduction in HCAs following introduction of the electronic audit and feedback system into current practice (table 5).

Cost-effectiveness analysis

Outputs from the model showed that introduction of the electronic audit and feedback system into current practice is expected to lead to a cost decrease and a corresponding increase in outcomes for an average hospital with 76 053 adult admissions per annum,²¹ 510 adult inpatient beds²² and 4473 front-line HCPs.²³ Thus, use of the electronic audit and feedback system potentially affords the NHS a cost-effective intervention, since it could lead to an improvement in outcomes for less cost.

Cost–benefit analysis

The net benefit of introducing the electronic audit and feedback system into current practice varied between £33 800 and £2.4 million, depending on the percentage reduction in the incidence of HCAs (table 6). The analyses showed that if the percentage reduction in the incidence of HCAs is ≥3%, then the cost of introducing the electronic audit and feedback system into current practice in an average general hospital would be offset by the ensuing cost-reductions. The cost-benefit ratio showed that for every £1 spent by an average general hospital on the electronic audit and feedback system, it could benefit from a reduction in costs of ≥£1.10 attributable to HCAs (table 6).

Sensitivity analyses

Probabilistic sensitivity analysis highlighted the distribution in the incremental costs and outcomes at 12 months between the two hand hygiene strategies (figure 2).



Table 3 Expected HCAI-related outcomes in an average general NHS hospital stratified by percentage reduction in HCAIs

Assume the electronic audit and feedback system protocol leads to a:											
		25% reduction in HCAIs		20% reduction in HCAIs		15% reduction in HCAIs		10% reduction in HCAIs		5% reduction in HCAIs	
Current practice	Current practice with the EAFS	Difference between the two strategies	Current practice with the EAFS	Difference between the two strategies	Current practice with the EAFS	Difference between the two strategies	Current practice with the EAFS	Difference between the two strategies	Current practice with the EAFS	Difference between the two strategies	Difference between the two strategies
Annual number of HCAIs avoided	76 843	921	77 580	737	77 396	552	77 212	368	77 027	184	
Annual number of deaths avoided due to HCAIs	75 927	31	75 952	25	75 946	19	75 940	13	75 933	6	
Annual number of days HCPs are absent from work due to HCAIs	345	86*	276	69*	293	52*	311	35*	328	17*	
Annual number of occupied hospital bed days due to HCAIs	31 176	-7794	24 941	-6235	26 500	-4676	28 058	-3118	29 617	-1559	

*Annual number of days of avoided absence due to HCAIs. EAFS, electronic audit and feedback system; HCAI, healthcare-associated infection; HCP, healthcare practitioner; NHS, National Health Service.

Table 4 Expected costs in an average general NHS hospital attributable to HCAs (assumes the electronic audit and feedback system protocol leads to a 25% reduction in HCAs)

In an average NHS hospital with 76 053 adult admissions per annum, 4473 HCPs and 510 adult inpatient beds			
	Current practice	Current practice with the electronic audit and feedback system	Cost difference between the two strategies
Annual cost of patient management for HCAs	£11 858 527 (99)	£8 893 895 (97)	–£2 964 632
Annual cost of HCP management for HCAs	£369 (<1)	£277 (<1)	–£92
Annual cost of bank/agency staff due to HCAs	£19 157 (<1)	£16 079 (<1)	–£3078
Annual cost of the electronic audit and feedback system		£278 958 (3)	£278 958
Total annual hospital cost attributable to HCAs	£11 878 053 (100)	£9 189 209 (100)	–£2 688 844

Per cent of total cost in parentheses.

HCAI, healthcare-associated infection; HCP, healthcare practitioner; NHS, National Health Service.

Outputs from the analysis suggest that use of the electronic audit and feedback system has to lead to a reduction in the incidence of HCAs by at least 15% in order to afford the NHS an intervention which has a sufficiently high probability of being cost-effective (ie, ≥ 0.75) (figure 3). In the base case model, the probability of the electronic audit and feedback system being cost-effective was ≥ 0.90 (figure 3).

Deterministic sensitivity analysis (table 7) was performed on the base case model (ie, by assuming the electronic audit and feedback system leads to a 25% reduction in the incidence of HCAs). The analysis suggests that the probability of the electronic audit and feedback system affording the NHS a cost-effective intervention is primarily sensitive to:

- ▶ Its ability to reduce the incidence of HCAs.
- ▶ Probability of patients acquiring a HCAI.
- ▶ Annual number of adult admissions into an average hospital.

- ▶ Average additional length of hospital stay after acquiring a HCAI.

The probability of the electronic audit and feedback system affording the NHS a cost-effective intervention was found to be less sensitive to changes in the other model inputs. In particular, increasing the cost of the electronic audit and feedback system has negligible effect on the results since it accounts for only 3% of the total cost attributable to HCAs incurred by an average NHS general hospital in the base case model.

DISCUSSION

This study estimated that in an average NHS hospital with 76 053 adult admissions per annum,¹² 510 adult inpatient beds¹³ and 4473 front-line HCPs,¹⁴ there are 3683 HCAs per annum, and as a consequence 31 176 bed days are occupied by patients with these infections. This equates to 17% of the annual number of all bed days in an average

Table 5 Expected costs in an average general NHS hospital attributable to HCAs stratified by percentage reduction in HCAs

Total annual hospital cost attributable to HCAs in an average NHS hospital with 76 053 adult admissions per annum, 4473 HCPs and 510 adult inpatient beds			
Percentage reduction in HCAs attributable to the electronic audit and feedback system	Current practice	Current practice with the electronic audit and feedback system	Cost difference between the two strategies
25%	£11 878 053	£9 189 209	–£2 688 844
20%	£11 878 053	£9 783 226	–£2 094 827
15%	£11 878 053	£10 377 243	–£1 500 810
10%	£11 878 053	£10 971 259	–£906 794
5%	£11 878 053	£11 565 276	–£312 777

HCAI, healthcare-associated infection; HCP, healthcare practitioner; NHS, National Health Service.

**Table 6** Cost-benefit analysis

	Assume the electronic audit and feedback system protocol leads to a:				
	25% reduction	20% reduction	15% reduction	10% reduction	5% reduction
	in HCAs	in HCAs	in HCAs	in HCAs	in HCAs
Annual number of episodes of HCAs following introduction of the electronic audit and feedback system into current practice	2762	2946	3130	3315	3499
Annual number of episodes of HCAs with current practice	3683	3683	3683	3683	3683
Number of avoided episodes of HCAs	921	737	553	368	184
Cost-reduction following introduction of the electronic audit and feedback system into current practice	£2 688 844	£2 094 827	£1 500 810	£906 794	£312 777
Cost of the electronic audit and feedback system	£278 958	£278 958	£278 958	£278 958	£278 958
Net benefit	£2 409 886	£1 815 869	£1 221 852	£627 836	£33 819
Return on investment (cost-benefit ratio)	£9.6	£7.5	£5.4	£3.3	£1.1

HCAI, healthcare-associated infection.

NHS hospital. Furthermore, if the mean additional length of hospital stay as a result of a HCAI was reduced by half (from 9.1 days¹⁹ to 4.5 days), 8% of all bed days would still be occupied by patients with a HCAI. There is an opportunity cost to this HCAI-related bed occupancy. There has been an increase in hospital bed occupancy in England in recent years, due in part to the increased levels of hospital activity.³³ Consequently, this impacts on the speed with which patients can be admitted into hospital. It has also been shown to be a significant factor in the deterioration in performance against the 4-hour standard for admitting or discharging patients from hospital accident and emergency departments.³³ The shortage of available beds has also contributed to patients being admitted to hospitals outside their local area, which may delay their recovery.³³ Hence, this study may have underestimated the potential cost-effectiveness of the electronic audit and feedback system, when one considers its potential to result in a decrease in the number of HCAI-related occupied bed days and thereby facilitate an increase in the speed of hospital admissions.

WHO guidance highlights tuberculosis as an occupational risk factor for HCPs³⁴; they are also at risk of acquiring bloodborne infections (eg, HIV, hepatitis B and C). While HCPs may not be at high-risk of 'classic' HCAs, they are at risk of community-acquired infections brought into a hospital by patients. These include gastrointestinal infections (eg, norovirus) and respiratory infections (eg, influenza, respiratory syncytial virus). Rarely, HCPs may also develop varicella, measles or mumps through patient contact. Risks of acquiring a HCAI are higher for HCPs than for members of the public visiting a hospital because

they have more patient contacts than visitors, which are sustained over a longer period of time. Poor hand hygiene plays an important role in the spread of gastrointestinal infections.³⁵⁻³⁷ Accordingly, the model estimated that 1.72% of front-line HCPs would acquire a HCAI.^{26 27} Sensitivity analyses showed that changing this value has negligible impact on the study's findings.

This study is predicated on an electronic audit and feedback system which monitors compliance with hand hygiene practices according to the WHO's Moments 1, 4 and 5¹⁰ which are designed to reduce transmission of pathogens between patients. This study showed that introducing such an electronic audit and feedback system into current practice to improve hand hygiene compliance in a hypothetical general hospital in England is potentially cost-effective providing it leads to a $\geq 15\%$ reduction in the incidence of HCAs. There is substantial evidence that increasing hand hygiene compliance is associated with reducing HCAs, although uncertainty remains about the proportion of HCAs that can be prevented by improving hand hygiene compliance.⁴ Moreover, it has been suggested that estimating hand hygiene compliance with the WHO's Moments 1, 4 and 5 by monitoring leads to reasonable estimates of overall compliance with all 5 Moments.^{38 39} Limitations with the published evidence are due to the fact that designing and conducting robust, ethical, randomised controlled trials in the field of hand hygiene is challenging.¹³ Consequently, the recommendations on hand hygiene protocols are based on evidence from non-randomised controlled studies, quasi-experimental studies, observational studies and laboratory studies with volunteers.¹⁰

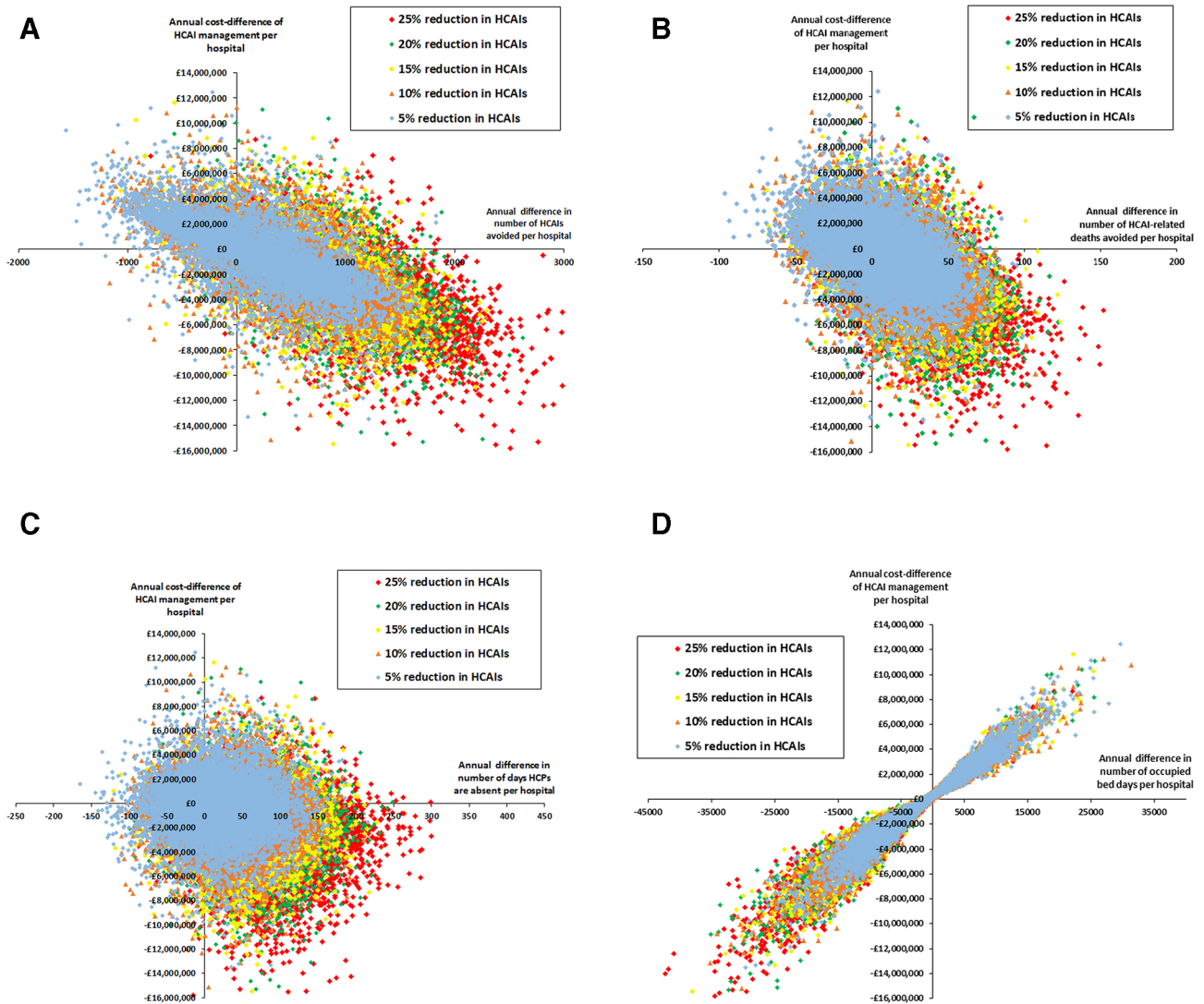


Figure 2 Scatterplot of the incremental costs and outcomes between the two strategies in 1 year in an average general hospital following 10 000 iterations of the model, stratified by reduction in HCAI incidence associated with the electronic audit and feedback system. (A) HCAs avoided. (B) Patient deaths avoided. (C) Days HCPs are absent from work. (D) Occupied hospital bed days. HCAI, healthcare-associated infection; HCP, healthcare practitioner.

There have been few studies assessing the health economic impact of hand hygiene protocols within healthcare settings. One review of economic studies on the impact of alcohol-based hand hygiene products in healthcare organisations⁴⁰ concluded that, while further research is required to measure the direct impact of improved hand hygiene on infection rates, the potential benefit of providing alcohol-based handrubs is likely to outweigh costs, and their wide-scale promotion should continue. Many of the older studies are not directly comparable to our study since they have examined direct costs of alternative handrubs, whereas this study has assessed the costs of introducing an electronic audit and feedback system into current practice to improve hand hygiene compliance with the clinical consequences and associated costs as they pertain to both patients (eg, increased length of hospital stay) and HCPs (eg, absenteeism from work).

One recent study has examined the cost-effectiveness of multi-modal hospital interventions to improve hand hygiene compliance in a middle-income country.⁴¹ However, this study was restricted to assessing the relationship between hand hygiene compliance and preventing a MRSA blood stream infection in ICU settings. Other economic studies in high-income countries^{20 42 43} reported the potential for a hand hygiene intervention to be cost-effective if the incidence of HCAs was reduced by at least 1%, without reporting the probability of the intervention being cost-effective. Our study also suggests that introducing an electronic audit and feedback system into current practice to improve hand hygiene compliance would be cost-saving and cost-effective if the incidence of HCAs was reduced by at least 3%. However, the probability of it being cost-effective is ≥ 0.75 if it leads to a $\geq 15\%$ reduction in the incidence of HCAs. Nevertheless, it is difficult to compare these studies with our own

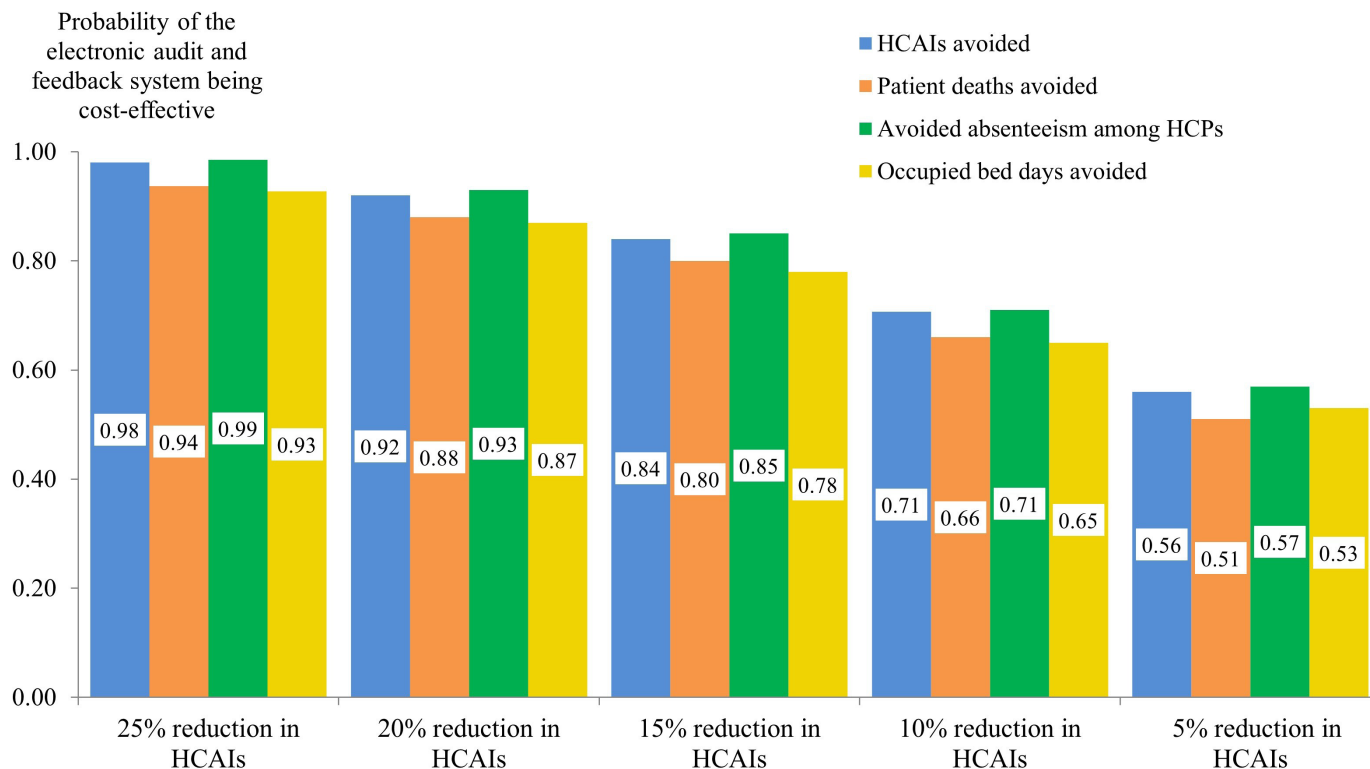


Figure 3 Probability of the electronic audit and feedback system being cost-effective compared with current practice, stratified by reduction in HCAI incidence. HCAI, healthcare-associated infection; HCP, healthcare practitioner.

due to different study designs and other methodological differences.

Observational studies of hand hygiene behaviour indicate an abundant risk of exogenous (cross) infection as HCPs move rapidly between patients, often without undertaking adequate hand hygiene.^{44 45} Additionally, the ICU environment is heavily contaminated with hospital strains of pathogenic organisms which have been shown to cause infection.⁴⁶ Increased hand hygiene performance has been shown to reduce endogenous infection.^{47 48} Improving HCPs' behaviour in infection prevention and control is challenging, since their behaviour is influenced, in part, by individual preferences and a degree of professional isolation.⁴⁹ Clearly, for any hand hygiene protocol to be clinically effective and cost-effective, HCPs' adherence to hand hygiene guidelines should be regularly audited, and the findings should be reported back in order to improve and sustain high levels of compliance. Additionally, healthcare organisations should provide regular training in risk assessment. A recent review concluded that the effectiveness of auditing and feedback depends on HCPs' baseline performance and how feedback is provided to them.⁵⁰ Moreover, such electronic audit and feedback can lead to small, but potentially important improvements in HCPs' practice.⁵⁰ Patients, relatives and other visitors should also be provided with information about the importance of hand hygiene and how to keep their own hands clean.

Study limitations

This health economic assessment of introducing an electronic audit and feedback system into current practice

to improve hand hygiene compliance among front-line HCPs is subject to some uncertainty because it was based on indirect sources of evidence and a series of assumptions. The relationship between HCPs improving compliance with hand hygiene and reducing the background incidence of HCAIs is uncertain. Moreover, the model does not consider HCPs' adaptation to the electronic audit and feedback system and subsequent decline in compliance. Furthermore, the model does not distinguish between different types of pathogens causing HCAIs and the definition of HCAI would appear to vary between clinicians.

The model was populated with estimates for an 'average general hospital' and 'average patients' and does not consider the impact of other factors that may affect the results, such as different ward types, patients' age or co-morbidities, clinician specialties etc. By restricting the framework of the model to the average general hospital, the analysis does not consider the impact of improving hand hygiene compliance in specialist centres such as cancer hospitals, mental health and disability units and women's hospitals. However, there is no reason to assume that the findings from this study would be any different in a specialist hospital. Additionally, the analysis is limited to HCAIs among adult inpatients and does not consider paediatric patients, accident and emergency or outpatient departments. Neither does the model consider that patients may acquire a HCAI and be discharged from hospital before symptoms emerge. The model assumes that patients who do not die from a HCAI are discharged,

Table 7 Deterministic sensitivity analysis (assumes the electronic audit and feedback system leads to a 25% reduction in the incidence of HCAs)

Variable (decreasing and increasing the base case by 25%)	Base case value	Difference in total cost	Difference in annual number of HCAs avoided	Difference in annual number of surviving patients	Difference in annual number of days HCPs are absent from work	Difference in annual number of occupied hospital bed days
Annual number of adult hospital admissions in an average hospital	76 053	-£1 918 167 – -£3 380 981	686–1131	23–39	not applicable	5769–9614
Probability of patients acquiring a HCAI	0.047	-£1 947 422 – -£3 429 740	695–1146	24–39	not applicable	5846–9742
Percentage reduction in the probability of patients acquiring a HCAI following introduction of the electronic audit and feedback system into current practice	25%	-£1 947 422 – -£3 429 740	695–1146	24–39	not applicable	5846–9742
Mean number of front-line HCPs per hospital	4473	-£2 687 764 – -£2 689 332	916–925	not applicable	64–107	not applicable
Probability of HCPs acquiring a HCAI	0.017	-£2 687 789 – -£2 689 374	916–926	not applicable	65–108	not applicable
Percentage reduction in the probability of HCPs acquiring a HCAI following introduction of the electronic audit and feedback system into current practice	25%	-£2 687 218 – -£2 689 944	916–926	not applicable	65–108	not applicable
Probability of patients dying from a HCAI	0.03	-£2 688 974 – -£2 688 189	not applicable	24–39	not applicable	not applicable
Length of time HCPs are absent from work and replaced by agency/bank staff (days)	5.00	-£2 687 812 – -£2 689 350	not applicable	not applicable	65–108	not applicable
Percentage of HCPs not absent from work after acquiring a HCAI	10%	-£2 688 669 – -£2 688 493	not applicable	not applicable	89–84	not applicable
Estimated percentage of HCPs admitted into hospital after acquiring a HCAI	0.1%	-£2 688 558 – -£2 688 604	not applicable	not applicable	86–86	7794–7794
Mean additional length of ward stay as a result of a HCAI (days)	9.1	-£1 958 861 – -£3 418 301	not applicable	not applicable	not applicable	5845–9742
Mean number of days spent in critical care	3.97	-£2 687 965 – -£2 689 197	not applicable	not applicable	not applicable	7794–7794
Percentage of patients placed in isolation after acquiring a HCAI	10%	-£2 642 792 – -£2 734 370	not applicable	not applicable	not applicable	7794–7794
Cost of electronic audit and feedback system per bed per day	£1.50	-£2 758 387 – -£2 618 775	not applicable	not applicable	not applicable	not applicable
Probability of absent HCPs being replaced by bank/agency staff	0.14	-£2 683 792 – -£2 693 370	not applicable	not applicable	not applicable	not applicable
Mean number of adult inpatient beds per hospital	510	-£2 761 706 – -£2 624 306	not applicable	not applicable	not applicable	not applicable
Percentage of all discharges resulting in a follow-up hospital outpatient appointment	34%	-£2 677 735 – -£2 699 427	not applicable	not applicable	not applicable	not applicable
Percentage of absent HCPs replaced by bank staff	70%	-£2 687 250 – -£2 689 912	not applicable	not applicable	not applicable	not applicable

HCAI, healthcare-associated infection; HCP, healthcare practitioner.

but in reality some patients may die from other reasons. The analysis excluded patients' costs and indirect costs incurred by society as a result of employed patients or HCPs taking time off work as a result of a HCAI. Additionally, estimating the value of improving hand hygiene overall is beyond the remit of this study. Notwithstanding this, the Authors chose to focus on electronic monitoring systems because of their higher degree of accuracy and current level of interest. The evidence shows that manual audits lead to a marked Hawthorne effect and other sources of bias (eg, postponing complicated clinical procedures until the auditor has gone).¹⁶ The other method of measuring adherence is product consumption which is not very accurate and provides little information.¹⁷ Inaccuracies associated with manual hand hygiene audit are such that it is no longer considered the best approach and there is increasing interest in combining periodic manual audit with continuing electronic monitoring to give an overall picture of behaviour.^{51 52} Clearly, a controlled study is required to compare the introduction of an electronic audit and feedback system into current practice to improve hand hygiene compliance with current practice in order to validate the outcomes of this analysis.

Conclusion

Within the study's limitations, the introduction of an electronic audit and feedback system into current practice to improve hand hygiene compliance among front-line HCPs in a hypothetical general hospital in England would afford the NHS a cost-effective intervention if it yielded a reduction in the incidence of HCAs by $\geq 15\%$.

Contributors JFG designed the study, managed the analyses, performed some analyses, checked all the other analyses and wrote the manuscript. TK conducted much of the analyses. DJG and NW scrutinised the analyses, suggested further analyses and helped interpret some of the findings. All the authors were involved in revising the manuscript and gave final approval. JFG is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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