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Modelling the annual NHS costs and outcomes attributable to healthcare-associated infections in England

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ABSTRACT

Objectives To estimate the annual health economic impact of healthcare-associated infections (HCAIs) to the National Health Service (NHS) in England.

Design A modelling study based on a combination of published data and clinical practice.

Setting NHS hospitals in England.

Primary and secondary outcome measures Annual number of HCAIs, additional NHS cost, number of occupied hospital bed days and number of days front-line healthcare professionals (HCPs) are absent from work.

Results In 2016/2017, there were an estimated 653 000 HCAIs among the 13.8 million adult inpatients in NHS general and teaching hospitals in England, of which 22 800 patients died as a result of their infection. Additionally, there were an estimated 13 900 HCAIs among 810 000 front-line HCPs in the year. These infections were estimated to account for a total of 5.6 million occupied hospital bed days and 62 500 days of absenteeism among front-line HCPs. In 2016/2017, HCAIs were estimated to have cost the NHS an estimated £2.1 billion, of which 99.8% was attributable to patient management and 0.2% was the additional cost of replacing absent front-line HCPs with bank or agency staff for a period of time. When the framework of the model was expanded to include all NHS hospitals in England (by adding specialist hospitals), there were an estimated 834 000 HCAIs in 2016/2017 costing the NHS £2.7 billion, and accounting for 28 500 patient deaths, 7.1 million occupied hospital bed days (equivalent to 21% of the annual number of all bed days across all NHS hospitals in England) and 79 700 days of absenteeism among front-line HCPs.

Conclusion This study should provide updated estimates with which to inform policy and budgetary decisions pertaining to preventing and managing these infections. Clinical and economic benefits could accrue from an increased awareness of the impact that HCAIs impose on patients, the NHS and society as a whole.

Strengths and limitations of this study

- ► This study is timely because it is the first economic study for 25 years to evaluate the annual health economic burden that healthcare-associated infections (HCAIs) impose on National Health Service hospitals in England.
- ► This was a modelling study based on disparate sources of published evidence.
- ► The costs and consequences of HCAIs were estimated from a model depicting the pathways and associated management of adult inpatients and front-line healthcare professionals who acquire a HCAI in the hospital environment over a period of 1 year.
- ► The results may be confounded by assumptions around the epidemiology of HCAIs, time-fixed excess length of hospital stay and outpatient appointments, and do not take into account time-dependent bias.
- ► The model is limited to HCAIs among adult inpatients and does not consider paediatric patients, accident and emergency or outpatient departments.

INTRODUCTION

Healthcare-associated infections (HCAIs) are defined as infections occurring in a healthcare setting that were not present prior to a patient entering that care setting.[1] These infections can develop either as a direct result of healthcare interventions or from being in contact with a healthcare setting.[2]

Within a general hospital, HCAIs are more likely to occur among patients who become vulnerable to infection due to 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.[3] Inadequate infection control expertise and insufficient hygiene levels can also be contributing factors.[3] HCAIs can be classified into six main types which account for 80% of all HCAIs. Within National Health Service (NHS) England, respiratory tract infections (pneumonia and other respiratory infections) account for 22.8% of all HCAIs, urinary tract infections for 17.2%, surgical site infections (SSI) for 15.7%, clinical sepsis for 10.5%, gastrointestinal infections for 8.8% and bloodstream infections for 7.3%.[4] These infection types are caused mainly by the pathogens *Escherichia coli* (*E. coli*), *Staphylococcus aureus* (*S. aureus*) and *Clostridium difficile* (*C. difficile*).[5] *C. difficile* infections account for 5.6% of all infections within NHS England.[4] The multidrug resistant forms of these organisms such

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as meticillin-resistant *S. aureus* can also cause HCAIs.[5] Antibiotics are the mainstay of treatment for managing HCAIs,[4] although their use can increase the likelihood of infection from drug-resistant organisms and *C. difficile*.[4 6]

In England, the annual incidence of HCAIs among patients in acute care hospitals is reported to be 0.047.[7] An estimated 3.5% of patients who acquire a HCAI are reported to die from their infection,[8] although these HCAI-related deaths are preventable.[8] The costs incurred to manage a patient who acquires a HCAI is around three times higher than that of managing a patient without a HCAI.[9] This potentially represents a significant cost to the whole NHS. Hospital inpatients who acquire a HCAI have a higher probability of having their length of admission extended.[3] Hence, the cost associated with HCAIs is primarily attributable to patients' increased length of hospital stay.[10] Healthcare professionals (HCPs) may also acquire a HCAI through patient contact.

Clearly HCAIs, and by extension the costs and consequences of their control, are important. Public Health England (PHE) monitors the epidemiology of certain HCAIs through routine surveillance programmes, and also advises on how to prevent and control infection in establishments, such as hospitals.[11] Additionally, all NHS hospitals must have an infection prevention service in place. Evidence-based guidelines for preventing HCAIs in NHS hospitals in England states that HCPs need to apply standard infection-control precautions to the care of all patients.[12] A potentially important aspect of infection control is the consistent adherence to a hand hygiene protocol. The National Institute for Health and Care Excellence (NICE) lists appropriate use of hand decontamination and the use of personal protective equipment as ways to combat HCAIs.[2] Additionally, we recently estimated the potential clinical and economic impact of introducing an electronic audit and feedback system into current practice to improve hand hygiene compliance in NHS hospitals in England, to reduce the incidence of HCAIs.[13]

Other infection control strategies can be employed which may result in HCAIs being avoided. A US study in an intensive care unit (ICU) showed that use of copper on high-risk surfaces within the hospital environment can be effective in reducing bacterial colonisation.[14] Various technology companies are producing products such as copper-coated clipboards and copper impregnated clothing for healthcare workers to help manage microbial transmission and infection. According to a 2017 literature review conducted by Health Protection Scotland antimicrobial copper surfaces are not widely used in healthcare settings within the UK.[15]

Against this background, the study objective was to estimate the annual number of HCAIs that occur in NHS hospitals in England, the annual amount of NHS resource use that is used to manage HCAIs and the amount the NHS spends on managing HCAIs in 2016/2017. The remit of this study was limited to adult inpatients and front-line HCPs in hospitals in England.

METHODS

Study design

This was a modelling study which estimated the total annual costs and consequences attributable to HCAIs among adult inpatients and front-line HCPs in hospitals in England.

Patient and public involvement

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

Data sources

A systematic literature search was performed using PubMed, the Kings Fund, House of Commons library, National Audit Office (NAO), NHS digital (Hospital Episode Statistics, workforce statistics and bed occupancy data), PHE and the Office for National Statistics (ONS). 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 searches were limited to articles published in the last 10 years, only 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 performed based on citations from 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 (ie, there was no clear focus on HCAIs, lack of distinction between HCAIs and community-acquired infections, lacked any useful quantitative estimates, characteristics of the inpatient population or hospital types was unclear). This left 99 articles for data extraction of which 23 contained relevant data which were used to construct this model (online supplementary figure S1).

Health economic modelling

A computer-based model in Excel 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 was used to estimate the resource implications and direct costs attributable to HCAIs in England in 2016/2017.

The model structure depicted that collectively across all general and teaching hospitals in England in 2016/2017 there were:

- 13.8 million adult (ie, ≥18 years of age) admissions.[16]
- 92 200 beds for adult inpatients.[17]

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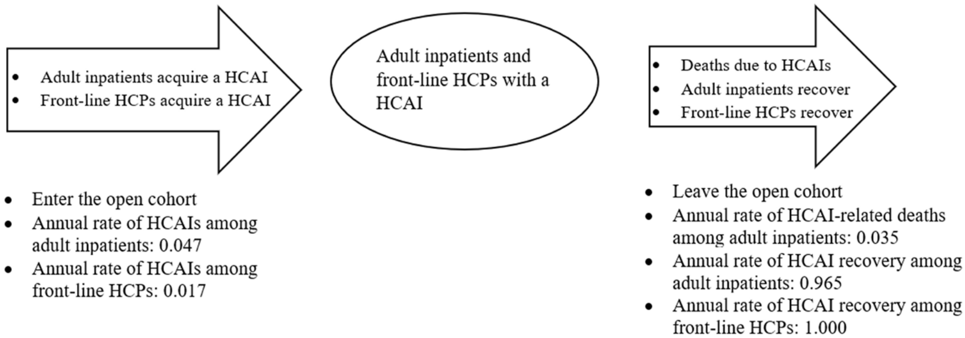

Figure 1 Cost of illness algorithm depicting the movement of adult inpatients and front-line HCPs entering and leaving the open cohort of those who acquire a HCAI in an average year. HCAI, healthcare-associated infection; HCP, healthcare professional.

- 810 000 front-line HCPs.[18]
- 4.7% of all adult inpatients acquired a HCAI.[7]
- 1.72% of front-line HCPs acquired a HCAI.[19 20]

The model adopts a cohort approach and subjects enter the model on acquiring a HCAI. The model assumed that 95% of patients who acquired a HCAI had an increased length of stay. Once a patient acquired a HCAI, the model assumed that 90% remained on the ward to which they were admitted, 10% would be isolated[21] and 0.04% went into intensive care (ICU).[16 22 23] Using NHS estimates of length of hospital stay, the model also assumed that a patient remained on the ward or in an isolation unit for a mean of 9.1 additional days (derived from a mean of 95 International Classification of Diseases 10th Revision (ICD 10) classification codes pertaining to 1.66 million finished consultant episodes of patients with an infection in the hospital episode statistics for 2016/2017).[16] If a patient was transferred to ICU, the model assumed they remained there for a mean of 4.0 days before being returned to the ward.[23] The management of patients and front-line HCPs who acquired a HCAI was assumed to be the same, based on the experience of the clinical authors. The model inputs are summarised in table 1.

Healthcare resource use

Healthcare resource use and corresponding costs pertaining to bed occupancy and outpatient visits are detailed in table 2. The daily cost of bed occupancy (at

Table 1 Model inputs

Parameter	Value	Source
Probabilities		
Probability of patients acquiring a HCAI	0.047	7
Probability of patients dying as a result of a HCAI	0.035	8
Probability of HCPs acquiring a HCAI	0.017	19 20
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	44
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	0.950	Assumption
Probability of HCPs being admitted into hospital as a result of acquiring a HCAI	0.100	Assumption
Probability of being placed in isolation following a HCAI	0.100	21
Probability of being transferred to ICU as a result of a HCAI	0.000	16 22 23
Probability of remaining on a ward after acquiring a HCAI	0.900	Calculation
Probability of a follow-up outpatient appointment after being discharged from hospital	0.310	16 45 46
Resource use		
Mean additional length of ward stay as a result of acquiring a HCAI (days)	9.100	16
Mean number of HCAI-related follow-up outpatient appointments following hospital discharge	0.800	47
Mean length of time in ICU (days)	3.970	23
Mean length of time HCPs are absent from work after acquiring a HCAI (days)	5.000	Assumption

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

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Table 2 Hospital resource costs at 2016/2017 prices

Resource	Cost	Source
General ward cost per bed day	£586.59	26
General ward cost per excess bed day	£351.00	26
Isolation ward cost per day	£586.00	26
ICU cost per day	£1621.16	26
Hospital outpatient cost per visit	£201.00	26
NHS bank staff per day	£286.19	48
Agency staff per day	£443.59	24

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

2016/2017 prices) was applied to the length of hospital stay to estimate the cost of hospital stay attributable to HCAIs. The costs of diagnostic tests, prescribed medication and clinician time were assumed to be included in the daily cost of hospital stay.

HCP 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 acquired a HCAI did 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 HCAIs 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.[18] The cost of agency staff was assumed to be the maximum 55% above the daily cost of NHS employees, whereas bank staff were assumed to cost the same as NHS staff.[24] 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, based on the experience of the clinical authors.

Model outputs

The model estimated for all general and teaching hospitals in England in 2016/2017:

- The annual number of adult inpatients who acquired a HCAI.
- The annual number of front-line HCPs who acquired a HCAI.
- The annual NHS costs attributable to HCAIs.
- The annual number of deaths attributable to HCAIs.
- The annual number of days front-line HCPs were absent from work as a result of HCAIs.
- The annual number of occupied hospital bed days due to HCAIs.

Addition of specialised hospitals to the base case analysis

The framework of the base case model was expanded to include hospitals that concentrate on individual specialities such as maternity, mental health, cancer, cardiovascular and so on. By including these specialised hospitals, the model depicted that there were 17.2 million adults admitted into hospitals in England in 2016/2017.[16 22] In total, these hospitals had 130 000 beds for adult inpatients[17] and 1.0 million front-line HCPs.[18]

Sensitivity analyses

Deterministic sensitivity analyses were undertaken to examine the effect of independently varying the values of individual parameters within the model. The parameter estimates were individually varied over plausible ranges by altering them to ±25% around the base case value. However, the percentages were bounded by 0% and 100%.

Probabilistic sensitivity analyses were undertaken to evaluate uncertainty within the model. This involved generating 10 000 iterations of the model by simultaneously varying the probabilities, resource use estimates and unit costs in the model. The probabilities were varied randomly according to a beta distribution and the resource use estimates and unit costs were varied randomly according to a gamma distribution by assuming a SE of 10% around the mean values This allowed the distribution of costs and outcomes to be estimated.

RESULTS

Prevalence of HCAIs in England in 2016/2017

According to the model, there were an estimated 653 000 HCAIs among the 13.8 million adult inpatients in NHS general and teaching hospitals in England in 2016/2017. Additionally, there were an estimated 13 900 HCAIs among the 810 000 front-line HCPs in the year (table 3).

Mortality arising from HCAIs in 2016/2017

Of the 653 000 adult inpatients who acquired a HCAI in 2016/2017, the model estimated that 630 200 patients were discharged from hospital and the other 22 800 patients died as a result of their infection (table 3). Of the 13 900 front-line HCPs who acquired a HCAI in 2016/2017, the model estimated that all HCPs recovered and none of them died as a result of their infection.

Total annual NHS costs attributable to HCAIs

The model estimated that the NHS incurred a cost of £2.1 billion in 2016/2017 as a result of HCAIs. Of this, 99.8% was attributable to patient management,<0.1% was due to front-line HCPs being admitted into hospital and 0.2% was the additional cost of replacing absent front-line HCPs with bank or agency staff for a period of time (table 3).

Resource implications of HCAIs

According to the model, there were 5.6 million occupied hospital bed days attributable to HCAIs. Of these, 99.9%

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Table 3 Annual costs and consequences of HCAIs to the NHS in England in 2016/2017

	Annual number with a HCAI	Additional NHS cost	Number of hospital bed days	Number of days front-line HCPs were absent from work
Patients acquired a HCAI, had an increased length of hospital stay and were discharged	598 426	£2 070 967 742	5 445 680	not applicable
Patients acquired a HCAI, had an increased length of hospital stay and then died	21 653	£73 855 238	197 044	not applicable
Patients acquired a HCAI, no increased length of hospital stay and were discharged	31 496	£1 570 478	0	not applicable
Patients acquired a HCAI, no increased length of hospital stay and then died	1140	£0	0	not applicable
Front-line HCPs who acquired a HCAI, were absent from work and replaced by bank or agency staff	1750	£3 476 760	16	8748
Front-line HCPs who acquired a HCAI, were absent from work and not replaced by bank or agency staff	10 748	£57 398	98	53 738
Front-line HCPs who acquired a HCAI, were not absent from work and unable to work at full capacity and replaced by bank or agency staff	0	£0	0	0
Front-line HCPs who acquired a HCAI, were not absent from work and unable to work at full capacity and not replaced by bank or agency staff	1319	£0	0	0
Front-line HCPs who acquired a HCAI, were not absent from work and continue to work at full capacity	69	£0	0	0
Total for patients	652 715	£2 146 393 457	5 642 723	0
Total for front-line HCPs	13 886	£3 534 158	114	62 486

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

were due to an increased length of hospital stay among adult inpatients (ie, 5.6 million occupied bed days) and <0.1% (114 occupied bed days) was due to front-line HCPs having been admitted into hospital because they had acquired a HCAI (table 3).

The model also estimated that HCAIs resulted in a total of 62 500 days of absenteeism among front-line HCPs across general and teaching hospitals in England in 2016/2017 (table 3).

Expanding the base case analysis to include specialised hospitals

When the framework of the model was expanded to include all NHS hospitals in England, it was estimated that there were 816 352 HCAIs among the 17.2 million adult inpatients in all NHS hospitals in England in 2016/2017 and an estimated 17 700 HCAIs among the front-line HCPs in that year. The model also estimated that 28 500 of these patients died as a result of their infection. These HCAIs were estimated to have cost the NHS £2.7 billion and to be responsible for a total of 7.1 million occupied hospital bed days and 79 700 days of absenteeism among front-line HCPs across all NHS hospitals in England.

Sensitivity analyses

Deterministic sensitivity analyses (table 4) showed that by individually varying the parameter estimates within the model, the results were affected to a greater extent by the percentage of adult inpatients and front-line HCPs who acquire a HCAI, the annual number of adult admissions into NHS hospitals, the annual number of front-line HCPs employed in NHS hospitals and the mean length of hospital stay after acquiring a HCAI. The results were also affected by the mean length of time front-line HCPs are absent from work after acquiring a HCAI and the cost of hospital bed occupancy. Simultaneously decreasing and increasing the daily cost of a bed day in intensive care, isolation ward and general ward by 25% would change the annual NHS cost of HCAIs by 23% (range £1.6–£2.7 billion). Varying the other model inputs and assumptions appeared to have a minimal impact on the results.

Probabilistic sensitivity analyses highlighted the distribution between NHS costs and patient deaths, days of absences among front-line HCPs, number of HCAIs and occupied hospital bed days attributable to HCAIs (figures 2–4). These analyses highlighted, in particular, the enormity of HCAIs' impact on occupied hospital bed days compared with the other outcomes evaluated in this study.

DISCUSSION

To the authors' knowledge, this is the first study for 25 years[25] to estimate the annual health economic impact of HCAIs in England. Furthermore, there is minimal

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Table 4 Deterministic sensitivity analyses showing the range of values when individual variables were changed by ±25%, but bounded by 0% and 100%

Variable	Base case value	Total annual hospital cost attributable to HCAIs	Annual number of HCAIs	Annual number of deaths attributable to HCAIs	Annual number of days of absenteeism from work among front-line HCPs due to HCAIs	Annual number of occupied hospital bed days due to HCAIs
Percentage of adult inpatients acquiring a HCAI	4.74%	£1 613 329 251–£2 686 525 980	503 422–829 780	17 095–28 491	not applicable	4 232 156–7 053 518
Annual number of adult admissions into NHS hospitals in England	13 765 571	£1 613 329 212–£2 686 525 980	503 422–829 780	17 095–28 491	not applicable	4 232 156–7 053 518
Percentage of front-line HCPs acquiring a HCAI	1.72%	£2 149 044 076–£2 150 811 155	663 130–670 072	not applicable	46 864–78 107	5 642 809–5 642 866
Annual number of front-line NHS staff working in NHS hospitals in England	809 661	£2 149 044 076–£2 150 811 155	663 130–670 072		46 864–78 107	5 642 809–5 642 866
Percentage of front-line HCPs who are absent from work after acquiring a HCAI	90.00%	£2 149 063 710–£2 150 320 299	not applicable	not applicable	47 211–69 428	5 642 809–5 642 850
Percentage of front-line HCPs admitted into hospital after acquiring a HCAI	0.10%	£2 149 910 930–£2 149 944 301	not applicable	not applicable	62 486–62 486	5 642 809–5 642 866
Percentage of front-line HCPs who are absent from work after acquiring a HCAI and replaced by bank or agency staff	14%	£2 149 060 761–£2 150 794 469	not applicable	not applicable	not applicable	not applicable
Mean length of time HCPs are absent from work after acquiring a HCAI (days)	5.00	£2 149 060 761–£2 150 794 469	not applicable	not applicable	46 864–78 107	not applicable
Mean length of stay in intensive care after acquiring a HCAI (days)	3.97	£2 149 481 612–£2 150 373 619	not applicable	not applicable	not applicable	not applicable
Percentage who are placed in isolation after acquiring a HCAI	10.00%	£2 116 776 617–£2 183 078 614	not applicable	not applicable	not applicable	not applicable
Mean length of ward stay as a result of acquiring a HCAI (days)	9.10	£1 621 610 957–£2 678 244 273	not applicable	not applicable	not applicable	4 232 128–7 053 546
Percentage of all HCAI-related discharges that result in an outpatient appointment	31.00%	£2 142 075 227–£2 157 780 004	not applicable	not applicable	not applicable	not applicable
Percentage of patients who die after acquiring a HCAI	3.49%	£2 150 211 742–£2 149 643 488	not applicable	17 095–28 491	not applicable	not applicable

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

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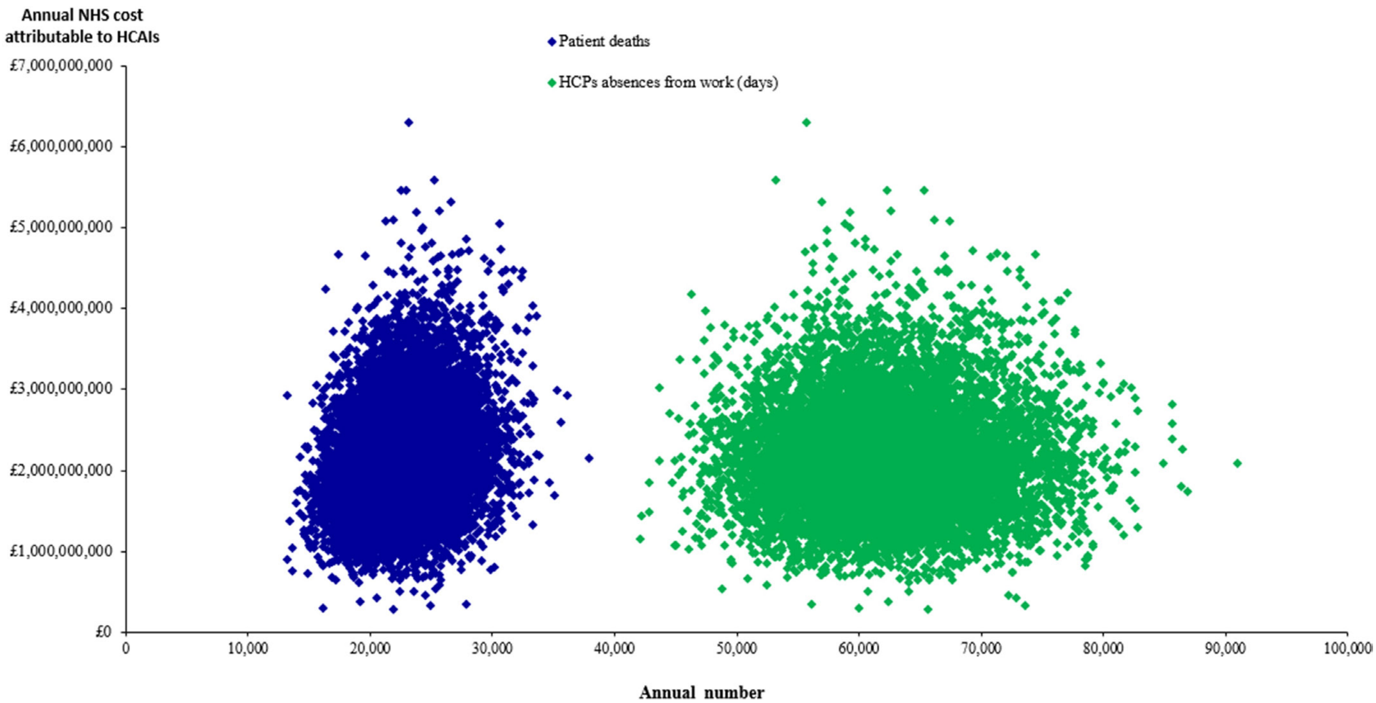

Figure 2 Distribution of costs and patient deaths and days of absences among front-line HCPs. HCAI, healthcare-associated infection; HCP, healthcare professional; NHS, National Health Service.

up to date information pertaining to the overall burden of HCAIs on health systems globally. According to our analysis, there were an estimated 653 000 HCAIs among the 13.8 million adult inpatients in NHS general and teaching hospitals in England in 2016/2017 and a further 13 900 HCAIs among 810 000 front-line HCPs in the year. These infections were estimated to have cost the NHS £2.1 billion and to have resulted in 22 800 patient deaths, 5.6 million occupied hospital bed days and 62 500 days of absenteeism among front-line HCPs. When the framework of the model was expanded to include all NHS hospitals in England, it was estimated there were 834 000 HCAIs in 2016/2017 costing the NHS £2.7 billion, and accounting for 28 500 patient deaths, 7.1 million occupied bed days and 79 700 days of absenteeism among front-line HCPs.

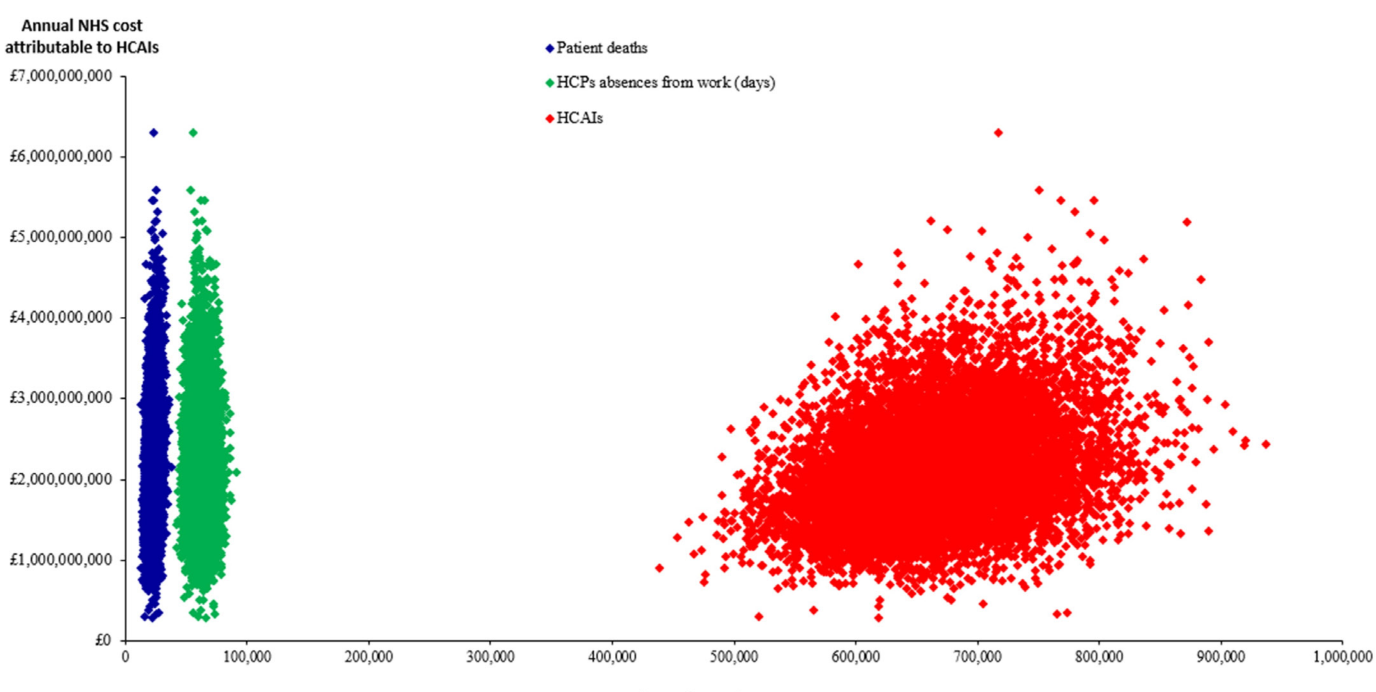

Figure 3 Distribution of costs and patient deaths, days of absences among front-line HCPs and number of HCAIs. HCAI, healthcare-associated infection; HCP, healthcare professional; NHS, National Health Service.

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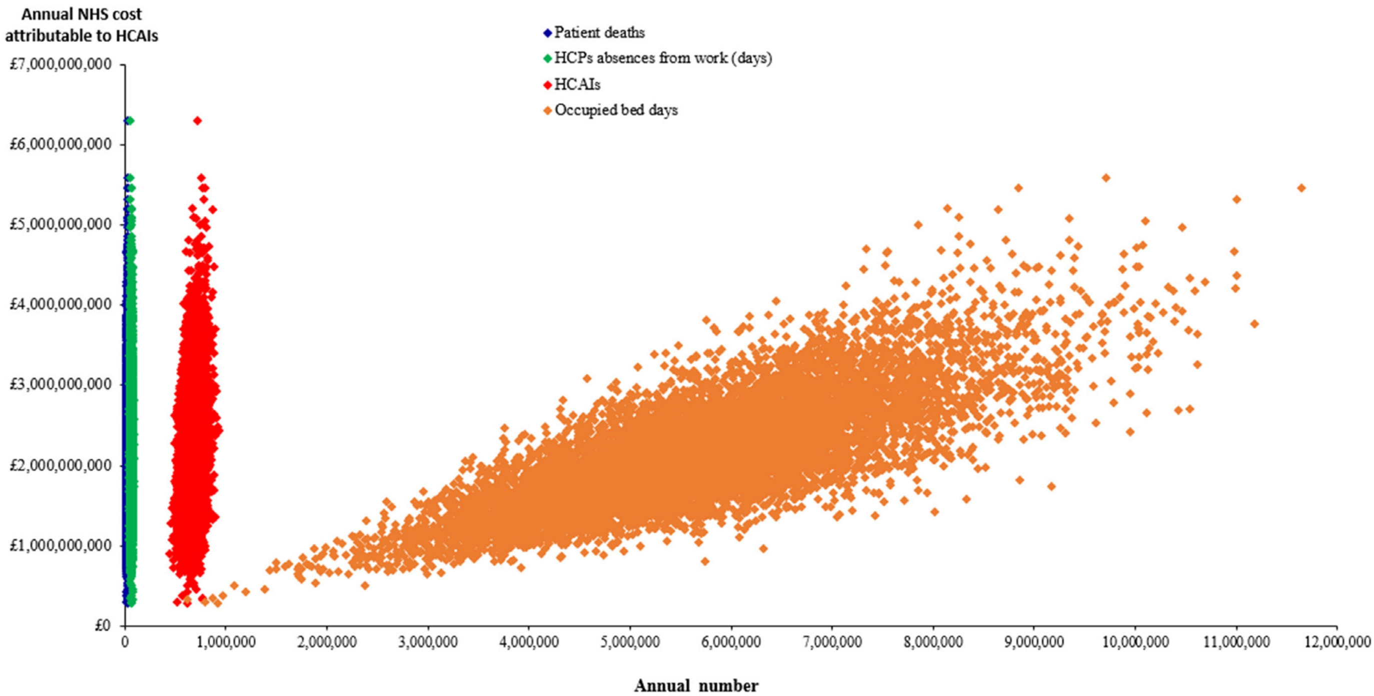

Figure 4 Distribution of costs and patient deaths, days of absences among front-line HCPs, number of HCAIs and occupied bed days attributable to HCAIs. HCAI, healthcare-associated infection; HCP, healthcare professional; NHS, National Health Service.

The key findings from this analysis emanate from a NHS-derived estimate that a HCAI will result in a patient's length of hospital stay being extended by a mean of 9 days.[16] A recent meta-analysis calculated that the mean excess length of hospital stay due to HCAIs was 15.9 days based on group comparisons, 9.6 days based on matching samples, 8.5 days based on multistate modelling, 7.6 days based on time-matched studies and 2.7 days based on regression analyses.[10] However, heterogeneity was very high in every group analysis. Nevertheless, the value of 9 days used in our model would appear to be concordant with the number of excess days obtained from the matched studies, and the impact of changing this value is reported in the sensitivity analyses. It is also noteworthy that within the NHS' National Schedule of Reference Costs, the length of hospital stay for patients with a code for an infection was a mean of 9 days per patient in 2016/2017. However, the excess length of hospital stay for patients with the same code was a mean of 29.4 days per patient.[26] There is clearly uncertainty surrounding the excess of length of hospital stay arising from a HCAI (as depicted in figure 4).

To put the 7.1 million occupied hospital bed days attributable to HCAIs into some perspective, 5.3 million bed days were occupied by patients with cancer in England in 2014 while receiving treatment in the first year of their diagnosis.[27] Additionally, lung diseases in the UK were associated with an estimated 6.1 million occupied bed days in 2011[28] and heart failure with an estimated 1 million bed days in 2014.[29]

The estimated 7.1 million occupied bed days accounts for 21% of the annual number of all bed days across NHS hospitals in England (ie, 33.7 million). If the mean additional length of hospital stay as a result of a HCAI was reduced by half (from 9.1[16] to 4.5 days), 11% of all hospital bed days would still be occupied by patients with a HCAI. In recent years, there has been an increase in hospital bed occupancy in England, partially due to increased levels of hospital activity.[30] Inevitably, this impacts on the speed with which patients can be admitted into hospital. It is also a significant factor in the deteriorating performance against the 4-hour standard for admitting or discharging patients from hospital accident and emergency departments.[30] Bed shortages have also contributed to patients being admitted to hospitals outside their local area which could delay their recovery.[30]

The original burden of HCAIs study in England estimated these infections occurring in adult patients admitted to NHS hospitals in England between April 1994 and May 1995 to cost £931 million.[25] We estimated the uprated value of this cost to be £1.7 billion at 2016/2017 prices. Comparison between the two studies which span 25 years, seems inappropriate because of changes in epidemiology of infection, infection control, infection management, hospital admission pathways and healthcare resource use over this period. At current prices, the annual NHS cost of HCAIs is comparable with that of smoking-related diseases which cost the NHS in England an estimated £2.6 billion per year.[31] To provide a further perspective, the annual NHS cost of managing nocturia has been estimated at £1.4 billion,[32] wounds and associated comorbidities at £5.3 billion[33] and obesity at £6.1 billion.[34] The estimated £2.7 billion cost of HCAIs represents 1.6% of the planned NHS annual budget for 2018/2019.[35]

In England, both NICE and PHE have produced guidance pertaining to the prevention of HCAIs and every NHS hospital must have an infection prevention protocol in place. Hand hygiene, antimicrobial stewardship and environmental cleanliness are currently identified as key strategies to combat HCAIs.[36] There is also monitoring through mandatory HCAI surveillance schemes conducted by PHE. However, if HCAIs are still costing up to an estimated £2.7 billion and resulting in an estimated 28 500 patient deaths, 7.1 million occupied bed days and 79 700 days of absenteeism among front-line HCPs, then improvement is necessary and closer monitoring of these strategies is required as well as the introduction of more effective infection control procedures.

The NAO produced a document in 2009 which compared the management, prevention and control of HCAIs among NHS acute trusts in England with hospitals in the USA, Australia, Canada, Northern Ireland, Scotland, Wales, Belgium, Denmark, France and Chile.[37] The infection control plans for HCAIs in these countries all have a common aspect when tackling HCAIs, namely the surveillance and recording of HCAIs.[37] Some countries also had antimicrobial stewardship and prescribing guidelines that made up part of the infection control programme, and hand hygiene remained an important factor in the prevention of infection. However, not all the countries were reported to perform audits of hand hygiene.[37] Nevertheless, guidelines for hand hygiene can be found in the public health websites of most countries and many countries are running campaigns to highlight its importance.[37 38] Moreover, the World Health Organization (WHO) has produced guides and conducted campaigns, and hand hygiene is evident in most if not all care settings as a key infection control strategy.

There are several different available technologies that can be used for infection control within a hospital, each employing very different methods. The types of technology available include, but are not limited to, automated hand hygiene monitoring, touchless technology, fluorescent marking of high-touch surfaces to ensure cleaning, copper surfaces and antimicrobial textiles.[39]

Automated hand hygiene monitoring can involve assessment of hand hygiene product usage to estimate hand hygiene events, or in fully automated systems the tracking of HCP activities in association with hand hygiene product dispensing.[39] These systems are able to detect hand hygiene events as healthcare workers enter and exit patient areas, and in some cases may monitor all five of the WHO's Moments of Hand Hygiene.[39] Touchless technologies include the use of room cleaning devices such as ultraviolet (UV) light or hydrogen peroxide emitting devices. These methods are used in addition to manual cleaning and the devices can only be deployed in empty rooms due to UV and hydrogen peroxide being harmful to humans.[39] ATP levels and fluorescent markers have been used as surrogates of contamination to assist in monitoring of cleaning. Fluorescent markers like ATP have also been used to teach and test adequacy of hand hygiene, by measuring the levels of ATP before and after cleaning with UV light.[39] Antimicrobial textiles such as silver-treated curtains and ammonium impregnated scrubs have been shown to be effective in preventing bacterial colonisation, but not after extended use of the same curtains or uniform.[39]

Despite the use of all the aforementioned technologies, infection can still persist in a hospital if an unseen reservoir of pathogens exists. This potential reservoir is hospital sinks (and possibly ventilation ducts). Such a reservoir constitutes the fabric of all hospitals and their wards, and the use of sinks is a key component of current infection control processes. A study in the Netherlands of five ICUs showed that removal of sinks from patient rooms and moving to a water-free patient care regime significantly reduced colonisation of patients with gram-negative and multidrug resistant bacteria.[40] However, this study only showed colonisation of patients and not infections.

HCAIs can have a significant social and emotional impact on the lives of patients.[41] A qualitative systematic review documenting HCAI patient experiences reported that patients felt frustration when trying to obtain treatment information regarding HCAIs from HCPs.[41] Patients with HCAIs also experienced restriction of access to other healthcare such as rehabilitation classes, having to take late clinic appointments to avoid other people and having to be visited at home by HCPs in protective clothing.[41] Other issues that can affect a patient's quality of life include fear and concern in relation to their illness/infection. There is the concern of transmission of the disease to family and friends, and as a result there can be a potential restriction of social interactions either by the patient or by their family and friends as a precaution against infection.[41] Patients with *C. difficile* infection were reported to self-exclude from social events due to the undesirable symptoms. This was also seen among patients with a SSI who had leaking wounds which could possibly be visible to family and friends.[41] Hence, HCAIs can cause patients to significantly alter their routine patterns of behaviour, such as avoidance of travelling on public transport or going to the gym.[41] Patients who acquire a HCAI can also feel the need to take excessive precautions in terms of cleaning and hand washing and even limiting potential occupations due to concerns over infection-transmission.

While this study has focused on hospitals in England, the findings are directly applicable to other hospitals in the other rest of the UK (Scotland, Wales and Northern Ireland). In principle, the results are indicative of the health economic impact of HCAIs in Europe, although some adaptation may be required. The health economic impact of HCAIs in the USA is likely to be very different due to differences in the incidence of HCAIs and ensuing management.[7]

Study limitations

The model was based on a number of assumptions around the epidemiology of HCAIs, excess length of hospital stays

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and outpatient appointments. The effect of these assumptions has been tested in sensitivity analyses, however the results may still be subject to unknown confounders and therefore our findings should be interpreted with some caution. In particular, it was not possible to estimate excess length of hospital stay using a time-varied methodology with the available data. Hence, our estimates of excess length of hospital stay may be affected by time-dependent bias and therefore could be overestimated.[10 42] Sensitivity analysis showed the impact of changing the excess length of hospital stay estimate. Another potential limitation is the daily cost of bed occupancy. Around 98% of the NHS cost of HCAIs was estimated to be attributable to hospital bed occupancy, which was based on bed occupancy costs obtained from the NHS' National Schedule of Reference Costs.[26] However, some argue that this costing approach could potentially under or over value bed occupancy due to disparity between accounting and economic costing of hospital beds.[43] Sensitivity analysis showed the impact of changing the daily cost of bed occupancy, although the actual value of bed occupancy costs in the UK is unknown.

The model was populated with estimates for all general and teaching hospitals in England and for 'average patients'. The model does not consider the impact of other factors that may affect the results, such as different ward types, patients' age, co-morbidities or clinicians' specialties. The model does not distinguish between different types of pathogens causing HCAIs and the definition of HCAI varies between clinicians. Nor does the model consider that HCAI is an umbrella term that describes many different infections which have different epidemiological attributes and differential impact on patients, all of which have the potential to affect resource use, costs and mortality. The model is limited to HCAIs among adult inpatients and does not consider paediatrics, accident and emergency or outpatient departments. The model does not consider patients acquiring a HCAI but being discharged from hospital before symptoms emerge. 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.

CONCLUSION

This study should provide updated estimates on NHS resource use and costs with which to inform policy and budgetary decisions pertaining to preventing and managing HCAIs. Clinical and economic benefits could accrue from an increased awareness of the impact that HCAIs impose on patients, the NHS and society as a whole and from strict adherence to infection control practices and guidelines. Investigation into potential technologies which augment infection control procedures may be worthwhile in endeavouring to combat HCAIs.

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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