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Impact of healthcare-associated infection on length of stay

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SUMMARY

Background: Increased length of stay (LOS) for patients is an important measure of the burden of healthcare-associated infection (HAI).
Aim: To estimate the excess LOS attributable to HAI.
Methods: This was a one-year prospective incidence study of HAI observed in one teaching hospital and one general hospital in NHS Scotland as part of the Evaluation of Cost of Nosocomial Infection (ECONI) study. All adult inpatients with an overnight stay were included. HAI was diagnosed using European Centres for Disease Prevention and Control definitions. A multi-state model was used to account for the time-varying nature of HAI and the competing risks of death and discharge.
Findings: The excess LOS attributable to HAI was 7.8 days (95% confidence interval (CI): 5.7–9.9). Median LOS for HAI patients was 30 days and for non-HAI patients was 3 days. Using a simple comparison of duration of hospital stay for HAI cases and non-cases would overestimate the excess LOS by 3.5 times (27 days compared with 7.8 days). The greatest impact on LOS was due to pneumonia (16.3 days; 95% CI: 7.5–25.2), bloodstream infections (11.4 days; 5.8–17.0) and surgical site infection (SSI) (9.8 days; 4.5–15.0). It is estimated that 58,000 bed-days are occupied due to HAI annually.
Conclusion: A reduction of 10% in HAI incidence could make 5800 bed-days available. These could be used to treat 1706 elective patients in Scotland annually and help reduce the number of patients awaiting planned treatment. This study has important implications for investment decisions in infection prevention and control interventions locally, nationally, and internationally.

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Introduction

Healthcare-associated infection (HAI) results in poor outcomes for patients in terms of morbidity and mortality as well as increased length of stay (LOS) and cost [1,2]. Increased LOS is a useful measure of the cost burden of HAI and is used to support arguments to increase investments in hospital infection prevention and control (IPC) [1,3]. To retain credibility with decision-makers and allocate scarce resources appropriately, it is important to report unbiased estimates of HAI burden [4].

Although LOS is relatively simple to measure and data are readily available on admission and discharge dates, several factors complicate these analyses. The study design, population under investigation, type of HAI, and approach to statistical analysis can result in large variations on estimates of excess LOS. The potential for bias, especially time-dependent bias, is not always accounted for in studies estimating the additional LOS due to HAI [5]. Time-dependent bias occurs when a patient's entire hospital stay, or even the entire period after the patient develops HAI, is attributed as additional LOS due to the HAI, and this may lead to inflated estimates in excess LOS linked with HAI. Despite these issues being well documented there are still a wide range of analytical approaches used to estimate the excess attributable LOS due to HAI that fail to address this issue [6–11]. The common analytical approaches compare LOS in HAI and non-HAI groups, matching HAI and non-HAI patients using characteristics that may affect LOS, with and without accounting for time of infection, survival analyses, and multi-state modelling [5]. There is considerable heterogeneity in both study designs and analytical approaches that prevent the use of meta-analysis or the use of these data to inform IPC priorities and interventions.

The primary objectives of this study were to report the LOS for patients with, and without, HAI and to report the excess LOS attributable to HAI in order to determine which types of HAI have the greatest impact on LOS.

Methods

Study design

The Evaluation of Cost of Nosocomial Infection (ECONI) study was designed to capture whole-hospital incidence including all HAI types over one calendar year within a large teaching hospital and a large general hospital within NHS Scotland. Data were collected from April 2018 to March 2019 within the large teaching hospital and from July 2018 until June 2019 in the general hospital [12]. The large teaching hospital had 981 beds including 16 general and nine cardiothoracic intensive care beds and 13 general, eight cardiothoracic, and 12 transplant and renal high-dependency beds, and the large general hospital had 492 beds including five intensive care and four high-dependency beds [13]. These incidence data have been used to estimate the excess LOS as a result of a range of types of HAI using a multi-state modelling approach [14]. The study hospitals were selected to be representative of acute adult healthcare within NHS Scotland [15]. They offer the majority of clinical specialties in Scotland and HAI prevalence was around the median within the most recent HAI prevalence survey undertaken before the study [16]. Teaching and general hospitals accounted for 91% of all admissions to acute care in Scotland in 2015 while the study was being developed [15]. Further detail of the method is described elsewhere [12].

All adults aged ≥18 years admitted overnight to the study hospital during the study period were included. HAI was diagnosed using the internationally accepted European Centre for Disease Prevention and Control (ECDC) case definitions [17]. Data were collected on all infection types applicable to adults, including bloodstream infection (BSI), urinary tract infection (UTI), lower respiratory tract infection (LRI), pneumonia, gastrointestinal infection (GI), surgical site infection (SSI), skin/soft tissue (SST), bone and joint (BJ), cardiovascular (CV), eye, ear, nose, and throat (EENT), and systemic infections.

Data collection

According to a previously published protocol, research nurses were trained on the case definitions and standardized data collection process [12]. Inter-rater reliability and validation were completed which indicated the data were of high quality. Suspected cases were identified by microbiology reports, then clinical notes were reviewed to ascertain whether the case met the ECDC case definitions. Cases which met the criteria were recorded electronically using a bespoke database designed for the study using REDCap software [18].

For all inpatients admitted to the study hospital, records were linked to the Scottish Morbidity Record 01 (SMR01), which covers all hospital admissions and discharges to acute hospitals, sourced from hospital administrative systems across Scotland [19]. SMR01 was used to collect information for every admission on date of the admission and discharge, age on admission, sex, Scottish Index of Multiple Deprivation (SIMD), specialty, and comorbidities using the International Classification of Diseases, 10th Revision (ICD-10) [20,21]. SIMD is the Scottish Government's standard approach to identify areas of multiple deprivation in Scotland, looking at the extent to which an area is deprived across seven domains: income, employment, education, health, access to services, crime, and housing [20]. Charlson Comorbidity Index was derived from the ICD-10 comorbidities recorded within the SMR data set in the two years prior to admission [22].

The two study hospitals had 107,244 admissions during 2015 when the study was being planned [12]. The primary power calculation was based upon estimating the risks of developing HAI. A hospital HAI incidence of about 0.5–1% of admissions was anticipated, yielding around 500–1000 incident HAI cases over the period of one year [12]. Previously published modelling using prevalence data from the last European point-prevalence survey estimated the expected hospital incidence of HAI using the Rhame and Sudderth equation to estimate incidence of HAI from prevalence data [23]. This was supported by the Scottish incidence of HAI within the Healthcare Associated Infection Annual report and the incidence of HAI reported within intensive care units [24]. Previous estimates of excess LOS suggested a range of 5–15 days with standard deviations around 8–15 days [14,25]. With 1000 incident HAI cases we anticipated estimating mean excess LOS to within ±1 day with 95% confidence; with 500 cases this would be ±1.4 days.

Estimation of excess LOS

Continuous variables were summarized as medians, ordinal variables as counts with percentages. Admission-level analyses

are reported and the analysis included all admissions treating each admission as independent; many patients had multiple admissions during the study period. An admission comprised a patient's continuous inpatient stay, defined as 'an unbroken period of time that a patient spends as an inpatient', and was obtained through record linkage to SMR01 data [26,27]. This continuous inpatient stay is made up of one or more discrete episodes of care within different specialties and significant facilities.

Data were collected on all inpatient admissions during the study period. Admissions and patient numbers included within this analysis are described in Figure 1. An admission-level approach to analysis was adopted as it was assumed that the patient's condition and likelihood to stay longer in hospital are not constant over time and that these can change from one admission to the next. Patient-level analysis may be further complicated by patients having both HAI admissions and non-HAI admissions during the study period. The approach used treats each admission as a new event, and the readmitted patients may, for example, have a different diagnosis or be older.

Multi-state model

A multi-state modelling approach was used, taking account of time-varying exposures and the competing risks of death and discharge (Figure 2). The critical parameters within the data set are date of admission, date of onset of HAI, and date of discharge or death. Patients entered the initial state on each admission to hospital unless the infection date was before or equal to the admission date, in which case the patient was assigned directly to the HAI state. The ECDC case definitions allow HAI to be diagnosed if the patient has recently been discharged from hospital. Patients

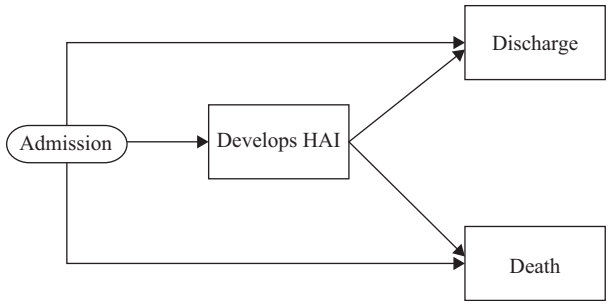

Figure 2. Four-state model used to estimate the excess length of stay due to healthcare-associated infection (HAI).

exited by entering one of two absorbing states of death or discharged alive, with or without passing through the intermediate HAI state. If an admission contained more than one HAI, the state-change to HAI occurred at the time of the first infection and the patient remained in the HAI state until death/discharge/censored. Since transition from admission to HAI could happen at any time, HAI was treated as a time-varying exposure.

The probabilities of transitions between states, that is from admission to discharge or death, or from admission to HAI and then to discharge or death during the admission, were estimated using the Aalen–Johansen estimator [28]. The mean excess LOS was then estimated by calculating the average difference in LOS between patients with and without HAI at each time, weighted by the observed distribution of time to HAI. A total of 50 bootstrap samples were generated and the distributional spread of the excess LOS assessed. Normality was

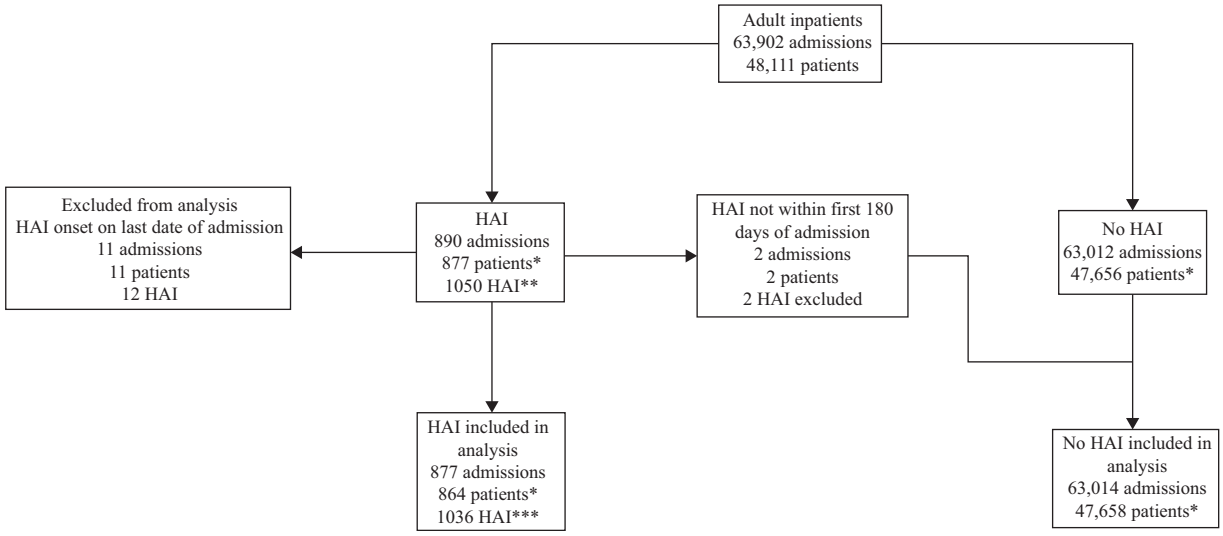

Figure 1. Patients included within the admission level multi-state model.

*A total of 422 patients were included in both the healthcare-associated infection (HAI) and no-HAI groups for different admissions (which are treated as independent).

**The ECONI study reported 1083 HAIs [30]. Thirty-three cases could not be linked to the Scottish Morbidity Record (SMR) dataset, 10 patients did not have valid Community Heath Index number (non-Scottish residents), 7 patients had no SMR01 record (still in hospital or transcription error), and 15 patients (with 16 infections) did not have an SMR01 record for the admission during which they had an HAI (may still be in hospital).

***The 877 admissions included in analysis contained 1036 HAIs. If an admission contained more than one HAI, the state-change to HAI occurred at the time of the first infection and the patient remained in the HAI state until death/discharge/censored.

Table I
Baseline descriptive unadjusted characteristics of patients during their admission (63,014 non-HAI and 877 HAI admissions)

Characteristic	Category	HAI	Non-HAI	All	Median post-infection LOS for HAI admission (IQR)	Median total LOS for HAI admission (IQR)	Median LOS for non-HAI admission (IQR)
		($N = 877$)	($N = 63,014$)	($N = 48,104$)			
Age (years)	<40	48 (5.5)	9203 (14.6)	9251 (14.5)	12.5 (6–25.25)	26 (10–46.5)	2 (1–3)
	40–49	62 (7.1)	6041 (9.6)	6103 (9.6)	14 (7–27.5)	23.5 (14–46.25)	2 (1–5)
	50–59	134 (15.3)	9502 (15.1)	9636 (15.1)	12 (6–28.75)	23 (11.25–49.25)	3 (1–6)
	60–69	157 (17.9)	11,388 (18.1)	11,545 (18.1)	13 (5–31)	26 (13–47)	3 (2–7)
	70–79	221 (25.2)	13,232 (21)	13,453 (21.1)	16 (6–38)	30 (14–56)	4 (2–9)
	≥80	255 (29.1)	13,648 (21.7)	13,903 (21.8)	17 (8–40)	37 (20–67.5)	6 (2–16)
Sex	Male	437 (49.8)	29,711 (47.1)	30,148 (47.2)	15 (7–37)	30 (15–55)	3 (1–7)
	Female	440 (50.2)	33,303 (52.9)	33,743 (52.8)	15 (6–32)	29.5 (14–57)	3 (1–8)
Charlson Comorbidity Index (CCI)	[0] No stay – not known	227 (25.9)	22,506 (35.7)	22,733 (35.6)	16 (6–36.5)	30 (15–57.5)	3 (1–6)
	[0] No score	272 (31)	21,080 (33.5)	21,352 (33.4)	17 (7–38)	31.5 (16–64.25)	3 (1–7)
	[1–2] Mild	230 (26.2)	13,011 (20.6)	13,241 (20.7)	14 (6–32.5)	29 (13–51.75)	4 (2–10)
	[3–5] Moderate	117 (13.3)	4658 (7.4)	4775 (7.5)	12 (6–30)	27 (14–55)	5 (2–12)
	[≥6] Severe	31 (3.5)	1759 (2.8)	1790 (2.8)	11 (6.5–27.5)	20 (12–36.5)	5 (2–11)
Scottish Index of Multiple Deprivation	1 (most deprived)	170 (19.4)	12,534 (19.9)	12,704 (19.9)	13.5 (5.25–31.5)	29 (13.25–55.5)	3 (1–8)
	2	267 (30.4)	16,556 (26.3)	16,823 (26.3)	18 (6–40)	31 (14–62)	3 (1–8)
	3	158 (18)	11,934 (18.9)	12,092 (18.9)	14.5 (7.25–33.75)	26.5 (15–50.75)	3 (1–8)
	4	121 (13.8)	10,215 (16.2)	10,336 (16.2)	12 (7–26)	30 (15–48)	3 (1–7.5)
	5 (least deprived)	158) (18)	11,438 (18.2)	11,596 (18.1)	16 (7.25–38.75)	29.5 (17–60.75)	3 (1–8)
	Unknown	3 (0.3)	337 (0.5)	340 (0.5)	19 (13–31.5)	39 (29.5–46.5)	2 (1–5)
Emergency admission	No	123 (14)	14,026 (22.3)	14,149 (22.1)	11 (5–23)	20 (10.5–35.5)	2 (1–5)
	Yes	754 (86)	48,988 (77.7)	49,742 (77.9)	16 (7–37)	31 (15–58)	4 (2–9)
Specialty group	Medicine	434 (49.5)	35,589 (56.5)	36,023 (56.4)	16 (7–36)	33 (18–59.75)	3 (1–8)
	High dependence	38 (4.3)	1034 (1.6)	1072 (1.7)	23.5 (13–37.75)	34.5 (20.25–58.75)	6 (3–12)
	Intensive care	65 (7.4)	2170 (3.4)	2235 (3.5)	17 (7–39)	31 (15–47)	4 (2–9)
	Obstetrics and gynaecology	10 (1.1)	1793 (2.8)	1803 (2.8)	8.5 (3.5–17.5)	15.5 (8.25–23.25)	1 (1–3)
	Surgery	330 (37.6)	22,255 (35.3)	22,585 (35.3)	13 (6–31)	23 (11–47)	3 (1–7)
	Other	0	173 (0.3)	173 (0.3)			1 (1–4)
Overall					15 (6–35)	30 (14–56)	3 (1–8)

HAI, healthcare-associated infection; LOS, length of stay; IQR, interquartile range.
Charlson Comorbidity Index score was calculated based on comorbidities recorded during previous admissions to hospital. Patients with no stay within the previous two years are classed as not known. Those who were admitted to hospital but had none of the comorbidities were included within the CCI.

Table II
Excess LOS calculated using admission level model (in days) due to HAI shown for HAI groups

HAI type[a]	HAI admissions	Non-HAI admissions	Excess LOS (days)	SD[b]	95% CI
All HAI	877	63,014	7.8	1.1	5.7–9.9
Bloodstream infection[c]	158	63,733	11.4	2.8	5.8–17.0
Gastrointestinal infection	139	63,752	6.0	3.4	−0.7 to 12.7
Lower respiratory infection	155	63,736	7.3	2.8	1.8–12.7
Pneumonia	81	63,810	16.3	4.5	7.5–25.2
Surgical site infection	130	63,761	9.8	2.7	4.5–15.0
Urinary tract infection	188	63,703	−1.0	1.7	−4.3 to 2.3
Other[d]	26	63,865	14.0	9.1	−3.9 to 31.8

LOS, length of stay; HAI, healthcare-associated infection; SD, standard deviation; CI, confidence interval.
N = 877 HAI admissions in total as this analysis was based on admissions which could be linked.
[a] For patients with multiple HAI admission is reported in the infection type of the first infection.
[b] Based on 50 Bootstrap (95% CI for excess LOS was calculated based on the fact that the access LOS follow a normal distribution).
[c] Included catheter-related infection type 3 (catheter-related bloodstream infection with microbiological documentation of the relationship between the vascular catheter and the BSI).
[d] Small numbers of infections, including skin soft tissue; bone and joint; cardiovascular; eye, ear, nose and throat; and systemic infections. These infections made up 3% of the total HAI but within this group there was a wide range of organs affected by this diverse group of HAIs.

Table III
Rank order of frequency of infection compared to excess LOS within the incidence cohort

Rank	Incidence rate per 100,000 AOBD		Excess LOS per infection		Total annual estimated AOBD	
	HAI type	Incidence rate per 100,000 AOBD	HAI type	Excess LOS per infection (days)	HAI type	Total annual estimated AOBD
	All HAI	249.6	All HAI	7.8	All HAI	58,010
1	UTI	51.2	PN	16.3	BSI	15,830
2	BSI	44.7	Other	14.0	PN	10,270
3	LRI	44.2	BSI	11.4	SSI	10,030
4	GI	39.2	SSI	9.8	LRI	7600
5	SSI	35.3	LRI	7.3	GI	7540
6	PN	23.5	GI	6.0	Other	6650
7	Other	13.6	UTI	0	UTI	0

LOS, length of stay; AOBD, acute occupied bed-days; HAI, healthcare-associated infection; UTI, urinary tract infection; BSI, bloodstream infection; LRI, lower respiratory tract infection; GI, gastrointestinal infection; SSI, surgical site infection; PN, pneumonia.
Total HAI admissions: 877 (which were linked to LOS data). Incidence data are reported elsewhere [30].

deemed to be followed, allowing estimation of asymptotic 95% confidence intervals using the standard error calculated derived from the 50 bootstrap samples.

The multi-state modelling was performed using the etm package in R (version 3.5.1) [29].

Ethics

This study was surveillance and therefore was confirmed as ineligible for ethical review (Bailey A. Personal communication to S. Stewart, September 8th, 2016. South East Scotland Research Ethics Service). It was approved by national information governance approvals: Public Benefit of Health and Social Care: Incidence study: 1617-0037.

Results

In total, 877 HAI-related admissions and 63,014 non-HAI-related admissions were included within the analysis (Figure 1). Admissions were excluded from the analysis if the patient did not have a valid Community Heath Index number (CHI) ($N = 17$), or were diagnosed with HAI on the last day of their stay or on the day they died ($N = 11$). Patients were censored after 180 days' post admission and censored if they were discharged to another hospital, since this reduced the influence of outliers. Consequently, two admissions with HAI were treated as non-HAI admissions due to the HAI occurring more than 180 days after initial admission.

Within the included adult admissions, the median patient age at admission was 66 years (interquartile range: 51–78); 52.8% were female. HAIs were identified a median of 9 days [4–19] after admission to hospital. The median LOS for admissions with HAI was 30 days [14–56] and for admissions with no HAI was 3 days [1–8]. At the end of the study, 649 (74%) HAI-related admissions had been discharged from hospital, 149 (17.0%) had died in hospital, and 79 (9.0%) remained in hospital. By contrast, 58,208 (92.4%) non-HAI-related admissions were discharged from hospital, 2414 (3.8%) died in hospital and 2392 (3.8%) remained in hospital.

The excess LOS for all HAI types was 7.8 days (95% CI: 5.7–9.9). The rank order of highest to lowest impact was pneumonia (16.3 days; 7.5–25.5), combined other HAI types (14 days; −3.9 to 31.8), BSI (11.4 days; 5.8–17.0), SSI (9.8 days; 4.5–15.0), LRI (7.3 days; 1.8–12.7), GI (6 days; −0.7 to 12.7), and UTI showing no excess LOS (Table II). Combined 'other' comprise a small number of infections, including SST, BJ, CV, EENT, and systemic infections. These infections made up 26

(3%) of the total HAI but within this group a wide range of organs are affected by this diverse HAI group.

The incidences of infection types with the greatest excess LOS were low: pneumonia 23.5 per 100,000 acute occupied bed-days (AOBD); other infections 13.6 per 100,000 AOBD [30] (Table III). BSI ranked second highest incidence at 44.7 per 100,000 AOBD; when the total annual number of excess bed-days was calculated using estimated total annual number of HAIs within Scotland, BSI had the greatest impact on acute care, with pneumonia second and SSI third [30] (Table III).

Discussion

This hospital incidence study is the first in the UK for more than 20 years to analyse LOS attributed to HAI derived from all adult specialties. It addresses the risk of time-dependent bias using a multi-state modelling approach and has found that the excess LOS attributable to HAI was 7.8 days (95% CI: 5.7–9.9) (Table II). Studies that account for time-dependent bias are rare in the published literature, and studies continue to be published without taking account of time-dependent bias [31–34].

The median LOS for HAI patients was 30 days and for non-HAI patients was 3 days (Table I). Patients within this study with HAI stayed in hospital for a substantially longer time than patients without HAI, and acquired an infection a median of 9 days (IQR: 4–19) into their stay [30]. This difference reflects the age, comorbidities, and severity of illness of patients who develop HAI, since many of these patients will stay in hospital for an extended period even if they do not develop HAI [30,35]. Studies continue to report the difference in total LOS between patients with and without HAI and attribute this difference wholly to HAI [31–33,36–48]. Patients with complex conditions and multiple morbidities are often at greater risk of developing HAI due to their intrinsic risk factors, or are exposed to extrinsic risks as a result of the treatment they receive during their hospital stay; these patients also potentially require a longer duration of treatment within hospital, increasing their risk of developing HAI. Using a simple comparison of duration of hospital admissions for HAI cases and non-cases would overestimate the excess LOS by 3.5 times (27 days compared with the estimate from the multi-state modelling of 7.8 days excess LOS). A systematic review identified seven studies that compared time-fixed comparisons methods to multi-state models resulting in estimates of the LOS to HAIs that were, on average, 9.4 days longer or 2.4 times greater than those generated using multi-state models [49]. These seven studies were undertaken in different countries and included studies that reported a range of infection types and causative organisms. Other studies have found this difference to be as high as 5.6 times [50].

This study's finding of 7.8 days excess LOS attributable to HAI is consistent with the estimates available from those few studies which have assessed the excess LOS attributable to HAI within a whole-hospital setting [50–53]. Preventing one case of HAI will reduce the average stay by 7.8 days. However, patients who are at risk of HAI will still be present in the hospital over a longer period due to their underlying health and will remain vulnerable to HAI throughout their stay. A total of 58,000 bed-days are occupied due to HAI in Scotland annually, which is equivalent to a small general hospital accommodating only patients with HAI [54]. The average LOS in NHS Scotland in 2018/19 was 6.0 days overall; 3.4 days for elective admissions, 6.6 for emergency admissions, and 13.2 for transfers [55]. For each HAI prevented, at least one other patient could have been treated, or two elective admissions could have been removed from a waiting list. Thus, even a reduction of 10% in HAI incidence has the potential to free up 5800 bed-days that could be used to treat an average of 1706 elective patients in Scotland annually and help to reduce the number of patients awaiting planned treatments [56–58].

Although UTIs showed no excess LOS overall in the ECONI study, this is not to say that the HAI had no impact on the patients or the health system – they simply did not cause patients to stay longer in hospital. The impact of UTIs on the healthcare system has been demonstrated elsewhere [59,60]. Further, UTIs are associated with secondary BSI, and therefore the importance of prevention of UTI remains critical. Three studies reported excess LOS due to UTI caused by any organism using a multi-state modelling approach and their estimates of excess LOS range from 0.34 to 5.3 days [50,51,61]. However, these studies were undertaken in China (lowest value), Australia, and Germany (higher value), with no comparable studies identified from the UK.

The three HAI types having the greatest impact on LOS per infection were pneumonia, BSI, and SSI (Table II). BSI not only had the second greatest impact on LOS but patients being treated for BSI accounted for the greatest number of bed-days when incidence was extrapolated at a national level (Table III). BSI, pneumonia, and SSI are high-volume and high-impact infections, and a focus on reducing these HAI types should be prioritized. To date in the UK and internationally, much of the focus has been on catheter-related BSI and ventilator-associated pneumonia [62,63]. However, the impact of these infections on LOS is such that a more comprehensive look at wider IPC interventions for non-device-associated BSI and pneumonia and beyond ICU is required.

All-cause mortality was higher within the HAI group (17.0%) compared to that in the non-HAI group (3.8%). A greater proportion of patients who developed HAI remained in hospital (9.0%) compared with non-HAI cases (3.8%). When the effect of a prognosis of death within six months for an underlying condition is considered, the impact of HAI on mortality is modified [64,65]. These deaths cannot be attributed to the HAI and these observations show how important it is to consider the complexity of attribution of mortality to HAI.

There are several limitations to this study. Regarding record linkage from national datasets, some patients were excluded – for example, patients who did not have valid CHI number, who remained in hospital, or who had not been discharged, although this number was small ($N = 33$) (Figure 1). Whereas multi-state modelling is proposed as the best methodology for estimating excess LOS due to HAI, this analysis did not account for patient characteristics such as severity of illness and comorbidities [6,10,14,66]. Although it is possible to include adjustments for all patient characteristics using pseudo-observations, the interpretation becomes complex, in that the adjusted excess LOS estimate was taken from the model intercept, and could therefore be interpreted as the excess LOS caused by infection in the patients who are in the reference group (aged <30 years, male, no prior hospital stay, most deprived area, elective, admission, treated in a medical specialty). This 'reference' group of patients does not reflect the majority of patient admissions and therefore could potentially overestimate the attributable LOS for the majority of patients.

Another benefit of the multi-state modelling approach is that cases and controls are not lost due to issues with matching, which often lead to bias as certain groups of cases are more likely to be excluded due to difficulties in finding controls (e.g. those with rare admission diagnosis, or young patients, or those in relatively small hospitals).

These results would be generalizable to UK NHS hospital settings as hospital care pathways; laboratory testing and treatments are broadly similar throughout the NHS in the UK. How far these findings are generalizable is unknown. The estimates of excess LOS are very similar to those reported overall within high-income countries, although differences in healthcare systems, case mix and incidence of different HAIs will affect overall outcome estimates.

In conclusion, this was a comprehensive study of incidence surveillance across whole-hospital populations and all types of HAI using ECDC case definitions of HAI and record linkage [17]. Excess LOS is the most important factor when considering the impact of HAI on patient services. Whereas a reduction in HAI incidence frees up hospital bed-days, allowing additional patients to be treated, the number of bed-days made available is less than previously estimated. However, the at-risk patients would still be treated in hospital for an extended period. These results can be used to inform studies assessing the cost-effectiveness of interventions to prevent HAI.

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Author contributions

S.S. led the study design, wrote study protocols and ethics and Public Benefit and Privacy Panel approvals, patient-facing materials, contributed to the design of the collection tools, contributed to development of statistical analysis, and developed the manuscript. C.R. contributed to the concept of the study, study design, and statistical analysis plan. C.R., S.K., K.K. undertook the statistical analysis and contributed to the manuscript. S.M. contributed to aspects of the study design and contributed to the manuscript. H.M. contributed to the study design and health economic aspects of the study. L.H. contributed to the development of study design, protocol and data management. S.D. and B.C. are the Principal Investigators at the recruiting sites. J.R. conceived the study and is Chief Investigator for the study.

Non-author collaborators

The ECONI Steering Committee. M.A. represented the funder, A.L., R.D., A.M., M.S. and J.I. represented the Scottish Government HAI policy unit on the Steering Committee. E.R. and L.R. represented Infection Prevention Society (IPS). M.W., L.B., and M.R. were lay representatives on the Steering Committee and M.W. and L.B. contributed to the development of the patient-facing materials for the study. Committee: Professor J. Reilly (J.R.), Professor M. Adil (M.A.), Dr H. Mason (H.M.), Professor C. Robertson (C.R.), Professor N. Graves (N.G.), J. Ives (J.I.), M. Syme (M.S.), R. Dunk (R.D.), A. Mullings (A.M.), E. Ross (E.R.), L. Ritchie (L.R.), Professor S. Dancer (S.D.), Dr B. Cook (B.C.), Professor A. Leonard (A.L.), M. Whyte (M.W.), M. Rodgers (M.R.), L. Brown (L.B.), S. Stewart (S.S.).

Conflict of interest statement

None declared.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jhin.2021.02.026.

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