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Epidemiology of healthcare-associated infection reported from a hospital-wide incidence study: considerations for infection prevention and control planning

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SUMMARY

Background: The measure of disease frequency most widely used to report healthcare-associated infection (HAI) is the point-prevalence survey. Incidence studies are rarely performed due to time and cost constraints; they show which patients are affected by HAI, when and where, and inform planning and design of infection prevention and control (IPC) measures.

Aim: To determine the epidemiology of HAI within a general and a teaching hospital in Scotland.

Methods: A prospective observational incidence study was undertaken for one year from April 2018 using data collected as part of the Evaluation of Cost of Nosocomial Infection (ECONI) study. A novel, robust approach was undertaken, using record linkage to national administrative data to provide full admission and discharge information. Cases were recorded if they met international HAI definitions.

Findings: Incidence of HAI for the combined hospitals was 250 HAI cases per 100,000 acute occupied bed-days (AOBD). Highest frequency was in urinary tract (51.2 per 100,000 AOBD), bloodstream (44.7), and lower respiratory tract infection (42.2). The most frequently reported organisms were *Escherichia coli*, *Staphylococcus aureus*, and norovirus. Incidence of HAI was higher in older people and emergency cases. There was an increase in the rate of HAI in summer months (pneumonia, respiratory, surgical, and gastrointestinal infection) and in winter months norovirus gastrointestinal infection ($P < 0.0001$). The

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highest incidence specialties were intensive care, renal medicine, and cardiothoracic surgery. HAI occurred at a median of 9 days (interquartile range: 4—19) after admission. Incidence data were extrapolated to provide an annual national estimate of HAI in NHS Scotland of 7437 (95% confidence interval: 7021—7849) cases.

Conclusion: This study provides a unique overview of incidence of HAI and identifies the burden of HAI at the national level for the first time. Understanding the incidence in different clinical settings, at different times, will allow targeting of IPC measures to those patients who would benefit the most.

Introduction

Healthcare-associated infection (HAI), especially those caused by antimicrobial-resistant pathogens, is an area of public health concern throughout the world. The World Health Organization estimates that HAI is the most frequently occurring adverse event in any healthcare system regardless of available resources [1]. There is evidence that many HAIs are avoidable and cause longer hospital stays and distress to patients [2—5].

The measure of disease frequency most commonly used to report HAI is the point-prevalence survey (PPS); these studies report the proportion of the population who have HAI at a given point in time. Within Europe it is estimated that 6.5% of patients treated within an acute care hospital have an HAI at the time of survey [6]. In Scotland in 2016 the overall point prevalence of HAI was 4.5% of acute hospital patients [7]. Although prevalence of HAI in 2016 was lower than that reported five years previously there remains the potential to reduce the number of patients affected [7—9]. Point-prevalence surveys are helpful for estimating the burden of disease, but longer duration incidence surveillance gives more comprehensive information on risk of developing HAI. Whereas incidence studies are rarely done due to time and cost constraints, they show which patients are affected by HAI, when and where, and inform planning and design of infection prevention and control (IPC) measures.

The aim of this study was to determine the incidence, HAI type, and the distribution of HAI within the study hospitals; we also report the time, place, and person characteristics affected by HAI. A national estimate of incidence of HAI was calculated by extrapolating the incidence found within the study hospitals.

Methods

The Evaluation of Cost of Nosocomial Infection (ECONI) study reports a two-centre, prospective, observational incidence study supplemented with hospital record linkage to provide full admission and discharge information on non-cases [10]. The participating hospitals were selected as being broadly representative of other acute hospitals in Scotland in terms of patient specialties, distribution of elective, emergency, and transfers, mean length of stay, previously reported HAI prevalence, patient mix, and rurality. Data were collected from June 28th, 2018 until June 27th, 2019 in the general hospital and from April 23rd, 2018 until April 22nd, 2019 in the teaching hospital [8,11,12]. Data sources for the study are listed in Appendix A, Table A.1. 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; the large general hospital had 492 beds including five intensive care and four high-dependency beds [10,13]. In 2015/16 when the study was planned the average beds were 886 (range: 711—1046) for the seven teaching hospitals and 479 (range: 245—57) for the 15 large general hospitals within NHS Scotland [12]. Mean length of stay (LOS) was 4.7 days overall in NHS Scotland, within the teaching hospital the mean LOS was 4.4 days and within the general hospital was 4.1 days. The teaching hospital had 831 available acute beds during the reporting period 2018/19, when data collection for the study took place, and the general hospital 418 [14]. The hospitals offered 91% of all specialties served within Scotland in 2016 when the study was being planned.

Case definitions

HAI was defined as an infection arising $\geq$48 h after admission to hospital and not present or incubating on admission, unless the patient had been discharged from hospital within a defined period. An incident HAI was defined by microbiologically confirmed European Centre for Disease Prevention and Control (ECDC) HAI epidemiological case definitions [15]. These definitions categorize HAI according to the organ/tissue system affected and have been adopted for use within Europe and internationally. Selected antimicrobial susceptibility testing data were recorded for micro-organisms recovered from HAI samples (see Appendix A, Table A.2). In NHS Scotland the European Committee on Antimicrobial Susceptibility Testing definitions of antibiotic susceptibility are used in all clinical laboratories including the two study hospitals [16].

Study design

The study team collected data on all adult overnight admissions that met the case definitions during the study period. Suspected HAI cases were identified by trained research nurses using the laboratory systems and cases were ascertained using case note review. Cases which met the ECDC HAI case definitions were recorded on a bespoke REDCap database [17]. This data set included HAI type, date of onset, causative organism, and selected antibiotic susceptibilities along with the patients' Community Health Index number (CHI)

according to the ECONI study protocol [10,18]. All isolates were recorded for each HAI and this provided a greater number of organisms than HAIs. Data linkage with NHS Scotland administrative data created a novel dataset on all adult overnight admissions to study hospitals to make the study more comprehensive. Day cases were excluded.

Statistical analysis

The incidence of HAI for each specialty and type of HAI was calculated as the number of HAI per 100,000 acute occupied bed-days (AOBD). The total number of bed-days occupied was derived from the Scottish Morbidity Record (SMR01), which is an episode-based record relating to all inpatients in NHS Scotland [19].

Temporal trend test

The incidence of new cases of HAI was calculated per 100,000 AOBD for each calendar month. χ^2-Test was used to assess whether the rates of HAI types were constant each month during the study. Additional data from the study period allowed calculation of the overall rate of each HAI type per admission episode. The expected numbers of HAI types each month were obtained from the admission episode and compared with observed numbers in each month.

Deriving national estimates for HAI incidence

Incidence rates of HAI per 100,000 AOBD, identified in the ECONI incidence study according to ECDC case definitions, were used to provide an overall estimate of HAI incidence for NHS Scotland [15]. Incidence of HAI (per 100,000 AOBD) varies by both hospital type and specialty. National estimates of the number of HAIs were derived by applying the incidence within each specialty group and hospital type [20]. This incidence rate was then applied to the total annual overnight admissions within NHS Scotland. Hospitals classified as children's hospitals were excluded from this extrapolation, as no information was available for these hospital types. The extrapolation was validated by estimating the total number of HAIs using total bed-days only and total bed-days and hospital type.

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

Quantifying HAI in the in-hospital population: incidence and type of HAI

During the study period there were 99,018 adult overnight admissions: 31,655 to the general hospital and 67,363 to the teaching hospital. Different patterns of HAI incidence were seen in the two hospital settings. In the general hospital 87 cases of HAI were identified (0.28% of admissions) and there were 996 in the teaching hospital (1.48% of admissions). Overall, 893 patients had one or more HAI during their stay in hospital. A total of 135,831 bed-days were occupied within the general hospital and 298,003 bed-days in the teaching hospital. Incidence of HAI was 64 per 100,000 AOBD in the general hospital and 334 per 100,000 AOBD in the teaching hospital, with an overall incidence for the combined hospitals of 250 per 100,000 AOBD.

The most frequently identified HAI types in the two hospitals were urinary tract infection (UTI) (51.2 per 100,000 AOBD), followed by bloodstream infection (BSI) (44.7 per 100,000 AOBD) (Table I). Combined respiratory tract infections (pneumonia: 23.5; lower respiratory tract infection (LRI): 42.2) were greater than UTI at 65.7 per 100,000 AOBD but these represented a wider range of illness severity. The rate of surgical site infection (SSI) was 35.3 per 100,000 AOBD and gastrointestinal infection (GI) rate was 39.2 per 100,000 AOBD. Of all HAI, 6.5% were defined as part of an outbreak [21].

Micro-organisms isolated from patients with HAI

Of the HAIs reported, 96.6% had an organism isolated, with 118 different species identified. A total of 1314 organisms were isolated from 1083 HAIs (Table II). Overall, the most frequently isolated bacterial species was *Escherichia coli* (18.4%),

Table I
Incidence of healthcare-associated infection (HAI) types by 100,000 acute occupied-bed-days (1083 cases of HAI within the two hospitals)

HAI type	Incidence of HAI types		Rank order
	Rate per 100,000 occupied bed-days	95% CI	
All HAIs	249.6	235.1–264.8	
Bloodstream infection	44.7	38.8–51.3	2
Gastrointestinal infection	39.2	33.6–45.4	4
Lower respiratory tract infection	42.2	36.4–48.6	3
Pneumonia	23.5	19.3–28.4	6
Surgical site infection	35.3	30.0–41.2	5
Urinary tract infection	51.2	44.8–58.2	1
Other[a]	13.6	10.5–17.4	7

[a] Low-number infections, including skin soft tissue, bone and joint, cardiovascular, eye–ear–nose–throat, and systemic infections. These infections made up 3% of the total HAIs but within this group there was a wide range of organs affected by this diverse group of HAIs.

Table II
Percentage of organisms identified by HAI type, for teaching and general hospitals combined

Organism/group	BSI	% HAI type						
		GI	LRI	PN	SSI	UTI	Other	Total
Gram-positive cocci	45.49	23.47	14.16	15.52	56.36	17.09	66.13	32.05
Staphylococcus aureus	14.75	1.02	8.41	8.62	22.46	1.28	30.65	10.81
Streptococcus spp.	6.56	1.02	2.20	3.45	2.53	0.43	4.84	2.82
Gram-positive cocci other	0.82	0.00	0.44	0.00	0.42	0.00	0.00	0.30
Coagulase-negative staphylococci	6.15	5.10	1.33	0.86	15.68	1.28	22.58	6.32
Enterococcus faecalis	8.61	5.10	1.33	1.72	10.17	1.28	4.84	5.02
Enterococcus faecium	7.79	8.16	0.44	0.86	4.24	3.85	1.61	4.34
Other *Enterococcus* sp.	0.82	3.06	0.00	0.00	0.85	8.97	1.61	2.44
Gram-negative cocci	0.82	0.51	13.27	10.34	0	0	0	3.42
Gram-positive bacilli	0.41	19.39	0.44	2.59	3.39	0	1.61	3.96
Clostridium difficile	0	18.88	0	0	0	0	0	2.82
Clostridium perfringens	0.41	0	0	0	0	0	0	0.08
Gram-positive bacilli other	0	0.51	0.44	2.59	3.39	0	1.61	1.07
Gram-negative bacilli	51.23	11.73	23.89	26.72	31.36	75.21	11.29	37.29
Escherichia coli	26.64	5.1	7.08	9.48	11.02	48.72	0	18.42
Klebsiella spp.	3.69	0	3.98	4.31	3.39	1.28	0	2.59
Klebsiella pneumoniae	6.15	1.53	3.1	4.31	2.97	8.12	1.61	4.34
Morganella morganii	0.41	0	0	0	1.27	0.85	0	0.46
Proteus mirabilis	1.64	0	1.33	0.86	2.54	9.4	0	2.74
Proteus spp.	0.41	0	0.44	0	1.27	0	0	0.38
Serratia marcescens	2.46	0	3.1	1.72	2.12	0.85	0	1.67
Other Enterobacterales	5.33	1.53	2.21	1.72	2.56	1.69	1.61	2.59
Acinetobacter spp.	1.64	0	0	0	0	0	1.61	0.38
Pseudomonas spp.	1.23	0.51	1.77	3.45	2.54	3.42	1.61	2.05
Other non-Enterobacterales	1.64	3.06	0.88	0.86	2.54	0	4.84	1.67
Viruses	0	40.31	36.73	29.31	0	0	8.06	15.3
Influenza	0	0	15.04	5.17	0	0	0	3.04
Parainfluenza virus	0	0	4.42	1.72	0	0	0	0.91
Norovirus	0	39.8	0	0	0	0	0	5.94
Rhinovirus	0	0	3.1	5.17	0	0	1.61	1.07
Human coronavirus[a] non-outbreak	0	0	2.65	6.9	0	0	0	1.07
Human metapneumovirus virus	0	0	2.65	3.45	0	0	0	0.76
Respiratory syncytial virus	0	0	5.75	3.45	0	0	0	1.29
Herpes simplex virus	0	0	1.77	1.72	0	0	4.84	0.68
Other virus	0	0.51	1.33	1.72	0	0	1.61	0.53
Fungi	2.05	2.55	11.5	15.52	6.78	7.69	12.9	7.31
Candida albicans	0.82	1.02	1.77	4.31	1.69	1.28	9.68	1.98
Candida other	1.23	1.53	6.64	7.76	3.39	5.98	1.61	4.03
Aspergillus spp.	0	0	1.33	2.59	0.85	0	1.61	0.68
Other fungi	0	0	1.77	0.86	0.85	0.43	0	0.61
Other	0	2.04	0	0	2.12	0	0	0.68

HAI, healthcare-associated infection; BSI, bloodstream infection; GI, gastrointestinal infection; LRI, lower respiratory tract infection; PN, pneumonia; SSI, surgical site infection; UTI, urinary tract infection.
The table reports the organisms identified by samples relating to each organ space. There are more confirmed organisms (1314) than the total number of HAIs (1083).
[a] Common type, not COVID-19 (Human.coronavirus.229E, Human.coronavirus.NL63, Human.coronavirus.OC43).

followed by *S. aureus* (10.8 %), *Enterococcus faecalis* (5.0%), *Enterococcus faecium* (4.3%), *Klebsiella pneumoniae* (4.3%), and *Clostridioides difficile* (2.8%). Among isolates examined, 15.3% were viruses (of all organisms identified influenza accounted for 3.0% of the total and norovirus 5.9%). Gram-negative bacilli were identified in 51% of all organisms from BSI, 91% of which were Enterobacterales. Gram-negative bacilli also comprised 75% of all organisms causing UTI. *E. coli* represented 48.7% of all UTI organisms and 26.6% of isolates from BSI. *Candia albicans* only represented 2% of overall isolates, but these were associated with 4.3% of isolates from pneumonia cases. Seventy of 1083 HAIs were classed as part of an outbreak [21]. Meticillin-resistant *S. aureus* (according to oxacillin resistance) was seen in 7.1% of *S. aureus* isolated from HAI. No antibiotic resistance was seen for *S. pneumoniae* or β-haemolytic streptococci (Table III).

Table III
Antibiotic susceptibilities of isolates by organism

Micro-organism	Antibiotic	No. of organisms isolated	No. of organisms reported	Susceptibility reported	Resistance reported	% resistance of reported
Staphylococcus aureus	Oxacillin	142	140	130	10	7.1%
	Teicoplanin	142	133	133	0	0
	Vancomycin	142	133	133	0	0
Streptococcus pneumoniae	Penicillin	6	6	6	0	0
	Co-amoxiclav	6	5	5	0	0
	Ciprofloxacin	6	5	5	0	0
β-Haemolytic streptococcus (Group A/B/C)	Penicillin	10	9	9	0	0
	Co-amoxiclav	10	4	4	0	0
	Ciprofloxacin	10	4	4	0	0
Enterococcus faecalis	Amoxicillin	66	58	50	8	14%
	Teicoplanin	66	55	53	2	4%
	Vancomycin	66	62	51	11	18%
Enterococcus faecium	Amoxicillin	57	54	6	48	89%
	Teicoplanin	57	52	17	35	67%
	Vancomycin	57	56	16	40	71%
Escherichia coli	Co-amoxiclav	242	237	115	122	51.5%
	Amoxicillin	242	239	87	152	63.6%
	Ceftazidime	242	234	213	21	9.0%
	Ciprofloxacin	242	236	201	35	14.8%
	Ceftriaxone	242	213	197	16	7.5%
	Gentamicin	242	236	224	12	5.1%
	Meropenem	242	236	236	0	0
	Piperacillin/tazobactam	242	235	216	19	8.1%
Klebsiella pneumoniae	Co-amoxiclav	57	56	45	11	19.6%
	Amoxicillin	57	56	2	54	96.4%
	Axtreonam	57	53	50	3	5.7%
	Ceftazidime	57	56	51	5	8.9%
	Ciprofloxacin	57	56	48	8	14.3%
	Ceftriaxone	57	52	48	4	7.7%
	Gentamicin	57	56	54	2	3.6%
	Meropenem	57	56	56	0	0
	Piperacillin/tazobactam	57	55	48	7	12.7%
Acinetobacter spp.	Ciprofloxacin	5	5	5	0	0
	Gentamicin	5	5	5	0	0
Pseudomonas aeruginosa	Ciprofloxacin	26	25	23	2	8.0%
	Levofloxacin	26	0	0	0	0
	Meropenem	26	25	22	3	12.0%
	Piperacillin/tazobactam	26	25	19	6	24.0%
Pseudomonas spp.	Ciprofloxacin	27	26	24	2	7.7%
	Ceftriaxone	27	0	0	0	0
	Levofloxacin	27	0	0	0	0
	Meropenem	27	26	23	3	11.5%
	Piperacillin/tazobactam	27	26	20	6	23.1%
	Meropenem	5	1	1	0	0

Origin of HAI

The presence of invasive devices before the onset of HAI was recorded for pneumonia, UTI and BSI (Table IV). Healthcare-associated pneumonia was associated with intubation in 40.2% of cases. UTI was associated with the presence of a urinary catheter in 37.8% of cases. Of BSI patients, 95.2% had a vascular catheter placement 48 h before the onset of their BSI. Of all BSI cases, 7.3% were assumed to be catheter-related, since phenotypically related organisms were isolated from catheter and blood. A primary infection source was identified for 16.5% of BSIs; the most common of these were UTIs (5.8% of total BSI) and GIs (5.8%).

Person: patient characteristics

Patients who developed HAI tended to be older, with 28% of all HAI found in patients aged >80 years and 71% of all HAI in patients aged >60 years. More HAIs occurred in patients who were admitted as emergency cases rather than as elective cases. Emergency cases made up 80.5% of all patients admitted to the study hospitals. There was no obvious trend in incidence

Table IV
Characteristics of HAIs, associated with invasive device use, origin of bloodstream infections ($N = 1083$ HAI cases)

Characteristic	No. of HAIs	% of total HAIs
Total no. of HAIs	1083	100%
Place where HAI became active		
HAIs present on admission	55	5.1%
Origin: same hospital	28	50.9%
Other Scottish NHS hospital	21	38.2%
Other hospital outside Scotland	6	10.9%
HAI onset during current admission	1028	94.9%
Day of HAI onset[a]		
Known date of admission	1050	
Day 1–2	117	10.8%
Day 3–4	124	11.4%
Day 5–7	180	16.6%
Day 8–14	225	20.8%
Day 15–21	113	10.4%
Post day 21	291	26.9%
Unable to obtain the date of admission	33	3.0%
Device-associated HAI		
Pneumonia total[b]	102	9.4%
Intubation 48 h before onset	41	40.2%
No intubation	61	59.8%
Urinary tract infections total	222	20.5%
Urinary catheter 7 days before of onset	84	37.8%
No urinary catheter	138	62.2%
Bloodstream infections	206	19.0%
Vascular catheter 48 h before onset	196	95.15%
No vascular catheter	10	4.85%
Origin of bloodstream infections (BSI)		
Total BSI[c]	206	100%
Catheter-related BSI[d]	15	7.3%
CVC[e]	13	6.3%
PVC[f]	2	1.0%
Source/primary infections linked to BSI[g]	34	16.5%
Pulmonary infection	4	1.94%
Urinary tract infection	12	5.83%
Surgical site infection	5	2.43%
Gastrointestinal tract infection	12	5.83%
Other infection sites	1	0.49%
Unknown origin[h]	157	76.21%

BSI, bloodstream infection; CVC, central vascular catheter; PVC, peripheral vascular catheter; CRI, catheter-related infection (with positive catheter tip microbiological results, see case definitions); CRI3, CRI with positive blood culture.

[a] HAIs with onset during current hospitalization only. Number of HAIs (1050): starting from 1083 infections, 33 cases were excluded (10 did not have a CHI number which indicates that the patients were not resident in Scotland; 7 were not linked; 16 onset not within continuous inpatient stay).

[b] Includes pneumonia subcategories PN1–PN5.

[c] Total BSI (including CRI3).

[d] % catheter-related BSI (CRI3: CRI with positive blood culture).

[e] % of total BSI[c] which is central vascular catheter-related.

[f] % of total BSI[c] which is peripheral vascular catheter-related.

[g] BSI secondary to another infection site.

[h] BSI origin was verified and confirmed to be unknown.

of HAI in the Scottish Index of Multiple Deprivation (SIMD) quintiles [22]. Appendix A, Table A.3 shows the characteristics of all admissions to the combined ECONI study hospitals. A total of 99,018 admission episodes to the study hospitals were included within the analysis.

Place: specialty of treatment

The highest HAI incidences by AOBD were for patients in intensive care units (ICUs) and high-dependency units (HDUs); most of these were in the respiratory tract (LRI and pneumonia) (Figure 1). ICU/HDU is a relatively small specialty in terms of total occupied bed-days within the study hospitals (9338) and the total number of HAIs (123 cases) was approximately half (54%) of the cases found in general surgery (226 cases). The second highest incidence was in renal medicine followed by cardiothoracic surgery. Renal medicine showed the highest incidence of BSI. In terms of total numbers, the specialties of general surgery, general medicine trauma and orthopaedic surgery and geriatric medicine (short and long stay) treat 59% of all HAI patients in the hospitals (Figure 1). These specialties have a large number of occupied bed-days and despite the actual numbers of HAI being relatively high the incidence of HAI is low. General medicine had the greatest number of admissions overall, but incidence is relatively low per AOBD (123.7 per 100,000 AOBD), which is lowest when the specialties are ranked from highest to lowest.

Time: when do HAIs occur?

There was an increase in the rate of HAI in summer months of June and July ($P < 0.0001$), largely associated with increased rates of pneumonia, LRI, SSI, and GI (Figure 2). BSI and combined 'other' infections did not exhibit a seasonal pattern. There were also winter peaks in the proportion of GI, which was mainly caused by norovirus in December and January.

HAI events occurred a median of 9 days (IQR: 4–19) after admission to hospital. A total of 40.1% of HAI occurred within seven days of admission (Figure 2). Just over one in ten HAIs (11.1%) occurred within 3 days of admission to hospital. The largest proportion of these (42.0%) were SSI, which may arise and meet the case definitions at any point up to 30 days post surgery for surgery with no implant and 90 days if surgery involves an implant.

National estimates for NHS Scotland

When the ECONI data was extrapolated for all admissions to hospital in NHS Scotland, the estimated annual number of HAI in teaching and general hospitals in Scotland was 7437 (95% confidence interval: 7021–7849). This extrapolation was based on the incidence within each specialty shown in Table I and the total AOBD within each specialty in NHS Scotland annually. This approach shown in Table V was selected as it takes account of the variation in incidence of HAI in both hospital and specialty type. When all HAI was extrapolated using total available beds, rather than varying the incidence by specialty of the occupied beds to take amount of the variation in incidence by specialty,

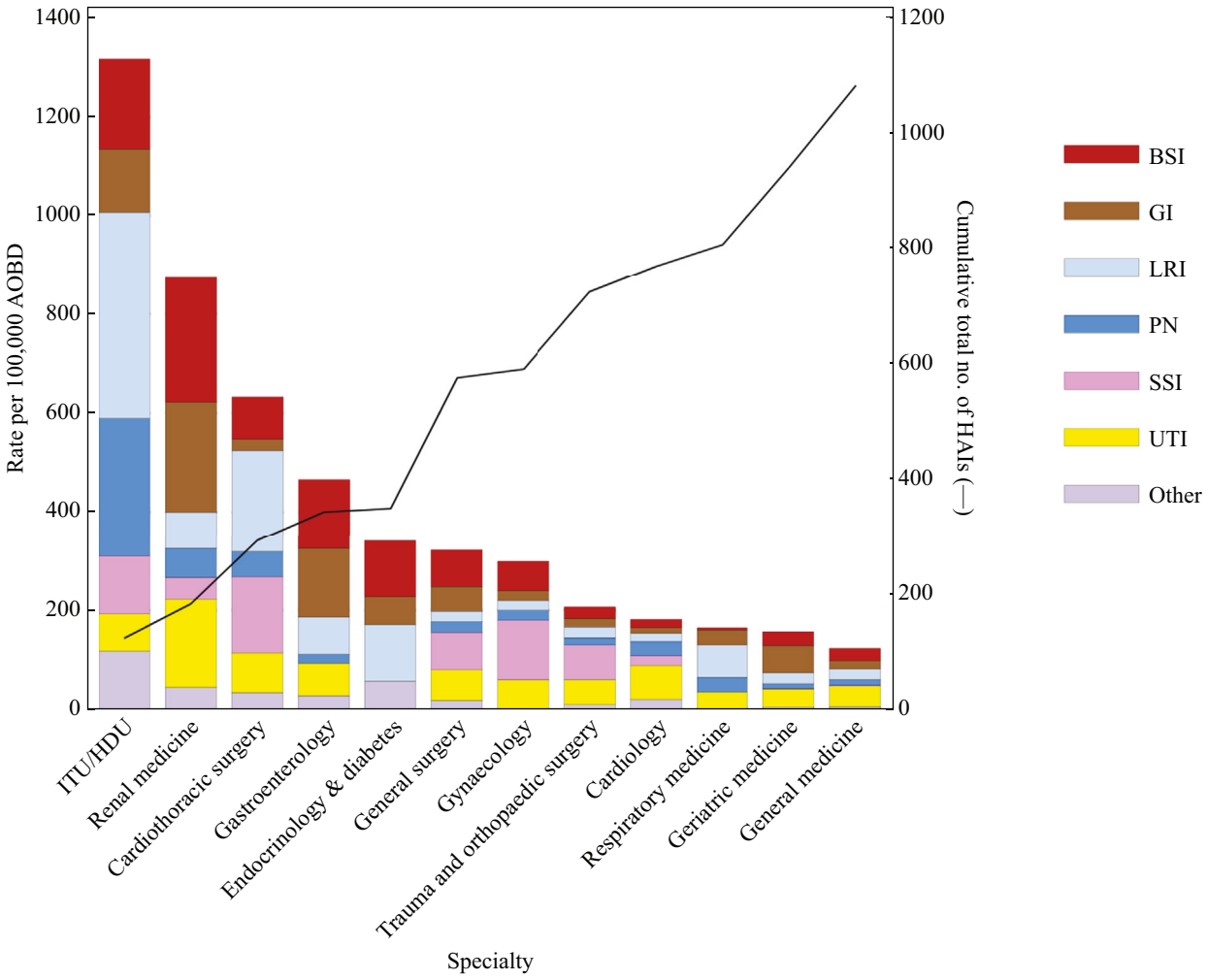

Figure 1. Incidence of HAI by specialty and distribution of HAI types by specialty. AOBD, acute occupied bed-days; ITU, intensive therapy unit; HDU, high-dependency unit; HAI, healthcare-associated infection; BSI, bloodstream infection; GI, gastrointestinal infection; LRI, lower respiratory tract infection; PN, pneumonia; SSI, surgical site infection; UTI, urinary tract infection.

the total number of annual HAIs in Scotland was estimated to be 10,594. When annual incidence was calculated based on total hospital beds but accounting for hospital type, i.e. higher incidence rate within teaching hospitals and lower within general hospitals, the estimate was 8438 HAIs per year.

Discussion

This is the first study of HAI incidence in the UK in more than 20 years [23]. Such studies are rarely done because they are resource intensive and the last decade has seen PPS predominate hospital surveillance across the globe as the main approach to estimating burden [24,25]. However, PPSs are limited, associations and risk are temporal, and biases mean that these results have been overinterpreted and may have resulted in overestimation of the true burden. Furthermore, there are limited opportunities to examine risk factors. This study provides unique insight into national HAI rates, with novel whole-hospital incidence data and record linkage data to make it more robust. The findings have international significance, since the focus of most countries in the last decade has been prevalence surveys to inform burden estimates and IPC planning. The study also has international implications for future planning of PPS and other surveillance studies. The HAI incidence was lower than previously reported, with an incidence rate of 64 per 100,000 AOBD in the general hospital and 334 per 100,000 AOBD in the teaching hospital, with an overall incidence for the combined hospitals of 250 per 100,000 AOBD. These estimates indicate that the annual HAI incidence in acute care in NHS Scotland was approximately one in every 100 patients (7437 HAIs/year). This is lower than the reported estimated incidence from prevalence studies published to date (55,307), which converted prevalence to incidence using an estimated duration of infection based on date of admission and date of survey [7,26]. The ECDC used another variation on the Rhame equation to estimate an overall incidence in NHS Scotland of 2.2% of admissions (1.5–3.2) and an overall estimate of 25,539 patients with at least one HAI annually in Scotland (16,992–36,977) [6]. There are known methodological issues with this conversion, so primary data collected with incidence data are more robust [26–28]. This means that previous incidence estimates derived from the prevalence HAI from every person in every ward, on any given day, across the NHS are an overestimate; it is likely that HAI impacts on a smaller

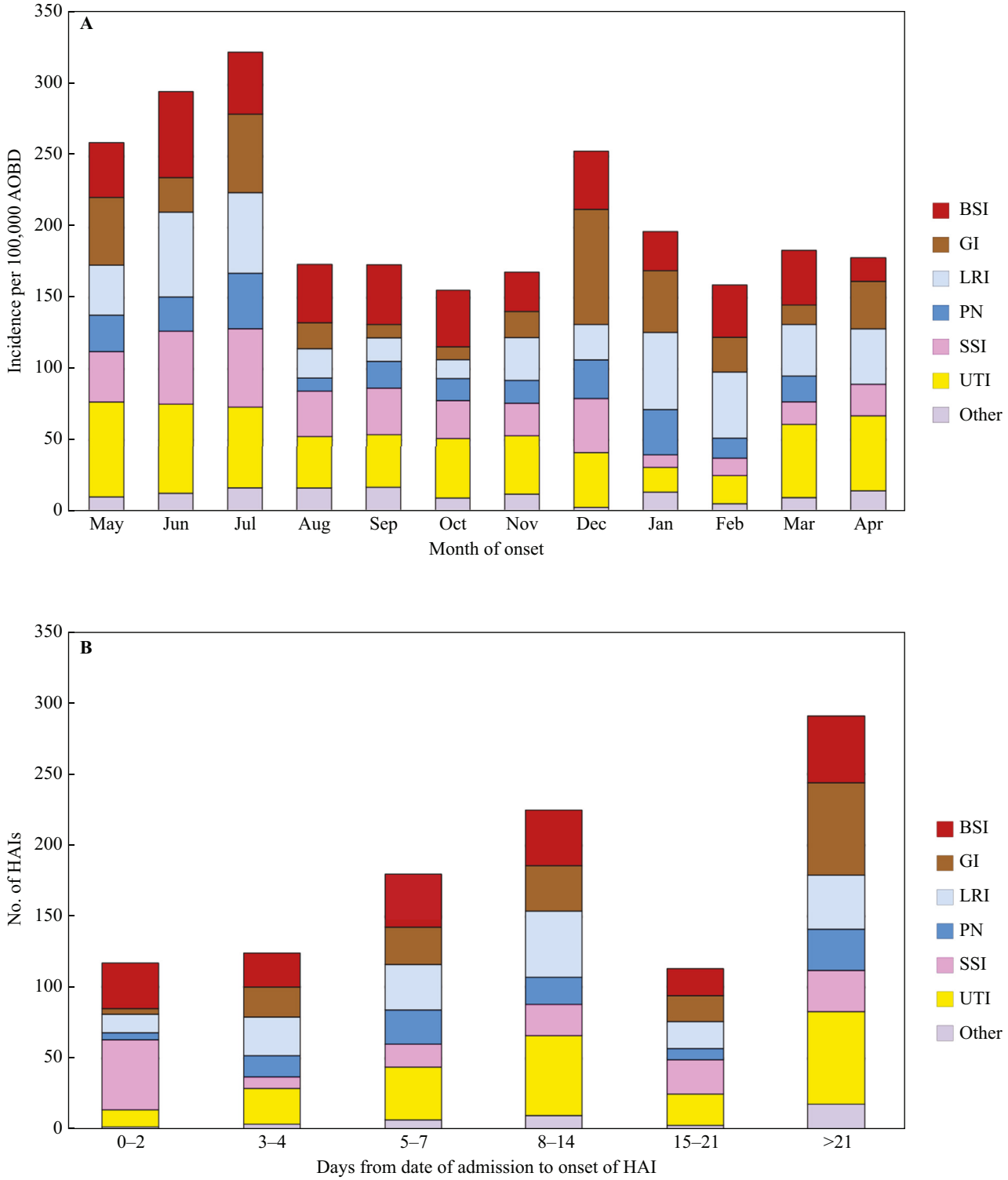

Figure 2. (A) Incidence of HAIs by type per 100,000 acute occupied bed-days (AOBDs) by month of onset. (B) Days from date of admission to onset of HAI start from 1083 HAIs. HAI, healthcare-associated infection; BSI, bloodstream infection; GI, gastrointestinal infection; LRI, lower respiratory tract infection; PN, pneumonia; SI, surgical site infection; UTI, urinary tract infection. Thirty-three cases were excluded, as date of onset and date of admission were not available.

proportion of the hospital population each year and therefore total costs are less than previously reported [7,29].

The rank order of HAI types was similar to the Scottish Point Prevalence Survey (PPS), which was performed between September and November 2016 [7]. BSI ranked higher in this incidence study. This is important because these HAIs have a high impact on morbidity and mortality [30]. The difference in rank order will be in part due to the limitations of prevalence

Table V
Estimated number of HAIs in Scotland extrapolated from ECONI using hospital and specialty incidence

HAI type	Incidence of HAI types in Scotland		Estimate of annual no. of HAIs in Scotland	
	Rate per 100,000 occupied bed-days	95% CI	Estimate	95% CI
All HAIs	187.2	176.8–197.6	7437	7021–7849
Bloodstream infection	35.0	31.3–39.5	1389	1245–1570
Gastrointestinal infection	31.6	28.2–36.3	1256	1122–1440
Lower respiratory tract	26.2	23.6–30.7	1041	937–1218
Pneumonia	15.9	13.7–19.2	630	544–764
Surgical site infection	25.8	22.8–30.5	1023	904–1210
Urinary tract infection	41.0	36.6–46.2	1628	1454–1836
Other	12.0	9.5–15.8	475	378–628

HAI, healthcare-associated infection; CI, confidence interval; ECONI, Evaluation of Cost of Nosocomial Infection study.

surveys wherein microbiology may not be available to confirm prevalent infections and bias in prevalence surveys towards those patient populations with longer length of stay (LOS). The causative organisms in both studies are very similar, with *E. coli* being the most common isolate, followed by *S. aureus*. Differences will also be due to the variation in incidence of certain organisms at different times of year. For example, norovirus was ranked fourth in order within the ECONI data set but does not appear in the top ten organisms within the prevalence survey. This has implications for choosing the best time for PPS studies in the future.

The origins of HAI show very similar patterns to those reported within the European PPS [6] (Table IV). This study reported a greater proportion of patients with vascular catheters present before developing BSI (95.1%) compared with the European prevalence survey, which reported 57.3% of cases having vascular catheters in place 48 h before the BSI onset. This is likely due to the limitations of prevalence survey methodologies with respect to the consistency of recording device use. The common use of vascular catheters within patients with BSI and the fact that 7.3% of BSIs were shown to be microbiologically linked to catheter use supports the case for the continued focus on existing vascular catheter-related infection prevention [31,32]. However, the majority of BSIs were not linked with devices and so there is a need also to further develop effective prevention measures for the most common BSI organisms (*E. coli* and *S. aureus*).

For *E. coli* the resistance percentages were broadly similar to the bacteraemia isolates reported in the Scottish national data [33]. Enterococci showed a higher proportion of resistance than reported within the Scottish One Health Antimicrobial Use and Antimicrobial Resistance (SONAAR) report for *E. faecalis* and for glycopeptide resistance in *E. faecium*. *K. pneumoniae* showed similar patterns of resistance to those shown for all isolates within the SONAAR report. *Pseudomonas aeruginosa* showed increased resistance to meropenem and piperacillin/tazobactam in the small number of samples from which it was isolated.

The rank order of primary HAI with a secondary BSI was very similar to the PPS with the most common in both studies being UTIs and GIs. Primary prevention strategies focused on UTI will not only reduce the overall number of patients with HAI but may be helpful in preventing BSI, even though only 5.8% of BSI had a laboratory confirmed primary UTI. Of patients who developed UTI, 37.8% had a urinary catheter within the 7 days preceding the UTI, which shows that there is a large proportion of patients who are not exposed to catheter use but who go on to develop UTI. This is important since successive PPS studies across Europe have identified UTI as a large burden and yet few countries have any IPC prevention activity other than that which is associated with catheter-associated urinary tract infection [6,34,35]. It may be that primary infection treatment should be the focus to prevent BSI [36]. Pneumonia contributes 9.4% of all HAI but within this study only 40% of patients were intubated within 48 h of onset, so this again reinforces the need for wider IPC measures to be implemented for healthcare-associated pneumonia [37,38].

Many countries have implemented national surveillance programmes and report SSI and ICU incidence data; some report BSI only in the ICU settings. In all cases, administrative registers are used for denominators and thus there are challenges in comparing these data [39–41]. Reporting of BSI incidence is dependent on case definitions, denominators, and methods, which differ in each surveillance data set. Due to this lack of consistency in surveillance reporting it is challenging to compare with other studies. Whereas the incidence of BSI may appear high within this study, BSI incidence reported here includes central line-associated bloodstream infection (CLABSI) along with bloodstream infections associated with other primary infections and those with undefined sources that meet the ECDC case definitions. A recent review has also indicated that CLABSI is likely underreported nationally when compared to expert review using consistently applied case definitions [42]. The specialties with the highest recorded incidence per 100,000 bed-days were ICU, renal medicine, and cardiothoracic surgery (Figure 1). Patients treated within these specialties are exposed to a range of interventions which are known to increase risk of HAI, for example a range of devices and intubation [43,44]. These high-incidence specialties treat a relatively small number of patients, and thus only contribute a smaller proportion of the total HAI cases. This is one of the challenges in relying on prevalence data alone, in that priorities may be given to high-volume areas rather than to high-risk specialties or patients [45]. The incidence within the large teaching hospital is greater than within the general hospital. Some of this is due to the difference in specialty mix between the two hospitals and the severity of cases being treated within the teaching hospital. The highest incidence specialties within both hospitals were ICUs: the teaching hospital has 25 ICU beds and 34 high-dependency beds compared with five and four, respectively, within the general hospital [13].

Figure 1 illustrates the challenges faced by infection prevention and control teams. Although certain specialties treat patients who are at increased risk of HAI, cases are distributed throughout all of the specialties served by the hospital, and to effectively ensure patient safety both the high-incidence and high-volume clinical settings should have appropriate IPC measures. Within high-incidence settings the benefit of implementing more complex or costly IPC interventions at a specialty level may have a greater benefit due to the number of HAI cases which could be prevented.

There are important findings in these data, related to seasonality and origin of HAI, which require consideration for IPC planning locally and nationally. Although only 5.1% of HAIs were present on admission to the study hospitals, 40% of these HAIs had originated in another hospital and one in ten of those from outside Scotland (Table IV). This provides important intelligence for consideration of network analysis in IPC planning and the importance of communications, at the system level, to manage HAI risk [46]. Understanding the referral networks within the system and dispersal of HAI, in patient movement and transfers, may offer a more integrated way of IPC planning. Strategic planning and information sharing at a systems level across healthcare networks are a key consideration for future IPC. The second issue is seasonality of HAI (Figure 2). This study points to some novel findings around the seasonality of pneumonia — LRI, SSI, and GI infection types being higher in the summer months, alongside the known issue of winter norovirus. The findings here also point to the importance of taking account of limitations of microbiology, risks, and seasonality in future PPS planning, especially if these data are to be used for estimating impact on length of stay and costs.

This study has limitations. Infections without laboratory-confirmed HAI may be underrepresented. Within this study, microbiology tests were used as an indicator of potential HAI for the research nurses to review against the case definitions; the samples sent to the laboratory by clinical staff may have varied dependent on infection type or clinical setting. A clinical symptom review of each patient admission could provide a more sensitive result, but this would require a daily review of each patient's notes. Underrepresentation of infections without laboratory confirmation is more likely to affect the diagnosis of pneumonia than other conditions, although ICU pneumonias are more likely to have laboratory samples [25]. UTIs may be underrepresented as some patients are unable to fully articulate signs and symptoms required to diagnose not microbiologically confirmed symptomatic HAI. As with all surveillance studies, there is a proportion of clinical infections being treated and managed as HAI without meeting the case definitions. This study only describes the epidemiology of the year in which the study was conducted; there are shifts in patient population and hospital epidemiology over time. Extrapolation of results from the two study hospitals to all acute hospitals in Scotland relies on the assumption that the two study hospitals are representative of hospitals of the same type. This was addressed by comparing the incidence rates in the study year with the prevalence reported in the last Scottish HAI PPS and examining routine data on hospital size, specialty distribution, and demographics [7,47,48]. The estimates for some of the individual HAI subtypes were also verified by comparing the estimated incidence from the ECONI study with previously published national data [49]. In both cases similar rates were obtained, providing evidence that the chosen approach was valid.

In conclusion, this is the most comprehensive study of incidence surveillance, across whole hospital populations and all types of HAI and their impact, performed anywhere in the UK for more than 20 years [23]. It is the first study of its kind in Scotland. With the addition of record linkage methods, it provides HAI estimates of country-level incidence. Studies of this type are rarely undertaken within whole hospital settings for a full year due to the cost and time required, and therefore HAI prevalence surveys have become the standard for estimating HAI burden during the last decade in Scotland, the UK, and Europe. This incidence study contributes important intelligence on HAI for local and national planning of IPC interventions, policy, and practice.

National and local IPC efforts over the last decade have rightly focused on the evidence-based prevention potential in device-related HAI. This study found a low incidence of device-related HAI in patients with HAI, but a high incidence of vascular device use, and thus continued value management in identifying IPC priorities should be considered. Consideration should be given to the oldest and highest-risk patients in hospital for whom the health impact of HAI would be greatest. Through knowledge and experience, clinical teams identify patients who are at particular risk of HAI from the start of their admission but intelligence on risk from incidence studies can be used at a hospital level to support planning and implementation of IPC measures. In addition, the adoption of a 'system thinking' approach may be helpful in managing those at high risk, those likely to have a long stay, and those effectively managing discharge planning to minimize transmission risk in and between hospitals and long-term care facilities as highlighted by the recent COVID-19 pandemic. These issues are of particular concern for patients at risk of antimicrobial resistance (AMR) infections and those who require frequent hospital care. The ECONI study has produced a data set using standard case definitions that can be used for further analysis and can support consideration of targeted IPC measures in the future. The intelligence from this study can also be used for future prevalence surveys to support HAI and AMR burden estimates.

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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.,

J.P., S.K. undertook the statistical analysis and contributed to the manuscript. SD contributed to the development of the manuscript. L.H. contributed the development of study design, protocol and data management. 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. K.K., contributed to the manuscript. 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 provided oversight of the project on behalf of the funder. 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 the 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.2021.03.031.

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