Journal of Hospital Infection 114 (2021) 32–42

Available online at www.sciencedirect.com

Journal of Hospital Infection

journal homepage: www.elsevier.com/locate/jhin

Personalized infection prevention and control: identifying patients at risk of healthcare-associated infection

S. Stewart [a,*], C. Robertson [b], S. Kennedy [c], K. Kavanagh [b], L. Haahr [a], S. Manoukian [d], H. Mason [d], S. Dancer [e,f], B. Cook [g], J. Reilly [a,h]

[a] *Safeguarding Health through Infection Prevention Research Group, Research Centre for Health (ReaCH), Glasgow Caledonian University, Glasgow, UK*
[b] *Department of Mathematics and Statistics, University of Strathclyde, Glasgow, UK*
[c] *Public Health Scotland, Glasgow, UK*
[d] *Yunus Centre for Social Business and Health, Glasgow Caledonian University, Glasgow, UK*
[e] *Department of Microbiology, Hairmyres Hospital, NHS Lanarkshire, UK*
[f] *School of Applied Science, Edinburgh Napier University, Edinburgh, UK*
[g] *Departments of Anaesthesia and Critical Care, Royal Infirmary of Edinburgh, Edinburgh, UK*
[h] *National Services Scotland (NSS), UK*

ARTICLE INFO

Article history:
Received 30 September 2020
Accepted 25 March 2021

Keywords:
Epidemiology
Hospital-acquired infection
Multivariate analysis
Adjustment
Risk
Risk factors
Logistic regression

SUMMARY

Background: Few healthcare-associated infection (HAI) studies focus on risk of HAI at the point of admission. Understanding this will enable planning and management of care with infection prevention at the heart of the patient journey from the point of admission.

Aim: To determine intrinsic characteristics of patients at hospital admission and extrinsic events, during the two years preceding admission, that increase risk of developing HAI.

Methods: An incidence survey of adults within two hospitals in NHS Scotland was undertaken for one year in 2018/19 as part of the Evaluation of Cost of Nosocomial Infection (ECONI) study. The primary outcome measure was developing any HAI using recognized case definitions. The cohort was derived from routine hospital episode data and linkage to community dispensed prescribing data.

Findings: The risk factors present on admission observed as being the most significant for the acquisition of HAI were: being treated in a teaching hospital, increasing age, comorbidities of cancer, cardiovascular disease, chronic renal failure and diabetes; and emergency admission. Relative risk of developing HAI increased with intensive care unit, high-dependency unit, and surgical specialties, and surgery <30 days before admission and a total length of stay of >30 days in the two years to admission.

Conclusion: Targeting patients at risk of HAI from the point of admission maximizes the potential for prevention, especially when extrinsic risk factors are known and managed. This study proposes a new approach to infection prevention and control (IPC), identifying

* Corresponding author. Address: Glasgow Caledonian University, Cowcaddens Road, Glasgow G4 0BA, UK. Tel.: +44 (0)1413 313536.
E-mail address: Sally.stewart@gcu.ac.uk (S. Stewart).

https://doi.org/10.1016/j.jhin.2021.03.032

those patients at greatest risk of developing a particular type of HAI who might be potential candidates for personalized IPC interventions.

Introduction

Healthcare-associated infections (HAIs) are a threat to patient safety; they affect patients in all healthcare settings contributing significantly to morbidity and mortality and cost of care [1,2]. Multiple factors contribute to risk of HAI including ageing population, complexity of therapies and emergence of antibiotic-resistant bacteria [3].

HAI describes multiple infection types that can affect any organ; these infections range from urinary tract infections to bloodstream infections (BSIs) [4]. Risk factors for these vary, and as the incidence of HAI at the hospital population level is relatively low, specific infection prevention and control (IPC) measures should be targeted at individuals at increased risk of developing particular HAIs. Identifying and understanding potential risk factors is an essential step in reducing individual risk of developing HAI. Risk factors include intrinsic characteristics of the patient and extrinsic risk factors or exposures that happen to patients during their hospital treatment. Many risk factors have been described for specific populations, for example intensive care unit (ICU) patients' risk of pneumonia [5—14]. However, these studies are by nature retrospective and include risks encountered by patients until the point that they develop HAI. Patient-centred care relies on the identification of high-risk patients on admission in order to enable effective IPC measures to be instigated from the outset. Whereas some studies have focused on extrinsic risk factors and others looked at point-of-transfer risks, some studies report whole-hospital data and a range of HAI types and risks [5,15—18]. Cheng *et al*. used a model analysing data from electronic patient records in Taiwan, recording intrinsic and extrinsic risk factors throughout the patient stay [18]. They proposed that this could be developed in future to identify patients at risk throughout their stay. This study reports a simpler approach to identify patients at increased risk of HAI on admission. A recent systematic review identified a wide range of intrinsic and extrinsic risk factors and concluded that there was a need to identify patients who are most at risk of HAI, in order to maximize patient safety [19].

This study aimed to assess the relative risk of developing the most frequently occurring HAI types in hospitals. The risk factors included are based on information that would be available on admission and could potentially be used to tailor interventions to manage specific patient risk of HAI. They include a combination of intrinsic and extrinsic factors to which patients have been exposed in the two years before their current admission.

Methods

Study design

The Evaluation of Cost of Nosocomial Infection (ECONI) study was an observational incidence surveillance study. The primary outcome measure was HAI defined by the internationally recognized European Centre for Disease Prevention and Control (ECDC) HAI case definitions [4]. Denominator data were collected via routine data sets and linked to the primary data collected on patients who developed HAI. A full list of data items obtained from routine data sets is shown in Appendix Table A2.

Setting

This study was undertaken within a teaching hospital and a general hospital in Scotland for one year ending June 2019. These settings 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, HAI prevalence, patient mix and rurality. For the two selected hospitals there were 107,244 inpatient admissions in 2014—15 when the study was being planned [20,21]. During the study period the large teaching hospital had 981 beds including 25 intensive care beds (16 general, and nine cardiothoracic), and 33 high-dependency beds (13 general, eight cardiothoracic, and 12 transplant and renal). The large general hospital had 492 beds including five intensive care and four high-dependency beds [22,23].

Participants

All adult overnight inpatient admissions were included within the denominator. Patients admitted as a day case to a study hospital or treated in accident and emergency and discharged without overnight admission were excluded.

Data collection

ECDC HAI epidemiological case definitions were used to define HAI as outcome variable [4]. ECONI study research nurses employed within the participating hospitals reviewed all positive reports from the hospital microbiology databases each day, which highlighted patients with suspected HAI. The patient information systems were then reviewed to establish whether the suspected cases met the ECDC HAI case definitions. These data sources included: patient management systems (TrakCare); prescribing systems; IC (infection control) net; medical and nursing notes; and direct observation. Cases meeting the ECDC HAI case definitions were recorded on a bespoke REDCap database [24,25]. This incidence data set included: hospital, HAI type, date of onset, causative organism, and antibiotic susceptibilities, along with the patients' Community Health Index number (CHI) [22]. CHI is the unique identifier for all patients registered for healthcare in NHS Scotland and was used to link patient records from routine data sources to the denominator record. The CHI number recorded by the ECONI research nurses was used to identify HAI cases within the incidence cohort and all admissions were classified as HAI admissions and non-HAI admissions. HAI admissions contained one or more episodes of HAI. The selection of covariates was based on risk factors identified for developing HAI in a systematic review and meta-analysis [19].

Data items collected through record linkage

The denominator for the incidence cohort study was all hospital stays containing one or more episodes of care in a study hospital within the study period, and was identified from Scottish Morbidity Records 'SMR01'. This data set includes dates and durations of all admissions and discharges to acute hospitals [21].

Data on all eligible inpatients included: date of admission and discharge, specialty, diagnosis for admission (International Classification of Diseases, 10th Revision: ICD-10), surgery defined by Office of Population Censuses and Surveys Classification of Surgical Operations and Procedures (OPCS)-4.8 in two years before admission and during admission, number and location of episodes of care, pre-admission outpatient attendances and surgical interventions in the year before admission [26,27]. The Scottish Index of Multiple Deprivation (SIMD) 2016 quintiles for Scotland were mapped to the National Records of Scotland (NRS) 2019 Scottish Postcode Directory and linked using the SMR01 patient postcode [28]. Charlson Comorbidity Index (CCI) values were calculated using ICD-10 V4 codes from all available SMR01 diagnosis fields, and scores divided into mild (1–2), moderate (3–5), and severe (≥6) categories for analysis [29,30]. A bespoke specialty group was derived using a combination of significant facility of treatment and specialty of consultant caring for the patients. These groups were high-dependency unit (HDU); intensive care unit (ICU); medicine (MED); obstetrics and gynaecology (OBGYN); all surgical specialties were combined (SUR). A bespoke group of comorbidities was derived based on the ICD-10 codes within SMR dataset. These included diabetes ICD-10 codes (E08–E14); chronic renal failure (CRF) (N17–N19); cardiovascular disease (I00–I99); cancers/malignant neoplasms (C00–C96); chronic pulmonary disease (COPD) (J40–J47); and nervous system diseases (G00–G99). These all referred to admissions prior to the admission episode analysed in the study.

The number of outpatient hospital visits and any outpatient procedures within the year preceding their admission to hospital were taken from the SMR00 data set, which records outpatient attendances [31]. Linkage to community dispensed prescribing via the 'Prescribing Information System for Scotland' (PIS) provided information on antibiotic exposure in the year before admission [32]. Details of all of the risk factors included in the model are outlined within the Supplementary Appendix. Antibiotic exposure refers to all community dispensed antibiotics and is expressed as the cumulative number of defined daily doses (DDDs) dispensed in the year before admission [33]. Time from when the last antibiotic was taken to admission was calculated. The date corresponding to the end of the antibiotic course was estimated by adding the number of DDDs to the dispensed date, and time to admission calculated in days as the duration from the end of course to admission. Time was set to zero where admission occurred before the estimated last day of taking the antibiotic.

Statistical methods

Each hospital stay contributed once to the analysis. A patient who was readmitted within the study period could contribute more than one stay to the denominator. Admissions with an onset of HAI on or before the date of admission or a date of onset of HAI that did not occur within an inpatient stay were excluded. Episode records within the SMR01 data set were created when a patient was discharged. Patients who remained in hospital at the time of the analysis would not yet have generated a discharge record and were also excluded. Linkage to the routine data sets was undertaken 90 days after the end of the study data collection period to allow for the time lag in data being available for analysis. Records with no valid CHI ($N = 10$) could not be linked and were excluded. Where a patient's admission contained more than one HAI, the first HAI was used to group the HAI type. The data, sourced from SMR01, were largely complete as these are mandatory data fields that are recorded for all patients [34]. SIMD was linked using patient postcode; where this was missing ($N = 340$) SIMD was categorized as 'unknown'.

Thirty-two potential risk factors were included within the analysis, and were based on biological plausibility and previously proposed factors within the existing literature [19,20]. This initial set of factors was included within a series of univariate analyses to identify predictors significantly associated with developing HAI. A test for trend was performed for continuous variables by comparing a linear regression model containing the only variable on its own against the null (intercept only) model using likelihood ratio test. No linear trends were identified. Backwards stepwise model selection was performed to identify those risk factors associated with HAI at the 5% significance level. Statistical significance of individual variables was evaluated using Wald's test, and likelihood ratio tests were used to compare nested models in the model build procedure.

A sequential approach was developed when building the model. Risk factors were split into three conceptual themes for modelling to help focus selection: m1, demographics; m2, factors pertaining to the denominator stay; and m3, factors pertaining to the period before admission to the denominator stay. The models were run sequentially, with m2 consisting of those factors identified in the m1 best-fitting model plus additional m2 factors, and m3 consisting of those factors identified in the m2 best-fitting model plus additional m3 factors. Details of the factors included within each model are described in detail in Appendix Table A2. The version retained for multivariate modelling was identified via the lowest Akaike information criterion (AIC) score from the previous best-fitting adjusted model. The factors included within the final model were then used within an adjusted analysis to evaluate the relative risk of the six most frequently occurring HAI types. A multinomial model was run to investigate the relative risk of developing six specific HAI types. All statistical analysis was performed using R software (version 3.5.1) [35].

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

During the study period there were a total of 99,018 adult overnight admissions. After the application of statistical

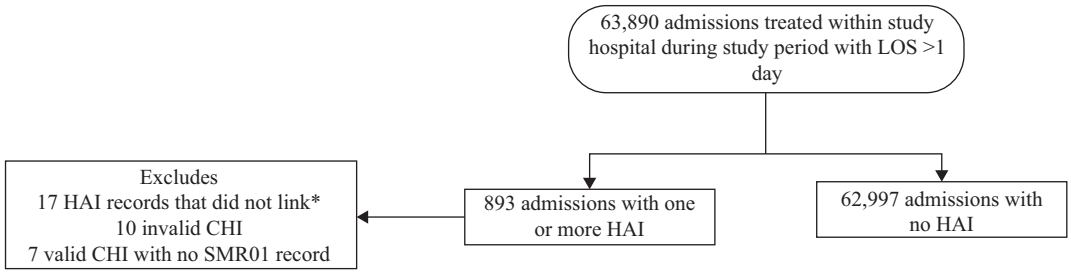

Figure 1. CONSORT diagram for inpatient stays included within the cohort study risk analysis. *Ten patients did not have valid Community Health Index number (CHI; non-Scottish residents), seven patients had no Scottish Morbidity Records (SMR01) available (still in hospital or transcription error). LOS, length of stay; HAI, healthcare-associated infection.

restrictions, the analysis included 63,890 eligible admissions to the study hospitals during the study period. There were 44,399 for the teaching hospital and 19,491 for the general hospital (Figure 1). A total of 893 admissions had one or more HAI, with 822 in the teaching hospital and 71 within the general hospital. Overall incidence was 1.4% with 1.9% within the teaching hospital and 0.4% in the general hospital (reported elsewhere [36]).

Table I shows the numbers and percentage of the risk factors included in the final multivariate model within these inpatient stays. Patients aged >60 years made up 61% of admissions. There were similar numbers of males and females. More than half of the admissions had been admitted to hospital at least once in the preceding two years (54.5%) and more than one-tenth (12.8%) were patients who had been in hospital for >30 days in the preceding two years. SIMD category two (second most deprived quintile) was the most frequently occurring (26.3%). More than three-quarters of admissions (77.9%) were emergency admissions. Descriptive frequencies and percentages of all potential risk variables included in the analysis are shown in Appendix Table A1.

Table I shows the unadjusted and adjusted relative risk (RR) and 95% confidence interval (CI). Comparing within variable groups, patients admitted to a general hospital had significantly lower risk of developing HAI compared with those in the teaching hospital. Risk of developing HAI increased with age, with those aged >80 years showing an RR of 2.47 (CI: 1.82–3.40) compared with those aged <40 years. The highest risk, adjusted for the effects of all other risk factors, was admission to an ICU specialty compared with general medicine (RR: 4.11; 95% CI: 3.34–5.02). This was followed by admission to an HDU specialty (RR: 2.70; 95% CI: 2.08–3.47) compared with a general medical specialty, those with chronic renal failure (RR: 2.19; 95% CI: 1.88–2.54) compared with those without the condition and emergency admissions compared with elective (RR: 2.0; CI: 1.64–2.46). There was an increased risk associated with surgeries within ≤30 days prior to admission (RR: 1.86; 95% CI: 1.49–2.32), and prior hospital stays of more than two weeks during the previous two years (1.37; 95% CI: 1.08–1.73 for 15–30 days; increasing to RR: 1.65; 95% CI: 1.34–2.04 for >30 days).

Despite showing no association at this point of analysis, sex was retained throughout the analysis as it was considered a clinically important patient characteristic, and later was shown to relate to specific HAI types. Patients in the two least deprived SIMD categories were less likely to develop HAI during their hospital stay than those in the most deprived.

Table II shows the adjusted risk by HAI type. There was a reduced risk of onset of any HAI type during a stay in the general hospital compared with the teaching hospital, although the small numbers in the general hospital studied, when analysed by infection type, may reduce the power to accurately detect associations for some infections.

For BSI the strongest associations were seen in patients previously diagnosed with chronic renal failure (RR: 4.73; 95% CI: 3.38–6.63) and cancer (3.24; 2.14–4.91), in emergency admissions (3.38; 1.97–5.79) or admission to HDU specialty, and an increased risk with age. BSI showed an increased risk (2.86; 1.31–6.25) in those aged >70 years relative to those aged <40 years.

Gastrointestinal infection (GI) also showed an increased risk in those aged >70 years, and in patients aged >80 years the risk was a factor of 5.22 (95% CI: 2.18–12.47) greater than that of those aged <40 years. Emergency admissions showed a 2.36 increase in RR (CI: 1.26–4.43). Patients with diabetes, chronic renal failure, and cancer all showed an increased risk of GI along with those with hospital stays of more than one week in the two years preceding denominator admission. Patients with total length of stay (LOS) >8 days in the two years before admission had an increased RR of GI infection; patients with LOS >30 days had three times greater risk (3.07; 1.79–5.28) than patients with no hospital stay in the previous two years.

There was an increased risk of lower respiratory tract infections (LRI) (RR: 9.86; 95% CI: 6.54–14.88) and pneumonia (19.56; 10.92–35.02) in those with an ICU admission. HDU patients had an increased risk relative to medical patients of LRI and pneumonia 3.53 (2.01–6.18) and 4.63 (1.90–11.30) respectively. Age showed less of an effect on relative risk of developing LRI or pneumonia. Total length of stay >30 days in the preceding two years was significant for both LRI (1.98; 1.17–3.35) and pneumonia (3.56; 1.68–7.55).

Although there was some evidence of a reduced risk in the intermediate compared with most deprived SIMD categories for those with a surgical site infection (SSI), there was no clear linear trend. There was an increased risk of SSI associated with time from last surgery to admission, with those having surgery within the 30 days before admission having a risk 6.28 times that of those not having surgery. There was no clear pattern observed in associations with time from surgery for other HAI types. Patients who had recent surgery are at increased risk of developing SSI on a subsequent admission. This is greatest during the first 30 days after surgery (RR: 6.28; 95% CI: 3.60–10.95) but an increased risk is shown in the period from

Table I
Demographics, univariate and multivariate risk ratios, and potential confounding variables for HAI within the final multivariate model

Variable	Group	No. of admissions eligible for study (variable %)	No. of HAIs (group %)	Univariate RR (95% CI)	Multivariate best-fitting RR (95% CI)
Hospital (first study hospital in stay)	Teaching	44,399 (69.5)	822 (1.9)	1	1
	General	19,491 (30.5)	71 (0.4)	0.20 (0.15–0.25)	0.16 (0.12–0.20)
Age group (years)	<40	9252 (14.5)	53 (0.6)	1	1
	40–49	6105 (9.6)	65 (1.1)	1.86 (1.30–2.67)	1.59 (1.11–2.29)
	50–59	9638 (15.1)	137 (1.4)	2.48 (1.81–3.40)	1.97 (1.44–2.74)
	60–69	11,540 (18.1)	157 (1.4)	2.37 (1.74–3.24)	1.76 (1.29–2.44)
	70–79	13,451 (21.1)	222 (1.7)	2.88 (2.14–3.88)	2.19 (1.62–3.01)
	≥80	13,904 (21.8)	259 (1.9)	3.25 (2.42–4.36)	2.47 (1.82–3.40)
Sex	Male	30,145 (47.2)	442 (1.5)	1	1
	Female	33,745 (52.8)	451 (1.3)	0.91 (0.80–1.04)	1.03 (0.90–1.17)
SIMD (1: most deprived; 5: least deprived)	1	12,705 (19.9)	177 (1.4)	1	1
	2	16,824 (26.3)	271 (1.6)	1.16 (0.96–1.40)	1.05 (0.88–1.27)
	3	12,088 (18.9)	157 (1.3)	0.93 (0.75–1.15)	0.84 (0.68–1.04)
	4	10,338 (16.2)	124 (1.2)	0.86 (0.69–1.08)	0.74 (0.59–0.93)
	5	11,595 (18.1)	160 (1.4)	0.99 (0.80–1.22)	0.77 (0.62–0.95)
	Unknown	340 (0.5)	4 (1.2)	0.84 (0.32–2.26)	0.85 (0.26–1.97)
Cancer (denominator stay)	No	59,206 (92.7)	780 (1.3)	1	1
	Yes	4684 (7.3)	113 (2.4)	1.83 (1.51–2.23)	1.72 (1.40–2.09)
Cardiovascular disease (denominator stay)	No	39,566 (61.9)	425 (1.1)	1	1
	Yes	24,324 (38.1)	468 (1.9)	1.79 (1.57–2.04)	1.40 (1.22–1.62)
Chronic renal failure (denominator stay)	No	56,278 (88.1)	621 (1.1)	1	1
	Yes	7612 (11.9)	272 (3.6)	3.24 (2.81–3.73)	2.19 (1.88–2.54)
Diabetes (denominator stay)	No	57,385 (89.8)	748 (1.3)	1	1
	Yes	6505 (10.2)	145 (2.2)	1.71 (1.43–2.04)	1.26 (1.05–1.51)
Admission type (denominator stay)	Elective	14,149 (22.1)	125 (0.9)	1	1
	Emergency	49,741 (77.9)	768 (1.5)	1.75 (1.45–2.11)	2.00 (1.64–2.46)
Specialty (admission to first study hospital in denominator stay)	MED	35,158 (55.2)	387 (1.1)	1	1
	HDU	1764 (2.7)	71 (4.2)	3.66 (2.85–4.69)	2.70 (2.08–3.47)
	ICU	2761 (4.2)	124 (4.7)	4.08 (3.35–4.98)	4.11 (3.34–5.02)
	OBGYN	1774 (2.8)	12 (0.7)	0.61 (0.35–1.09)	1.21 (0.63–2.08)
	SUR	22,433 (35.1)	299 (1.4)	1.21 (1.04–1.41)	1.67 (1.43–1.96)
Time since last surgery (days to admission)	None[a]	35,656 (55.8)	406 (1.1)	1	1
	≤30	4523 (7.1)	135 (3.0)	2.62 (2.16–3.18)	1.86 (1.49–2.32)
	31–90	5250 (8.2)	105 (2.0)	1.76 (1.42–2.17)	1.29 (1.01–1.62)
	91–180	5026 (7.9)	82 (1.6)	1.43 (1.13–1.81)	1.19 (0.92–1.52)
	≥181	13,435 (21.0)	165 (1.2)	1.08 (0.90–1.29)	0.96 (0.79–1.17)
Total length of stay in 2 years to admission (days)	0	29,083 (45.5)	307 (1.1)	1	1
	1–2	6763 (10.6)	82 (1.2)	1.15 (0.90–1.46)	1.11 (0.86–1.42)
	3–7	8231 (12.9)	86 (1.0)	0.99 (0.78–1.26)	0.85 (0.66–1.09)
	8–14	5681 (8.9)	94 (1.7)	1.57 (1.25–1.97)	1.19 (0.93–1.52)
	15–30	5978 (9.4)	119 (2.0)	1.89 (1.53–2.33)	1.37 (1.08–1.73)
	>30	8154 (12.8)	205 (2.5)	2.38 (2.00–2.84)	1.65 (1.34–2.04)

HAI, healthcare-associated infection; RR, relative risk; CI confidence interval; IMD, Scottish Index of Multiple Deprivation. Bespoke specialties: HDU, high-dependency unit; ICU, intensive care unit; MED, medicine; OBGYN, obstetrics and gynaecology; SUR, all surgical specialties.
The full tables including factors not included within the final multivariate model are available in the Supplementary Appendix.
[a] Patients did not have a surgery as defined by Office of Population Censuses and Surveys Classification of Surgical Operations and Procedures within the two years preceding the admission.

31–90 days (2.75; 1.45–5.21). It is important to note that the cohort study analysis did not include surgery within the current admission.

Urinary tract infection (UTI) showed an increased RR with age, with those aged >80 years having five times the risk of those aged <40 years (RR: 5.13; 95% CI: 2.26–11.65). There was an increased risk in emergency compared with elective admissions for patients with UTI. There was 67% increased risk of UTI onset during a hospital stay in females compared with males. This was the only HAI type which showed an increased RR for either sex.

Table II
Adjusted risk ratios (95% confidence intervals) for the risk of developing one of six HAI types during an inpatient stay in hospital, based on the multivariate final model

Variable	Group	BSI	GI	LRI	PN	SSI	UTI
Hospital (first study hospital in stay)	Teaching	1	1	1	1	1	1
	General	0.11 (0.06–0.21)	0.02 (0.01–0.10)	0.01 (0.00–0.08)	0.10 (0.03–0.26)	0.47 (0.30–0.75)	0.19 (0.12–0.31)
Age group (years)	<40	1	1	1	1	1	1
	40–49	1.55 (0.60–4.06)	2.84 (1.08–7.52)	1.72 (0.76–3.86)	2.23 (0.66–7.55)	0.94 (0.40–2.24)	1.67 (0.60–4.63)
	50–59	2.09 (0.91–4.78)	1.92 (0.73–5.04)	2.10 (1.01–4.36)	2.76 (0.90–8.49)	1.72 (0.86–3.44)	2.71 (1.13–6.50)
	60–69	2.13 (0.95–4.78)	1.93 (0.75–4.93)	1.49 (0.71–3.14)	2.37 (0.77–7.29)	1.26 (0.62–2.60)	2.95 (1.26–6.94)
	70–79	2.86 (1.31–6.25)	2.58 (1.05–6.37)	1.93 (0.93–3.99)	2.01 (0.63–6.35)	1.81 (0.91–3.61)	3.56 (1.55–8.18)
	≥80	2.33 (1.05–5.18)	5.22 (2.18–12.47)	1.85 (0.87–3.93)	2.87 (0.91–9.07)	0.96 (0.43–2.14)	5.13 (2.26–11.65)
Sex	Male	1	1	1	1	1	1
	Female	0.87 (0.63–1.19)	0.84 (0.60–1.19)	0.87 (0.63–1.20)	0.95 (0.60–1.51)	0.88 (0.61–1.28)	1.67 (1.23–2.26)
SIMD (1: most deprived; 5: least deprived)	1	1	1	1	1	1	1
	2	1.35 (0.85–2.15)	1.22 (0.75–2.01)	1.17 (0.73–1.88)	0.91 (0.48–1.74)	0.78 (0.48–1.25)	0.96 (0.64–1.46)
	3	0.96 (0.56–1.63)	0.85 (0.47–1.51)	1.07 (0.64–1.80)	1.19 (0.62–2.28)	0.50 (0.28–0.91)	0.75 (0.47–1.21)
	4	0.81 (0.45–1.44)	0.96 (0.54–1.71)	0.77 (0.43–1.39)	0.65 (0.29–1.44)	0.54 (0.30–0.97)	0.64 (0.38–1.06)
	5	0.95 (0.56–1.60)	0.75 (0.42–1.32)	0.94 (0.55–1.59)	0.48 (0.21–1.09)	0.57 (0.32–1.02)	0.80 (0.51–1.25)
	Unknown	1.49 (0.20–11.17)	1.64 (0.22–12.34)	1.66 (0.38–7.25)	-	-	-
Cancer (denominator stay)	No	1	1	1	1	1	1
	Yes	3.24 (2.14–4.91)	1.72 (1.03–2.89)	2.19 (1.33–3.59)	1.87 (0.92–3.80)	0.84 (0.45–1.57)	1.32 (0.79–2.21)
Cardiovascular disease (denominator stay)	No	1	1	1	1	1	1
	Yes	1.39 (0.99–1.94)	0.68 (0.47–0.98)	1.21 (0.85–1.72)	1.47 (0.87–2.48)	2.02 (1.34–3.02)	2.23 (1.63–3.07)
Chronic renal failure (denominator stay)	No	1	1	1	1	1	1
	Yes	4.73 (3.38–6.63)	2.18 (1.49–3.18)	2.20 (1.53–3.17)	1.51 (0.87–2.63)	1.59 (0.98–2.58)	1.92 (1.37–2.70)
Diabetes (denominator stay)	No	1	1	1	1	1	1
	Yes	1.18 (0.77–1.81)	1.64 (1.05–2.56)	1.80 (1.19–2.70)	0.76 (0.36–1.62)	0.79 (0.44–1.42)	1.15 (0.76–1.76)
Admission type (denominator stay)	Elective	1	1	1	1	1	1
	Emergency	3.38 (1.97–5.79)	2.36 (1.26–4.43)	1.02 (0.66–1.59)	1.56 (0.79–3.10)	1.88 (1.19–2.96)	2.91 (1.79–4.74)
Specialty (admission to first study hospital in denominator stay)	MED	1	1	1	1	1	1
	HDU	2.90 (1.65–5.08)	1.70 (0.82–3.52)	3.53 (2.01–6.18)	4.63 (1.90–11.30)	11.18 (4.06–30.79)	1.38 (0.60–3.23)
	ICU	1.40 (0.69–2.86)	1.44 (0.61–3.39)	9.86 (6.54–14.88)	19.56 (10.92–35.02)	17.90 (7.59–42.21)	1.23 (0.61–2.49)
	OBGYN	1.21 (0.28–5.20)	–	0.37 (0.05–2.79)	1.36 (0.17–10.77)	22.43 (6.96–72.31)	1.75 (0.52–5.87)
	SUR	1.81 (1.26–2.60)	0.75 (0.49–1.16)	0.63 (0.39–1.03)	1.07 (0.53–2.16)	19.28 (9.58–38.79)	2.04 (1.48–2.80)
Time since last inpatient surgery (days to admission)	None[a]	1	1	1	1	1	1
	≤30	1.70 (0.99–2.94)	1.80 (1.03–3.15)	0.68 (0.34–1.38)	1.66 (0.78–3.53)	6.28 (3.60–10.95)	1.53 (0.88–2.66)
	31–90	0.97 (0.52–1.80)	1.26 (0.70–2.25)	0.81 (0.44–1.50)	1.19 (0.54–2.62)	2.75 (1.45–5.21)	1.42 (0.84–2.42)
	91–180	1.08 (0.57–2.04)	1.40 (0.78–2.51)	1.15 (0.65–2.05)	0.67 (0.25–1.83)	1.38 (0.63–3.03)	1.42 (0.82–2.43)

(*continued on next page*)

Table II (*continued*)

Variable	Group	BSI	GI	LRI	PN	SSI	UTI
	≥181	1.23 (0.79–1.92)	0.75 (0.45–1.24)	0.83 (0.52–1.34)	0.66 (0.32–1.36)	0.92 (0.47–1.81)	1.08 (0.72–1.63)
Total length of stay in 2 years to admission (days)	0	1	1	1	1	1	1
	1–2	1.16 (0.67–2.01)	0.54 (0.19–1.54)	1.27 (0.72–2.24)	2.74 (1.31–5.73)	1.09 (0.54–2.19)	0.87 (0.51–1.50)
	3–7	0.66 (0.36–1.19)	1.42 (0.74–2.73)	0.54 (0.26–1.11)	1.33 (0.56–3.16)	1.14 (0.60–2.16)	0.67 (0.39–1.15)
	8–14	0.82 (0.44–1.51)	2.12 (1.13–3.99)	1.49 (0.83–2.67)	1.42 (0.53–3.76)	1.54 (0.81–2.96)	0.72 (0.40–1.29)
	15–30	0.99 (0.56–1.72)	2.95 (1.66–5.24)	1.48 (0.82–2.67)	2.12 (0.89–5.07)	1.17 (0.58–2.37)	1.02 (0.62–1.68)
	>30	1.14 (0.69–1.88)	3.07 (1.79–5.28)	1.98 (1.17–3.35)	3.56 (1.68–7.55)	1.65 (0.87–3.13)	1.11 (0.71–1.74)

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; SIMD, Scottish Index of Multiple Deprivation. Bespoke specialties: HDU, high-dependency unit; ICU, intensive care unit; MED, medicine; OBGYN, obstetrics and gynaecology; SUR, all surgical specialties.

[a] No surgery in previous two years.

Discussion

Identifying patients who are at greater risk of developing HAI at the start of their hospital stay and managing their care to optimize infection prevention is critical. HAI in the hospital population is a relatively infrequent event, with less than 2% of admissions developing HAI during their stay within the ECONI study [36]. This measure of disease frequency is only useful if it can be used to prevent HAI following admission to hospital. Extrinsic risk factors, such as clinical device insertion, are well established in the literature but illustrated only a small proportion of all infections in the ECONI study [36]. Previous studies have tended to focus on specific HAIs, types, causative organisms, or risk factors [19]. However, identifying risk factors that are known at the start of a patient's admission is more valuable because this allows targeted IPC measures to be implemented early [3]. This study provides a novel whole-hospital analysis of the factors that increase the risk of HAI, and individual HAI types at the point of admission. The findings have important implications for hospital IPC strategy nationally and locally. This should inform targeting interventions to patients in selected specialties, with the greatly increased risk of developing HAI or a particular HAI type. The opportunity to undertake these types of analyses is rare as data collection is intensive and costly.

The greatest risk factors for development of any HAI were: being treated in a teaching hospital, increasing age, emergency admission and comorbidities of cancer, cardiovascular disease, chronic renal failure, and diabetes. There are differences in teaching and general hospitals in terms of severity of illness of patients and complexity of treatments provided for those patients. Previous studies have shown there to be a higher risk of infection in larger teaching hospitals [37–39]. Comparisons tend to focus on the difference in prevalence of HAI between acute care, combining general and teaching hospitals and primary care combining community and long-stay hospitals [20,40]. Whole-hospital incidence studies are rare and a previous study within the UK focused on a single general hospital [41]. Many of these factors have featured in similar studies to date. However, hospital presentation and socioeconomic status have not been identified in the latest systematic review and require further research [19]. This may be because previous studies have not considered risk for all HAIs at the point of admission, but have retrospectively considered all risks for the entire inpatient stay. Further, the focus of many papers continues to be on those risk factors that are modifiable, rather than considering how best to manage those factors, from an IPC perspective, which cannot be modified.

Hospital type and specialty are an important consideration for prioritizing organizational IPC resources based on risk [42]. In addition, consideration of the historical patient pathway to the current admission is essential. Patients with more than 15 days total stay in hospital, during the two years before their current admission, made up 22.2% of all admissions and those with >30 days were 12.8% of all admissions. Patients at risk of readmissions are linked to long-term conditions and frailty, or emergency admission in younger patients [43]. Previous studies have found that length of stay in older medical patients was related to functional status score, illness severity, cognitive score, poor nutrition, comorbidity score, diagnosis or presenting illness, polypharmacy, age, and gender [44]. With the

move from hospital care to managing patients with complex needs in the community, there is clear potential for reduction in both number and length of hospital stay to reduce risk of HAI.

Most studies of HAI identify age as a risk factor, in line with the findings here. Older adults are vulnerable to a range of adverse events within the hospital setting compared with younger patients, including malnutrition and pressure ulcers [45–48]. These patients have an increased incidence of comorbidities [49], multiple drugs, and impaired motor and sensory and immune function [50,51]. In line with previous studies, older age increased the relative risk for BSI, GI, and UTI [15,52–54]. The increasing risk of HAI with age, especially in those aged >70 years, points to a need for risk assessment for HAI at point of admission, particularly given the projected 34% increase in the population aged ≥75 years by 2030 in the UK and what this means for risk of HAI and need for refocused IPC in hospitals [55]. For example, specific interventions, that may appear costly prevention measures if implemented at a whole-hospital level, could be targeted to a group of patients who are known to be vulnerable to infection and who have poorer outcomes if they develop HAI.

Multimodal prevention of UTI – the HAI type on which the effect of age is greatest – has been a focus for some years in the form of care bundles for all catheterized patients [56]. There has been a great deal of research into device-related UTI over the last 10 years, especially in relation to antimicrobial materials used in catheters; and although evidence exists for efficacy, there is very limited literature on the cost-effectiveness of infection prevention interventions [57,58]. Despite the increased cost of these specialized IPC measures, if overall numbers of infections are reduced significantly and their use is limited to patients who are likely to benefit the most, it is possible that they may well be cost-effective [59].

There is a considerable overlap in the factors predicting extended LOS and risk of HAI, many of which contribute to overall frailty of the patient. Incidence, bed-day use and cost of HAI are often compared with other diseases in the literature, showing that cancers, cardiovascular diseases, and diabetes achieve greater recognition and funding than HAI, when HAI is a similar burden [60]. However, this study has shown that such a 'comparative approach' is a rather simplistic way of looking at the problem [60,61]. The patients with these conditions are the very same patients who are most at risk of HAI.

This study has shown that, for several HAI types, the factors affecting development of HAI that could be identified on admission include some data not currently routinely available to clinical teams. A potential limitation of this risk factor analysis, and of national data sets more broadly, is the exclusion of devices present on admission as a risk factor. However, this is likely to be a small proportion of all admissions to hospital. There is a need for further development of current patient management systems in order to fully achieve this potential. In order to develop the potential for risk assessment on admission, we recommend that hospital admission systems not only include the risk factors identified within this study but in addition record devices *in situ*. This study demonstrates the potential of creating risk assessment tools on admission, if these data are available, for identifying those most at risk of HAI and prioritizing additional IPC measures in their care pathways to mitigate that risk.

The ECONI surveillance study included all patient admissions to the study hospitals. The two hospitals selected to participate in the study represent about 10% of annual admissions to acute Scottish hospitals. The patient population is similar to the overall NHS Scotland population [21]. Limited identifiable data were recorded for the study; only CHI number was used to divide the cases and non-cases into two groups. This reduced recruitment bias, but resulted in exclusion of those not resident in Scotland (0.1% of all admissions). Charlson comorbidity score data showed that 35.6% of patients did not have a previous admission to derive a CCI score, and that the overall comorbidity summary was not as strong a predictor as a set of individual comorbidities.

In conclusion, this study used a large cohort design to identify and quantify risk of HAI based on factors that are known at point of admission. Most previous studies examined retrospective risk based on cumulative factors that occur during the hospital stay. These findings may help develop a clinical decision tool to identify patients at greatest risk of developing a particular type of HAI. These patients would be potential candidates for personalized infection prevention interventions.

Acknowledgements

Data collection could not have been completed without the enormous effort from the ECONI research nurses N. Williamson, H. Thain, R. Boyle, A. McAlpine, and C. Beith. The study was supported by the clinical staff in the study hospitals, particularly the infection control teams, laboratory staff, and research and development teams.

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. L.H. contributed to the development of study design, protocol and data management. S.M. contributed to aspects of the study design, contributed to the manuscript. H.M. contributed to the study design and health economic aspects of the study. 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.

Funding sources
This work was supported by Health Protection Scotland Programme, NHS National Services Scotland (RIE reference 14-154) from October 2015 to January 2020. The work was also pump-primed by the Scottish Healthcare Associated Infection Prevention Institute (SHAIPI), which has been set up with Scottish Government funding via the Scottish Infection Research Network.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jhin.2021.03.032.

References

[1] World Health Organization. Report on the burden of endemic health care-associated infection worldwide. Geneva: WHO; 2011. Available at: http://apps.who.int/iris/handle/10665/80135 [last accessed March 2020].
[2] Graves N, Weinhold D, Tong E, Birrell F, Doidge S, Ramritu P, et al. Effect of healthcare-acquired infection on length of hospital stay and cost. Infect Control Hosp Epidemiol 2007;28:280–92. https://doi.org/10.1086/512642.
[3] Freeman J, McGowan Jr JE. Risk factors for nosocomial infection. J Infect Dis 1978;138:811–9. https://doi.org/10.1093/infdis/138.6.811.
[4] European Centre for Disease Prevention and Control. Point prevalence survey of healthcare-associated infections and antimicrobial use in European acute care hospitals – protocol version 5.3. Stockholm: ECDC; 2016. Available at: https://www.ecdc.europa.eu/sites/default/files/media/en/publications/Publications/PPS-HAI-antimicrobial-use-EU-acute-care-hospitals-V5-3.pdf [last accessed February 2020].
[5] Kaye KS, Marchaim D, Chen TY, Chopra T, Anderson DJ, Choi Y, et al. Predictors of nosocomial bloodstream infections in older adults. J Am Geriatr Soc 2011;59:622–7. https://doi.org/10.1111/j.1532-5415.2010.03289.x.
[6] Wolkewitz M, Vonberg RP, Grundmann H, Beyersmann J, Gastmeier P, Barwolff S, et al. Risk factors for the development of nosocomial pneumonia and mortality on intensive care units: application of competing risks models. Crit Care 2008;12:R44. https://doi.org/10.1186/cc6852.
[7] Bhadade R, Harde M, deSouza R, More A, Bharmal R. Emerging trends of nosocomial pneumonia in intensive care unit of a tertiary care public teaching hospital in Western India. Ann Afr Med 2017;16:107–13. https://doi.org/10.4103/aam.aam_7_17.
[8] But A, Yetkin MA, Kanyilmaz D, Aslaner H, Bastug A, Aypak A, et al. Analysis of epidemiology and risk factors for mortality in ventilator-associated pneumonia attacks in intensive care unit patients. Turk J Med Sci 2017;47:812–6. https://doi.org/10.3906/sag-1601-38.
[9] Michetti CP, Prentice HA, Rodriguez J, Newcomb A. Supine position and nonmodifiable risk factors for ventilator-associated pneumonia in trauma patients. Am J Surg 2017;213:405–12. https://doi.org/10.1016/j.amjsurg.2016.05.019.
[10] Uvizl R, Kolar M, Herkel T, Vobrova M, Langova K. Possibilities for modifying risk factors for the development of hospital-acquired pneumonia in intensive care patients: results of a retrospective, observational study. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub 2017;161:303–9. https://doi.org/10.5507/bp.2017.019.
[11] Karakuzu Z, Iscimen R, Akalin H, Kelebek Girgin N, Kahveci F, Sinirtas M. Prognostic risk factors in ventilator-associated pneumonia. Med Sci Monit 2018;24:1321–8. https://doi.org/10.12659/msm.905919.
[12] van der Kooi TII, Boshuizen H, Wille JC, de Greeff SC, van Dissel JT, Schoffelen AF, et al. Using flexible methods to determine risk factors for ventilator-associated pneumonia in the Netherlands. PLoS One 2019;14:e0218372. https://doi.org/10.1371/journal.pone.0218372.
[13] Wolkewitz M, Palomar-Martinez M, Alvarez-Lerma F, Olaechea-Astigarraga P, Schumacher M. Analyzing the impact of duration of ventilation, hospitalization, and ventilation episodes on the risk of pneumonia. Infect Control Hosp Epidemiol 2019;40:301–6. https://doi.org/10.1017/ice.2018.360.
[14] Xu Y, Lai C, Xu G, Meng W, Zhang J, Hou H, et al. Risk factors of ventilator-associated pneumonia in elderly patients receiving mechanical ventilation. Clin Interv Aging 2019;14:1027–38. https://doi.org/10.2147/CIA.S197146.
[15] King C, Garcia Alvarez L, Holmes A, Moore L, Galletly T, Aylin P. Risk factors for healthcare-associated urinary tract infection and their applications in surveillance using hospital administrative data: a systematic review. J Hosp Infect 2012;82:219–26. https://doi.org/10.1016/j.jhin.2012.05.004.
[16] Nguyen-Van-Tam SE, Nguyen-Van-Tam JS, Myint S, Pearson JC. Risk factors for hospital-acquired urinary tract infection in a large English teaching hospital: a case–control study. Infection 1999;27:192–7. https://doi.org/10.1007/bf02561527.
[17] Ferreira E, Pina E, Sousa-Uva M, Sousa-Uva A. Risk factors for health care-associated infections: from better knowledge to better prevention. Am J Infect Control 2017;45:e103–7. https://doi.org/10.1016/j.ajic.2017.03.036.
[18] Chang Y-J, Yeh M-L, Li Y-C, Hsu C-Y, Lin C-C, Hsu M-S, et al. Predicting hospital-acquired infections by scoring system with simple parameters. PLoS One 2011;6:e23137. https://doi.org/10.1371/journal.pone.0023137.
[19] Rodriguez-Acelas AL, de Abreu Almeida M, Engelman B, Canon-Montanez W. Risk factors for health care-associated infection in hospitalized adults: systematic review and meta-analysis. Am J Infect Control 2017;45:e149–56. https://doi.org/10.1016/j.ajic.2017.08.016.
[20] Health Protection Scotland. Scottish National Point Prevalence Survey of Healthcare Associated Infection and Antimicrobial Prescribing 2016. Glasgow: HPS; 2017. Available at: https://www.hps.scot.nhs.uk/web-resources-container/national-point-prevalence-survey-of-healthcare-associated-infection-and-antimicrobial-prescribing-2016/ [last accessed February 2020].
[21] Information Services Division (ISD). Scotland. SMR01 – General/Acute Inpatient and Day Case. 2017. Available at: http://www.ndc.scot.nhs.uk/Data-Dictionary/SMR-Datasets/SMR01-General-Acute-Inpatient-and-Day-Case/ [last accessed October 2017].
[22] Stewart S, Robertson C, Manoukian S, Haahr L, Mason H, McFarland A, et al. How do we evaluate the cost of nosocomial infection? The ECONI protocol: an incidence study with nested case–control evaluating cost and quality of life. BMJ Open 2019;9:e026687. https://doi.org/10.1136/bmjopen-2018-026687.
[23] Scottish Intensive Care Society Audit Group. Audit of critical care in Scotland 2019 reporting on 2018. NHS Scoland; 2019. Available at: https://www.sicsag.scot.nhs.uk/publications/_docs/2019/2019-08-13-SICSAG-report.pdf?1 [last accessed June 2020].
[24] Harris PA, Taylor R, Minor BL, Elliott V, Fernandez M, O'Neal L, et al. The REDCap consortium: building an international community of software platform partners. J Biomed Inform 2019;95:103208. https://doi.org/10.1016/j.jbi.2019.103208.
[25] Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—a metadata-driven

methodology and workflow process for providing translational research informatics support. J Biomed Inform 2009;42:377–81. https://doi.org/10.1016/j.jbi.2008.08.010.
[26] NHS National Services Scotland. Scottish Clinical Coding Standards ICD-10. NHS National Services Scotland; 2017. Available at: http://www.isdscotland.org/Products-and-Services/Terminology-Services/Clinical-Coding-Guidelines/Docs/23-Consolidation-with-listings-170605b.pdf.
[27] Health and Social Care Information Centre. OPCS Classification of Interventions and Procedures Version 4.7 Volume I – Tabular List. London: Stationery Office; 2014.
[28] Scottish Index of Multiple Deprivation 2016. 2016. Available at: http://simd.scot/2016/#/simd2016/BTTTFTT/9/-4.0000/55.9000/ [last accessed September 2017].
[29] Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chron Dis 1987;40:373–83.
[30] Quan H, Li B, Couris CM, Fushimi K, Graham P, Hider P, et al. Updating and validating the Charlson comorbidity index and score for risk adjustment in hospital discharge abstracts using data from 6 countries. Am J Epidemiol 2011;173:676–82. https://doi.org/10.1093/aje/kwq433.
[31] Information Services Division (ISD) Scotland. SMR00 – Outpatient Attendance. 2017. Available at: http://www.ndc.scot.nhs.uk/Data-Dictionary/SMR-Datasets/SMR00-Outpatient-Attendance/ [last accessed October 2017].
[32] Information Services Division (ISD) Scotland. Prescribing information system for Scotland (PRISMS). 2016. Available at: http://www.ndc.scot.nhs.uk/National-Datasets/data.asp?SubID=102 [last accessed July 2018].
[33] World Health Organization. Anatomical therapeutic chemical (ATC)/defined daily dose (DDD) toolkit. 2019. Available at: https://www.who.int/medicines/regulation/medicines-safety/toolkit/en/ [last accessed March 2020].
[34] Law S. SMR completeness estimates. 2017. Available at: http://www.isdscotland.org/Products-and-Services/Data-Support-and-Monitoring/SMR-Completeness/ [last accessed September 2017].
[35] R Core Team. R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing; 2020.
[36] Stewart S, Robertson C, Pan J, Kennedy S, Dancer S, Haahr L, et al. Epidemiology of healthcare-associated infection reported from a hospital-wide incidence study: considerations for infection prevention and control planning. J Hosp Infect 2021;114:10–22. https://doi.org/10.1016/j.jhin.2021.03.031.
[37] Magill SS, O'Leary E, Janelle SJ, Thompson DL, Dumyati G, Nadle J, et al. Changes in prevalence of health care-associated infections in U.S. hospitals. N Engl J Med 2018;379:1732–44. https://doi.org/10.1056/NEJMoa1801550.
[38] Deptula A, Trejnowska E, Ozorowski T, Hryniewicz W. Risk factors for healthcare-associated infection in light of two years of experience with the ECDC point prevalence survey of healthcare-associated infection and antimicrobial use in Poland. J Hosp Infect 2015;90:310–5. https://doi.org/10.1016/j.jhin.2015.03.005.
[39] Donker T, Wallinga J, Grundmann H. Patient referral patterns and the spread of hospital-acquired infections through national health care networks. PLoS Comput Biol 2010;6:e1000715. https://doi.org/10.1371/journal.pcbi.1000715.
[40] European Centre for Disease Prevention and Control. Point prevalence survey of healthcare-associated infections and antimicrobial use in European acute care hospitals 2011–2012. Stockholm: ECDC; 2013. Available at: http://ecdc.europa.eu/en/publications/Publications/healthcare-associated-infections-antimicrobial-use-PPS.pdf.
[41] Plowman R, Graves N, Griffin MA, Roberts JA, Swan AV, Cookson B, et al. The rate and cost of hospital-acquired infections occurring in patients admitted to selected specialties of a district general hospital in England and the national burden imposed. J Hosp Infect 2001;47:198–209. https://doi.org/10.1053/jhin.2000.0881.
[42] Wang RF, Shen SH, Yen AM, Wang TL, Jang TN, Lee SH, et al. Risk factors for incidence and case-fatality rates of healthcare-associated infections: a 20-year follow-up of a hospital-based cohort. Epidemiol Infect 2016;144:198–206. https://doi.org/10.1017/S0950268815000369.
[43] Information and Statistics Division. Scottish patients at risk of readmission and admission (SPARRA). 2019. Available at: https://www.isdscotland.org/Health-Topics/Health-and-Social-Community-Care/SPARRA/.
[44] Campbell SE, Seymour DG, Primrose WR, for the ACMEplus project. A systematic literature review of factors affecting outcome in older medical patients admitted to hospital. Age Ageing 2004;33:110–15. https://doi.org/10.1093/ageing/afh036.
[45] Aranaz-Andrés JM, Limón R, Mira JJ, Aibar C, Gea MT, Agra Y, et al. What makes hospitalized patients more vulnerable and increases their risk of experiencing an adverse event? Int J Qual Health Care 2011;23:705–12. https://doi.org/10.1093/intqhc/mzr059.
[46] Nauman J, Soteriades ES, Hashim MJ, Govender R, Al Darmaki RS, Al Falasi RJ, et al. Global incidence and mortality trends due to adverse effects of medical treatment, 1990–2017: a systematic analysis from the Global Burden of Diseases, Injuries and Risk Factors Study. Cureus 2020;12:e7265. https://doi.org/10.7759/cureus.7265.
[47] O'Shea E, Trawley S, Manning E, Barrett A, Browne V, Timmons S. Malnutrition in hospitalised older adults: a multicentre observational study of prevalence, associations and outcomes. J Nutr Health Aging 2017;21:830–6. https://doi.org/10.1007/s12603-016-0831-x.
[48] Jaul E, Barron J, Rosenzweig JP, Menczel J. An overview of co-morbidities and the development of pressure ulcers among older adults. BMC Geriatr 2018;18:305. https://doi.org/10.1186/s12877-018-0997-7.
[49] Kuh D, Wong A, Shah I, Moore A, Popham M, Curran P, et al. The MRC National Survey of Health and Development reaches age 70: maintaining participation at older ages in a birth cohort study. Eur J Epidemiol 2016;31:1135–47. https://doi.org/10.1007/s10654-016-0217-8.
[50] Rawle MJ, Richards M, Davis D, Kuh D. The prevalence and determinants of polypharmacy at age 69: a British birth cohort study. BMC Geriatr 2018;18:118. https://doi.org/10.1186/s12877-018-0795-2.
[51] Guthrie B, Makubate B, Hernandez-Santiago V, Dreischulte T. The rising tide of polypharmacy and drug–drug interactions: population database analysis 1995–2010. BMC Med 2015;13:74. https://doi.org/10.1186/s12916-015-0322-7.
[52] Poolman JT, Anderson AS. *Escherichia coli* and *Staphylococcus aureus*: leading bacterial pathogens of healthcare associated infections and bacteremia in older-age populations. Expert Rev Vaccines 2018;17:607–18. https://doi.org/10.1080/14760584.2018.1488590.
[53] Daneman N, Guttmann A, Wang X, Ma X, Gibson D, Stukel TA. The association of hospital prevention processes and patient risk factors with the risk of *Clostridium difficile* infection: a population-based cohort study. BMJ Qual Saf 2015;24:435–43. https://doi.org/10.1136/bmjqs-2014-003863.
[54] Belliot G, Lopman BA, Ambert-Balay K, Pothier P. The burden of norovirus gastroenteritis: an important foodborne and healthcare-related infection. Clin Microbiol Infect 2014;20:724–30. https://doi.org/10.1111/1469-0691.12722.
[55] Fried LP, Ferrucci L, Darer J, Williamson JD, Anderson G. Untangling the concepts of disability, frailty, and comorbidity: implications for improved targeting and care. J Gerontol: Series A 2004;59:M255–63. https://doi.org/10.1093/gerona/59.3.M255.
[56] Health Protection Scotland. Preventing catheter associated urinary tract infections – acute settings. 2018. Available at: https://www.hps.scot.nhs.uk/web-resources-container/preventing-catheter-associated-urinary-tract-infections-acute-settings/ [last accessed June 2020].

[57] Majeed A, Sagar F, Latif A, Hassan H, Iftikhar A, Darouiche RO, et al. Does antimicrobial coating and impregnation of urinary catheters prevent catheter-associated urinary tract infection? A review of clinical and preclinical studies. Expert Rev Med Devices 2019;16:809—20. https://doi.org/10.1080/17434440.2019.1661774.

[58] Al-Qahtani M, Safan A, Jassim G, Abadla S. Efficacy of anti-microbial catheters in preventing catheter associated urinary tract infections in hospitalized patients: a review on recent updates. J Infect Public Health 2019;12:760—6. https://doi.org/10.1016/j.jiph.2019.09.009.

[59] Loveday HP, Wilson JA, Pratt RJ, Golsorkhi M, Tingle A, Bak A, et al. epic3: national evidence-based guidelines for preventing healthcare-associated infections in NHS hospitals in England. J Hosp Infect 2014;86(Suppl 1):S1—70. https://doi.org/10.1016/S0195-6701(13)60012-2.

[60] Cassini A, Plachouras D, Eckmanns T, Abu Sin M, Blank HP, Ducomble T, et al. Burden of six healthcare-associated infections on European population health: estimating incidence-based disability-adjusted life years through a population prevalence-based modelling study. PLoS Med 2016;13:e1002150. https://doi.org/10.1371/journal.pmed.1002150.

[61] Guest JF, Keating T, Gould D, Wigglesworth N. Modelling the annual NHS costs and outcomes attributable to healthcare-associated infections in England. BMJ Open 2020;10:e033367. https://doi.org/10.1136/bmjopen-2019-033367.