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Epidemiology and health-economic burden of urinary-catheter-associated infection in English NHS hospitals: a probabilistic modelling study

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SUMMARY

Background: Catheter-associated urinary tract infection (CAUTI) and bloodstream infection (CABSI) are leading causes of healthcare-associated infection in England's National Health Service (NHS), but health-economic evidence to inform investment in prevention is lacking.

Aims: To quantify the health-economic burden and value of prevention of urinary-catheter-associated infection among adult inpatients admitted to NHS trusts in 2016/17.

Methods: A decision-analytic model was developed to estimate the annual prevalence of CAUTI and CABSI, and their associated excess health burdens [quality-adjusted life-years (QALYs)] and economic costs (£ 2017). Patient-level datasets and literature were synthesized to estimate population structure, model parameters and associated uncertainty. Health and economic benefits of catheter prevention were estimated. Scenario and probabilistic sensitivity analyses were conducted.

Findings: The model estimated 52,085 [95% uncertainty interval (UI) 42,967–61,360] CAUTIs and 7529 (UI 6857–8622) CABSIs, of which 38,084 (UI 30,236–46,541) and 2524 (UI 2319–2956) were hospital-onset infections, respectively. Catheter-associated infections incurred 45,717 (UI 18,115–74,662) excess bed-days, 1467 (UI 1337–1707) deaths and 10,471 (UI 4783–13,499) lost QALYs. Total direct hospital costs were estimated at £54.4M (UI £37.3–77.8M), with an additional £209.4M (UI £95.7–270.0M) in economic value of QALYs lost assuming a willingness-to-pay threshold of £20,000/QALY. Respectively, CABSI

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accounted for 47% (UI 32–67%) and 97% (UI 93–98%) of direct costs and QALYs lost. Every catheter prevented could save £30 (UI £20–44) in direct hospital costs and £112 (UI £52–146) in QALY value.

Conclusions: Hospital catheter prevention is poised to reap substantial health-economic gains, but community-oriented interventions are needed to target the large burden imposed by community-onset infection.

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Introduction

Urinary tract infection (UTI) is a leading cause of healthcare-associated infection (HCAI) and Gram-negative bloodstream infection (GNBSI) in England [1–3]. Urinary catheters (henceforth ‘catheters’) are associated with the majority of urinary HCAs and are an important risk factor for the incidence and severity of GNBSI [4–7]. Yet catheters are often inserted without appropriate indication and left in for longer than clinically necessary [8], putting patients needlessly at risk of infection and contributing to the burden imposed by HCAI and GNBSI in England’s National Health Service (NHS) [1,9].

In response to an unprecedented increase in the incidence of GNBSI, in 2016 the UK Government pledged to halve healthcare-associated GNBSI by 2020 [10]. Achieving reductions of this scale is made difficult by resource constraints and the fact that most GNBSIs are caused by typically commensal bacteria such as *Escherichia coli* [9,11]. However, recent estimates suggest that 34–56% of hospital catheter-associated UTIs (CAUTIs) may be preventable, in particular through prevention of unnecessary urinary catheterization [12]. This highlights the potential for catheter prevention interventions to reduce the burden of HCAI and contribute to reduction targets for GNBSI [13].

Catheter prevention interventions are typically implemented as multi-modal care bundles or quality improvement programmes, ranging from behavioural interventions (e.g. insertion checklists) to medical devices (e.g. ultrasound bladder scanners) to staff education initiatives (e.g. coaching calls) [12,14]. In particular, prevention of unnecessary catheterization via catheter reminders (prompts for ongoing assessment of catheter need) and stop orders (predated prompts for catheter removal subject to clinical review) has been observed to reduce the incidence of CAUTI and has been highlighted in national infection prevention guidelines [1,8]. However, unlike other CAUTI prevention interventions (e.g. antimicrobial catheters [15]), health-economic evidence for catheter prevention in English hospitals is scarce. This study addresses this evidence gap by modelling the epidemiology, burden and value of prevention of catheter-associated infection in English NHS hospitals.

Methods

Health-economic model

A probabilistic decision-analytic model of adult inpatients admitted to NHS England trusts was developed to estimate the

annual prevalence of: (i) urinary catheter; (ii) symptomatic CAUTI; (iii) catheter-associated bloodstream infection (CABSI) secondary to CAUTI; (iv) chronic CABSI sequelae; and (v) mortality due to CABSI (Box 1). The model accounted for inpatient population structure, including age, sex, comorbidity and hospital length of stay (LOS), and considered cases with both hospital and community onset (infections were classed as having hospital onset when occurring >48 h after hospital admission). The model was ultimately used to quantify the excess health burden and economic costs owing to catheter-associated infection.

Synthesis of primary data sources and literature

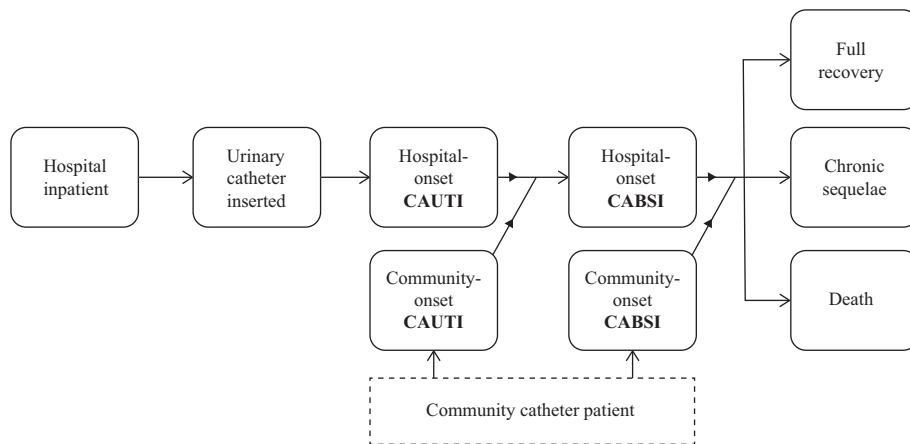
Four primary data sources were synthesized to inform and parameterize the model (Box 1). Briefly, data from Hospital Episode Statistics (HES) were used to describe the size and demographic structure of the patient population, as well as patient LOS and in-hospital mortality. A Public Health England (PHE) Point Prevalence Survey (PPS) of HCAI was used to estimate the proportion of CAUTI having hospital onset, as well as to model associations between patient traits and: (i) presence of catheter; (ii) symptomatic CAUTI; and (iii) McCabe score, a subjective measure of underlying health classifying patients as non-fatal (1), ultimately fatal (2), or rapidly fatal (3). Data from NHS Safety Thermometer (NST) were used to scale estimated catheter and CAUTI population structures to reported national prevalence. Lastly, PHE’s Data Capture System (DCS) was used to describe the epidemiology of CABSI. Only *E. coli* data were available from DCS, so the overall prevalence of CABSI was scaled by the estimated proportion of CABSI caused by *E. coli*. Remaining model parameters were estimated from the literature, with priority given to randomized controlled trials in NHS hospitals or previous analyses of the primary data sources used in this study. Parameter probability distributions were stratified by patient characteristics where possible. All parameters and their sources are provided in Table 1.

Quantifying disease burden

Methods for quantifying burden were adapted from the Burden of Communicable Diseases in Europe project, using NHS-specific data sources, parameter estimates and recommendations for health-economic evaluation [19,25,26]. Patient health-related quality of life (HRQoL) was measured using a utility score ranging from 0 (dead) to 1 (perfect health), and translated into quality-adjusted life years (QALYs). QALY burden was built into the model as reduction in background

Box 1

Model structure and description of primary data sources. Full methods are reported in Appendix A.

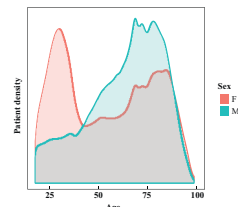


Decision-analytic model structure. Patients move through the model with transition probabilities $0 < P < 1$. Patients in the community (dashed box) were not explicitly modelled prior to hospital admission, but their impact on hospital burden and dynamics were incorporated. Model parameters are described in Table I.

Data source	Data use and inclusion criteria	Illustrative figure
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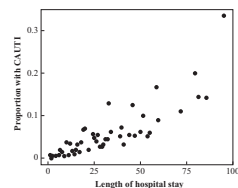
NHS Hospital Episode Statistics Database containing electronic medical records of all patient admissions to NHS England trusts (included trusts listed in Table A1, see online supplementary material).

Patient-level data used to describe the size and structure of the model population, accounting for joint distributions of patient age, sex, binary comorbidity score, in-hospital mortality and LOS. Patients aged 18–99 years were included if admitted to any acute care NHS trust between 1 April 2016 and 31 March 2017 with $24 \text{ h} < \text{LOS} < 100$ days. **Figure:** Age distributions of male and female hospital patients.



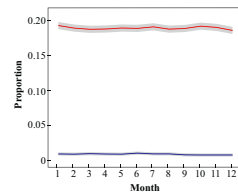
PHE Point Prevalence Survey Point prevalence survey of HCAI conducted by PHE across nine randomly selected UK trusts. Data collected in autumn 2016 by trained physicians and infection prevention and control nurses.

Patient-level data used to inform multi-variable logistic regression models to predict urinary catheter prevalence, CAUTI prevalence and McCabe score (Tables A2–A4 and Figure A1, see online supplementary material). Patients aged 18–99 years with $24 \text{ h} < \text{LOS} < 100$ days were included. CAUTI was identified in patients having confirmed: (i) urinary catheter, (ii) HCAI and (iii) urinary infection site. Data were also used to determine hospital-onset vs community-onset infection. **Figure:** Proportion of catheterized inpatients with CAUTI, as a function of hospital LOS at the time of survey.



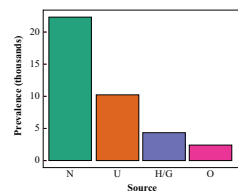
NHS Safety Thermometer Monthly point prevalence estimates of patient harms self-reported by NHS organizations. Data are publicly available.

Aggregated data used to estimate total inpatient catheter and CAUTI prevalence, estimated as mean of monthly estimates from April 2016 to March 2017 in acute NHS trusts. **Figure:** Point prevalence reported as proportion of patients with catheter (red) and CAUTI (blue) in participating trusts.



PHE Data Capture System Database containing all national records of *Escherichia coli* bacteraemia reported through mandatory surveillance.

Patient-level data used to quantify prevalence and population structure of CABSIs, accounting for patient age, sex and location of infection onset. All unique records in inpatients aged 18–99 years with urinary catheter-associated, urinary source infection were included. Hospital-onset infection was defined in patients with infection onset $>48 \text{ h}$ after admission. Missing data were imputed probabilistically using Monte Carlo methods (Figures A2 and A3, and Table B1, see online supplementary material). **Figure:** Annual prevalence of *Escherichia coli* bacteraemia; except for cases with no clinical code (N), the most common sources of infection were urinary tract (U) and hepatobiliary/gastrointestinal tracts (H/G), followed by all other sources (O).



CAUTI, catheter-associated urinary tract infection; CABSIs, catheter-associated bloodstream infection; NHS, National Health Service; LOS, length of stay; PHE, Public Health England; HCAI, healthcare-associated infection. Full methods are reported in Appendix A.

patient age- and sex-adjusted utility via: (i) acute burden of initial infection (at six weeks post-catheterization in CAUTI, three months post-onset in CABSIs); (ii) lifelong burden of CABSIs sequelae; and (iii) mortality due to CABSIs. For (ii), CABSIs survivors were assigned probabilities of developing four lifelong sequelae with associated disability weights (post-traumatic stress disorder, cognitive impairment, physical impairment, and renal failure with renal replacement therapy) [19,24]. For (iii), background patient utility was summed over remaining life expectancy, estimated using McCabe score (1=background life expectancy, 2=five years, 3=one year). CABSIs in-hospital mortality and excess LOS were estimated from NHS patients with *E. coli* bacteraemia using a previously linked HES/DCS dataset and methods described elsewhere [18]. Burden was considered from the perspective of NHS trusts with a one-year time horizon over FY2016/17, although future QALYs lost to chronic sequelae and mortality were considered over a lifetime horizon and discounted annually at 3.5% [25].

Quantifying economic burden

Economic costs were measured in £ 2017, with prior cost estimates adjusted for inflation using the consumer price index [27]. Excess direct hospital costs associated with each health state were estimated from the literature, including catheter unit costs and costs of treating inpatients admitted with CAUTI and CABSIs (Table I). Excess LOS estimates for CAUTI and CABSIs were considered separately from direct hospital costs. Future direct hospital costs from re-admission due to sequelae were not included. Economic value of QALYs lost is reported assuming a standard willingness-to-pay threshold of £20,000/QALY (i.e. the approximate societal value of one QALY) [25].

Quantifying value of catheter prevention

To estimate excess health-economic costs per catheter, model outcomes were averaged across the total number used. Potential health-economic value of intervention was estimated by simulating catheter prevention using catheter reminder/stop order efficacy estimates from the literature. Catheter reminders and stop orders concern removal of unnecessary catheters rather than prevention of initial catheter placement, so no difference was assumed in the total number of catheters used. To estimate per-hospital benefits of intervention, outcomes were averaged across all included trusts. Intervention costs were not included.

Scenario and sensitivity analyses

Four scenario analyses were conducted to account for model uncertainty in quantifying the burden of CABSIs: (i) missing DCS data were not imputed; (ii) DCS data were not scaled to account for non-*E. coli* CABSIs, with and without data imputation; (iii) probability of developing CABSIs subsequent to CAUTI was estimated from the literature and applied to the model, but was unstratified by patient characteristics; and (iv) three alternative means of quantifying CABSIs sequelae were adapted from a previous health-economic evaluation of hospital BSI [28]. The first assumed no sequelae; the second assigned sequelae patients a flat HRQoL utility of 0.6 for five years, followed by a return to the population norm if still alive;

and the third assigned sequelae patients a flat HRQoL utility of 0.6 for their remaining life expectancy.

Univariate sensitivity analyses were conducted across the range or 95% confidence interval of all parameters estimated from the literature (parameter distributions in Table I). To evaluate uncertainty across all parameters simultaneously, a probabilistic sensitivity analysis (PSA) was conducted using 10,000 Monte Carlo simulations, in which patient characteristics from HES were kept static, with all other parameters drawn probabilistically from their respective distributions, accounting for correlation between parameters using Cholesky decomposition. In the PSA, unique probabilistic imputations of missing DCS data were conducted for each simulation (Appendix A). PSA results were ultimately used to quantify uncertainty around all model outcomes as 95% uncertainty intervals (UIs). Economic outcomes were rounded to the nearest thousand (K) or million (M) pounds.

The model was developed and reported in accordance with ISPOR guidelines for health-economic evaluation (CHEERS checklist in Table A10, see online supplementary material) [29].

Results

Model population

The model included 5,203,496 adult inpatients from 153 acute trusts. The mean annual number of patients per trust was 34,010 [interquartile range (IQR) 21,943–44,400]. Mean patient age was 59 years (IQR 38–78), 41.0% were male, and 67.7% had comorbidity (population structure in Figure B1, see online supplementary material).

Catheter, CAUTI and CABSIs epidemiology

Primary model outcomes are reported in Table II. There were an estimated 997,814 (UI 977,306–1,018,205) catheterized patients, who were on average older (mean age 66 years, UI 65–67) and more likely to be male (51.8%, UI 50.0–53.6%) or have comorbidity (79.3%, UI 77.9–80.7%) than the general patient population (Figure B2, see online supplementary material).

Approximately 3.8% (UI 3.0–4.7%) of inpatients with catheters developed hospital-onset CAUTI, accounting for 38,084 (UI 30,236–46,541) of a total 52,085 (UI 42,967–61,360) CAUTIs. Catheterized patients with longer LOS were more likely to develop CAUTI, ranging from 3.1% (UI 2.4–3.9%) patients with LOS of two days to 13.2% (UI 8.0–21.2%) for patients with LOS lasting ≥ 40 days. An estimated 4.8% (UI 4.1–6.3%) of inpatients with CAUTI further developed hospital-onset CABSIs, representing 2524 infections (UI 2319–2956). Patients admitted to hospital with community-onset CABSIs accounted for an additional 5005 (UI 4509–5695) infections, for a total estimated 7529 (UI 6857–8622) cases of CABSIs across all trusts.

The mean age of patients with CAUTI was 67 years (UI 66–68), of whom 52.5% (UI 50.7–54.3%) were male, while the mean age of patients with CABSIs was 76 years (UI 76–77), of whom 64.1% (UI 62.9–65.7%) were male (Figure 1). Patients with community-onset CABSIs were older (77 years, UI 77–78) and more likely to be male (66.7%, UI 65.2–68.6%) than patients with hospital-onset CABSIs (74, UI 74–75; 59.0%, UI

Table 1
Model parameter estimates

Parameter	Value (range)		Distribution	Description of estimate	Source
	Mean (95% CI)	Mean of means (range of means)			
Clinical parameters					
Urinary catheter prevalence (%)	19.2 (18.8–19.6)	/	Normal	Average monthly point prevalence of urinary catheter in acute NHS trusts	NST
CAUTI prevalence (%)	1.0 (0.8–1.2)	/	Normal	Average monthly point prevalence of CAUTI in acute NHS trusts	NST
Proportion of CAUTI with community onset	0.27 (0.18–0.37)	/	Binomial	Proportion of CAUTI inpatients with infection onset within 48 h of admission	PPS
Proportion of CABSIs caused by <i>E. coli</i>	0.57 (0.51–0.63)	/	Normal	Mixed effects meta-regression of studies reporting the proportion of GNBSIs caused by <i>E. coli</i> (Figure A4, see online supplementary material)	[3,16,17]
Probability of CABSIs mortality	/	0.20 (0.05–0.36)	Normal	In-hospital mortality among patients with <i>E. coli</i> bacteraemia, stratified by age, sex and location of infection onset in Table A5 (see online supplementary material)	HES, DCS [18]
Probability of any sequelae among CABSIs survivors	0.41 (0.34–0.47)	/	Uniform	Probability of sequelae following ‘complicated’ healthcare-associated bloodstream infection; see probabilities of individual sequelae in Table A6 (see online supplementary material)	[19]
Hospital resource use parameters					
Catheter unit cost (£)	1.08 (0.30–3.87)	/	Log normal	Unit cost of PTFE Foley catheter, adjusted for inflation using the consumer price index	[15]
Excess cost per CAUTI (£)	532 (274–789)	/	Normal	Excess hospital resource use cost per CAUTI patient compared with controls, adjusted for inflation using the consumer price index	[15]
Excess cost per CABSIs (£)	3401 (2061–5613)	/	Log normal	Direct hospital cost of treating CAUTI-associated bacteraemia, adjusted for inflation using the consumer price index	[20]
Excess LOS per CAUTI (days)	0.63 (0.11–1.15)	/	Normal	Excess LOS among CAUTI patients compared with controls	[15]
Excess LOS per CABSIs (days)		1.83 (0.73–3.73)	Normal	Excess LOS among <i>E. coli</i> bacteraemia patients compared with controls, stratified by age, sex and location of infection onset in Table A5 (see online supplementary material)	HES, DCS [18]
HRQoL parameters					
Background remaining life expectancy (years)	/	32 (2–65)	Point estimates	Remaining life expectancies calculated from national English life tables, stratified by age and sex in Table A7 (see online supplementary material)	[21]
Background utility	/	0.85 (0.71–0.94)	Beta	English HRQoL utility population norms measured using EQ-5D, stratified by age and sex in Table A8 (see online supplementary material)	[22]
QALY loss per CAUTI	0.006 (0.004–0.008)	/	Normal	Difference in self-reported QALYs between CAUTI patients and controls, measured using EQ-5D up to six weeks post-catheterization	[15]
Patient utility from CABSIs onset until 3 months post-infection	0.31 (0.25–0.37)	/	Normal	Self-reported HRQoL utility in survivors of bloodstream infection up to three months post-infection, measured using EQ-5D	[23]

Annual QALY loss per CABSIs sequelae	/	0.06 (0.02–0.11)	Uniform	Sequelae disability weights averaged across probabilities of developing each sequela; see values for individual sequelae in Table A9 (see online supplementary material)	[19,24]
Annual QALY discount rate (%)	3.5 (0, 5.0)	/	/	Standard QALY discount rate; only varied in univariate sensitivity analysis	[25]
Intervention parameters					
Hospital-onset CAUTI risk reduction due to catheter reminder/stop order intervention	0.72 (0.52–0.99)	/	Log normal	Risk ratio for developing CAUTI when exposed to catheter reminder/stop order intervention	[8]

CAUTI, catheter-associated urinary tract infection; CABSIs, catheter-associated bloodstream infection; NHS, National Health Service; HRQoL, health-related quality of life; QALY, quality-adjusted life-year; EQ-5D, EuroQoL 5-dimension; *E. coli*, *Escherichia coli*; NST, National Safety Thermometer; PPS, Point Prevalence Survey; HES, Hospital Episode Statistics; DCS, Data Capture System.
Parameter values stratified by one or more variables (e.g. sex or patient age) are reported as means of all estimates, i.e. mean of means. Full parameter tables, regression parameters and methodological detail are reported in [Appendix A](#) (see online supplementary material).

57.4–61.0%). CABSIs was fatal in 19.5% of patients (UI 18.8–20.5%), although mortality was substantially higher among patients with hospital-onset CABSIs (31.6%, UI 29.9–33.5%) than community-onset CABSIs (13.4%, UI 12.7–14.2%). Among CABSIs survivors, 2455 (UI 2023–3038) developed chronic sequelae.

Health-economic outcomes

CABSIs accounted for nearly half of direct hospital costs (47.1%, UI 31.6–67.0%), although CAUTI still accounted for the majority of excess bed-days in most simulations (71.8%, UI 29.5–82.8%). CABSIs also accounted for the vast majority of QALYs lost (97.0%, UI 93.3–98.2%). The QALY burden of CABSIs was driven by patient mortality, which accounted for 78.8% (UI 69.1–83.8%) of all QALYs lost. On average, each CABSIs resulted in a lifetime loss of 1.3 (UI 0.6–1.7) QALYs. Despite having lower mortality risk, average QALY loss per CABSIs was higher among younger patients owing to a greater potential number of life-years to lose. In total, each CAUTI was estimated at £532 (UI £274–791) in direct hospital costs and £120 (UI £81–158) in value of QALYs lost, compared with £3.4K (UI £2.1–5.6K) and £27.0K (UI £11.8–33.0K), respectively, for CABSIs. Health-economic outcomes varied substantially between hospital- and community-onset infection ([Table B2](#), see online supplementary material).

Benefits of prevention of CAUTI and CABSIs

Each catheter was associated with an average 0.04 (0.03–0.05) excess hospital-onset CAUTIs, 0.003 (0.002–0.003) excess hospital-onset CABSIs, £30 (UI £20–44) in excess direct hospital costs, and a further 0.006 (UI 0.003–0.007) lost QALYs valued at £112 (UI £52–146). Accordingly, in an average NHS trust, every percent reduction in inpatient catheter prevalence could prevent 13 (UI 10–16) hospital-onset CAUTIs, 0.9 (UI 0.8–1.0) hospital-onset CABSIs, £9.8K (UI £6.6–14.8K) in direct hospital costs, and a further 1.9 (UI 0.9–2.5) lost QALYs valued at £38.5K (UI £17.6–49.8K). As such, a catheter reminder/stop order intervention implemented in a typical NHS trust could prevent 70 (UI 0–123) excess hospital-onset CAUTIs, 5 (UI 0–8) excess hospital-onset CABSIs, £52.8K (UI £0.0–103.7K) in direct hospital costs, and a further 12 (UI 0–19) lost QALYs valued at £236.2K (UI £0.2–381.5K) ([Figure 2A](#)).

Parameter uncertainty and scenario analyses

Univariate sensitivity analyses indicated that uncertainty in estimated total health-economic costs was primarily driven by background HRQoL and CABSIs-related parameters ([Figure 2B](#)), several of which were varied in scenario analyses ([Table B3](#), see online supplementary material). When only *E. coli* CABSIs was included, there were an estimated 4367 infections at a total health-economic cost of £167.7M. When the risk of CABSIs was estimated from the literature instead of DCS, the prevalence of CABSIs was 29% lower than baseline but total health-economic costs were only 12% lower, owing to greater QALY losses from a younger CABSIs patient population. Across four included sequelae scenarios, QALY loss resulting from CABSIs sequelae varied from 0 to 3037 and total health-economic costs from £239.4M to £300.2M.

Table II
Model outputs

	Totals (95% UI)	
	All trusts (N=5,203,496)	Typical trust (N=34,010)
Health outcomes (number of patients)		
Catheter	997,814 (977,306–1,018,205)	6522 (6388–6655)
CAUTI	52,085 (42,967–61,360)	340 (281–401)
Hospital-onset	38,084 (30,236–46,541)	249 (198–304)
Community-onset	14,001 (8988–19,603)	92 (59–128)
CABSI	7529 (6857–8622)	49 (45–56)
Hospital-onset	2524 (2319–2956)	16 (15–19)
Community-onset	5005 (4509–5695)	33 (29–37)
CABSI sequelae	2455 (2023–3038)	16 (13–20)
CABSI mortality	1467 (1337–1707)	10 (9–11)
Excess LOS (bed-days)		
CAUTI	32,814 (5329–61,475)	214 (35–402)
CABSI	12,904 (11,194–15,047)	84 (73–98)
Total	45,717 (18,115–74,662)	299 (118–488)
Excess health burden (QALY loss)		
CAUTI		
6-weeks post-catheterization	313 (202–433)	2 (1–3)
CABSI		
3 months post-infection	689 (552–854)	5 (4–6)
Lifelong sequelae	1215 (401–1901)	8 (3–12)
Mortality	8255 (3328–10,860)	54 (22–71)
Total	10,471 (4783–13,499)	68 (31–88)
Excess direct hospital costs (£)		
Catheter unit costs	1.1M (0.3–3.8M)	7.1K (1.9–25.0K)
CAUTI resource costs	27.7M (13.8–42.3M)	181.0K (90.0–276.3K)
CABSI resource costs	25.6M (15.6–43.0M)	167.4K (102.0–281.3K)
Total	54.4M (37.3–77.8M)	355.4K (244.1–508.6K)
Value of excess QALYs lost (£)		
CAUTI		
6 weeks post-catheterization	6.3M (4.0–8.7M)	40.9K (26.4–56.6K)
CABSI		
3 months post-infection	13.8M (11.0–17.1M)	90.0K (72.1–111.7K)
Lifelong sequelae	24.3M (8.0–38.0M)	158.8K (52.4–248.5K)
Mortality	165.1M (66.6–217.2M)	1.1M (0.4–1.4M)
Total	209.4M (95.7–270.0M)	1.4M (0.6–1.8M)
Total excess economic burden (£)		
Total	263.8M (150.3–330.9M)	1.7M (1.0–2.2M)

UI, uncertainty interval; CAUTI, catheter-associated urinary tract infection; CABSI, catheter-associated bloodstream infection; K, thousand; M, million; QALY, quality-adjusted life-years; LOS, length of stay.
Economic costs rounded to the nearest thousand or million.

Discussion

Approximately one in five NHS hospital inpatients has a urinary catheter inserted at any given time. This may be substantially higher than necessary, entailing burdensome healthcare-associated infections that may be largely preventable through prevention of unnecessary urinary catheterization [1,12,30]. This study synthesized patient-level data and relevant literature to inform and calibrate a probabilistic health-economic model describing the epidemiology, quantifying the burden and predicting benefits of prevention of

catheter-associated infection among inpatients admitted to NHS England trusts. The following estimates were made: 43–61K CAUTIs and 6.9–8.6K CABSI per year resulting in 1.3–1.7K deaths, £37–78M in direct hospital costs, and 4.8–13.5K lost QALYs valued at £96–270M, for a total economic burden of £150–331M. For each percent reduction in urinary catheter prevalence, it was estimated that trusts could avoid an average £7–15K in excess direct costs owing from hospital-onset infection, and £24–65K in total economic costs. These estimates may inform investment in improved catheter care.

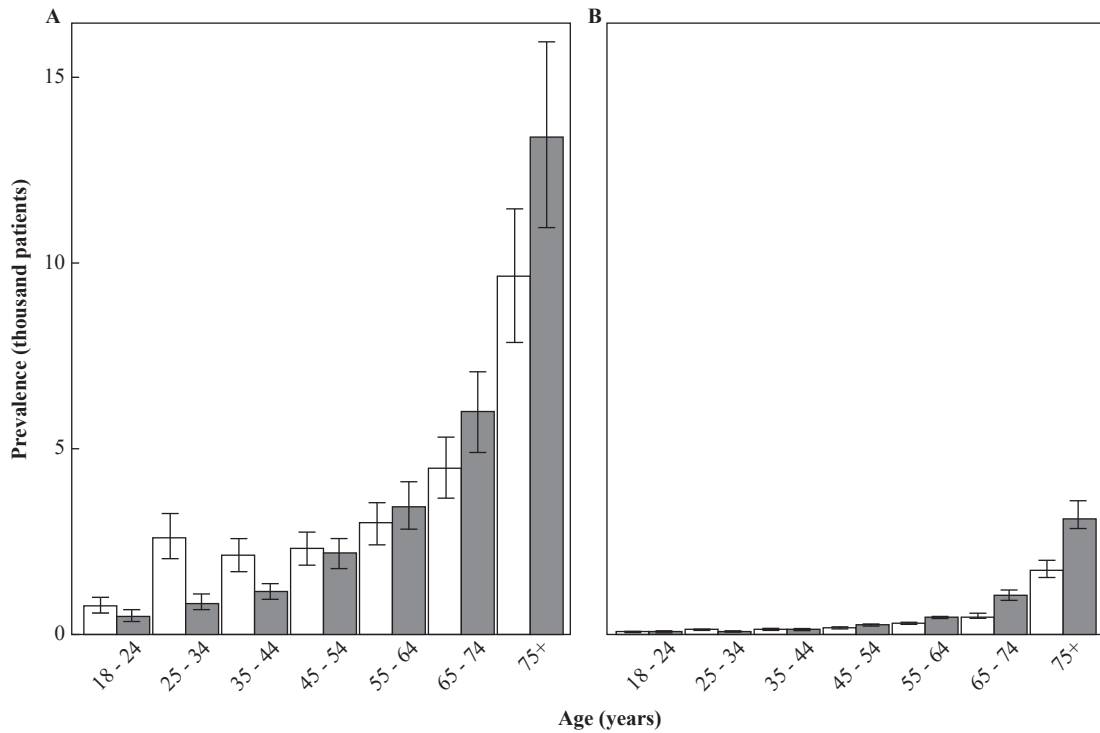


Figure 1. Age and sex distributions of the prevalence rates of (a) catheter-associated urinary tract infection and (b) catheter-associated bloodstream infection. Error bars represent 95% uncertainty intervals. Female, white bars; male, grey bars.

It was estimated that national implementation of a generic catheter reminder/stop order intervention in NHS hospitals could prevent approximately 11,000 hospital-onset CAUTIs and 700 hospital-onset GNBSIs annually, representing almost 10% of all CABSIs. Although of large clinical and economic significance, this represents only a fraction of the projected incidence of healthcare-associated *E. coli* bacteraemia (exceeding 30,000 by 2021) [31]. Potential limited capacity of hospital catheter

interventions to reduce GNBSI burden is consistent with the viewpoint that multi-faceted, community-oriented approaches are necessary to tackle the many, as yet poorly understood sources of GNBSI [9,13,32].

The annual incidence of healthcare-associated UTI (HAUTI) in Europe has recently been estimated at 145–161/100,000 population at a lifetime 47–66 life-years lost/100,000 [19]. Applied to a population of 40M English adults, this translates

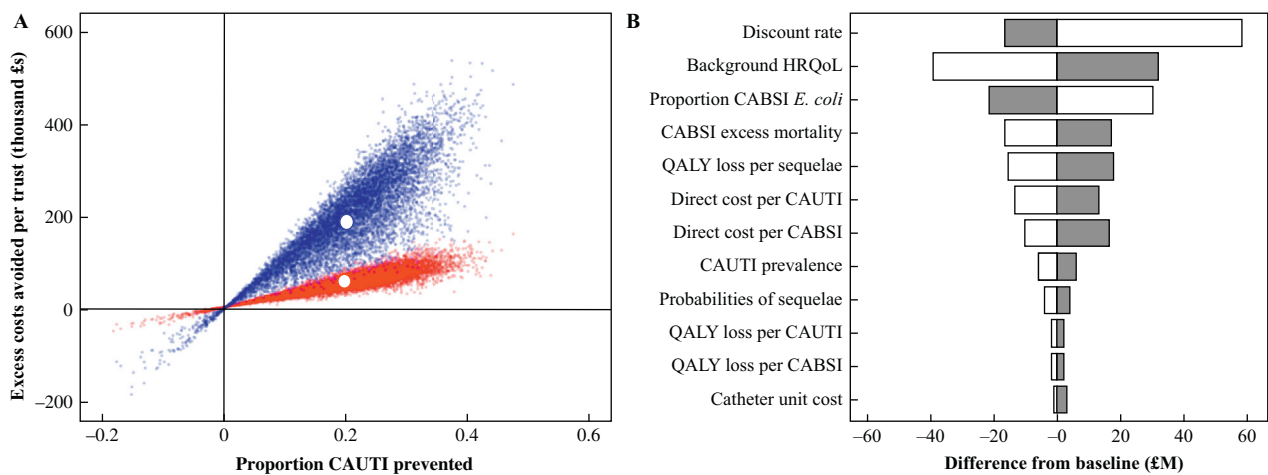


Figure 2. (A) Projected annual excess economic costs [direct (red dots) and through QALY loss (blue dots)] averted in a typical National Health Service trust following implementation of a generic catheter reminder/stop order intervention. Each probabilistic sensitivity analysis (PSA) simulation is represented as a coloured dot, with baseline estimates represented as white circles. (B) Univariate sensitivity analyses showing contribution of individual parameter uncertainty to uncertainty in total estimated health-economic cost of catheter-associated infection. White bars, low limit; grey bars, high limit. All parameters except discount rate were varied probabilistically in the PSA. CAUTI, catheter-associated urinary tract infection; CABSI, catheter-associated bloodstream infection; *E. coli*, *Escherichia coli*; HRQoL, health-related quality of life; QALY, quality-adjusted life-years.

to 58–65K HAUTIs and 19–27K quality-unadjusted, undiscounted life-years lost, compared with the 43–61K CAUTIs and 5–13K lost QALYs estimated here. The burden of CAUTI in NHS trusts has also been estimated using data from 1994/95 at an annual 67K CAUTIs and £68M in direct hospital costs, compared with the presently estimated 43–61K CAUTIs at £13.8–42.3M in direct costs [33]. Disparities between these estimates may reflect both methodological differences and real improvement in care over the last quarter century. For example, their model inputs included substantially higher estimates of hospital catheter prevalence (28% vs 18.8–19.6%), CAUTI prevalence among catheter patients (7.3% vs 4.3–6.1%) and excess direct costs per CAUTI (£1021 unadjusted for inflation vs £274–789).

Comparable estimates of the burden of CABSIs are scarce. In 2009, Tacconelli *et al.* [34] quantified the burden of intensive-care-unit-onset central-venous-catheter-related BSI in UK hospitals, finding, in general, slightly higher estimates than those in this study in terms of the prevalence of infection (8940 vs 6857–8622) and excess bed-days per infection (1.9–4.0 vs 1.5–1.9), and comparable annual direct costs to NHS hospitals (£19.1–36.2 unadjusted for inflation vs £15.6–43.0). Relevant health-economic burden studies have also been conducted in other settings, but direct comparison with NHS hospitals is difficult and estimates vary widely (e.g. from €953 per nosocomial BSI in France to \$8473 per complicated carbapenem-non-susceptible UTI in the USA [35,36]).

This study identified that 63–82% of inpatient CAUTIs originated in hospital compared with 33–35% of CABSIs, highlighting that community-oriented approaches are necessary to effectively reduce the burden of CABSIs. Studies of community catheter-associated infection are lacking, although Shackley *et al.* [37] observed 75,000 catheter patients annually in community NHS organizations reporting to NST, and Gage *et al.* [38] estimated 90,000 long-term community catheter users in England. It is difficult to infer overall infection risk in community catheter patients, particularly in CAUTI, as relative use of primary vs secondary care services is unknown. However, although these figures may not be representative, crude comparison with the present results suggests that $\geq 10\%$ of community catheter patients are hospitalized annually with CAUTI and $\geq 5\%$ with CABSIs.

This study was strengthened through use of established burden estimation and health-economic modelling methodologies, synthesis of multiple primary sources of NHS patient data, cross-validation of outcomes across available data and literature, and use of scenario and probabilistic sensitivity analyses.

The scope of this study was principally limited by data availability. Incidence of antimicrobial resistance among Gram-negative CAUTI-causing bacteria is alarmingly high, and resistant infections may be more expensive to treat [39,40]; however, data limitations prevented explicit modelling of resistance burden. Prior use of healthcare services among model patients could not be determined, hindering estimation of the proportions of community-onset CABSIs occurring in long-term community catheter users as opposed to patients recently discharged from hospital after short-term catheterization. Accordingly, it was not possible to quantify knock-on benefits of hospital intervention in reducing subsequent community-onset but ultimately hospital-associated infection. Insufficient data also necessitated synthesis of imperfect parameter estimates such as the use of *E. coli* bacteraemia mortality as a proxy measure for CABSIs mortality. Lastly, long-

stay patients may have been oversampled in PPS data, which could not be corrected for owing to a lack of data on total LOS among included patients.

This study was not framed in terms of a traditional intervention-based cost-effectiveness analysis, where potential intervention benefits are offset against health-economic costs. These include precise implementation costs and potential negative impacts on patient quality of life (e.g. inappropriate catheter removal resulting in re-insertion, urogenital trauma and increased infection risk) [41]. Owing to a lack of relevant trial data, as well as the context specificity, multimodal nature and relative intangibility of catheter prevention, estimation of intervention costs was deemed out of scope. Although the NHS implements evidence-based standards for catheter care [1], actual catheter use is ultimately driven by local policy, resources and culture, and in the absence of a clear one-size-fits-all intervention, this study sought to simulate potential benefits of generic catheter prevention.

In conclusion, these findings suggest the potential for large health-economic gains resulting from urinary catheter prevention in NHS trusts, but highlight the importance of community-oriented approaches to effectively prevent the disproportionate burden of community-onset CABSIs. Future work should explore the epidemiological profiles of long-term and community catheter patients, their use of NHS services, and optimal targets for intervention.

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Conflict of interest statement

None declared.

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Appendices A and B. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jhin.2019.04.010>.

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