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The cost-effectiveness of temporary single-patient rooms to reduce risks of healthcare-associated infection

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SUMMARY

Background: The use of single rooms for patient isolation often forms part of a wider bundle to prevent certain healthcare-associated infections (HAIs) in hospitals. Demand for single rooms often exceeds what is available and the use of temporary isolation rooms may help resolve this. Changes to infection prevention practice should be supported by evidence showing that cost-effectiveness is plausible and likely.

Aim: To perform a cost-effectiveness evaluation of adopting temporary single rooms into UK National Health Service (NHS) hospitals.

Methods: The cost-effectiveness of a decision to adopt a temporary, single-patient, isolation room to the current infection prevention efforts of an NHS hospital was modelled. Primary outcomes are the expected change to total costs and life-years from an NHS perspective.

Findings: The mean expected incremental cost per life-year gained (LYG) is £5,829. The probability that adoption is cost-effective against a £20,000 threshold per additional LYG is 93%, and for a £13,000 threshold the probability is 87%. The conclusions are robust to scenarios for key model parameters. If a temporary single-patient isolation room reduces risks of HAI by 16.5% then an adoption decision is more likely to be cost-effective than not. Our estimate of the effectiveness reflects guidelines and reasonable assumptions and the theoretical rationale is strong.

Conclusion: Despite uncertainties about the effectiveness of temporary isolation rooms for reducing risks of HAI, there is some evidence that an adoption decision is likely to be cost-effective for the NHS setting. Prospective studies will be useful to reduce this source of uncertainty.

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Introduction

Risks of healthcare-associated infection (HAI) are typically managed by a combination of active surveillance, compliance with hand hygiene protocols, antimicrobial stewardship, environmental cleaning, use of personal protective equipment, and the isolation of patients colonised with certain pathogens and those deemed high risk [1—4]. Any changes to infection prevention programmes by the addition or subtraction of a specific activity should be cost-effective and demonstrate value for money. If scarce resources are used for interventions that are not cost-effective it is likely that other interventions, that are better value for money, are displaced. This situation would then reduce total health outcomes and quality of care for a hospital's population of patients [5].

Clinical guidelines recommend single-room isolation for patients with multidrug-resistant pathogens and pathogens that are spread via the droplet route [6—9]. There are plausible mechanisms for benefit even when the research evidence is patchy [10] and the marginal effects of isolation are difficult to disentangle from a bundled strategy. It is challenging to establish by experiment the role of single-room isolation on risks of HAI. Two systematic reviews provide some evidence that isolation rooms are effective at reducing risks of HAI [10,11]. There is also research on the adverse effects of isolation showing that the mental well-being of patients is affected, that healthcare workers spend less time with patients, and that rates of adverse events are increased [12].

The aim of this study is to examine the potential value of adding 'Rediroom' [13,14] into UK National Health Service (NHS) hospitals. This is a temporary, single-patient, isolation room that can be deployed in a patient care area or ward. A cart containing the room can be moved to the required area and a canopy deployed to create an isolation space to care for infectious patients under contact or droplet precautions. It is an air-filtered isolation room with hands-free entry and an integrated PPE station. The room can be deployed by a single person in less than 5 min. The canopy of the room, which is the only part that could become contaminated, is single use and is disposed of. The frame of the room is smooth and can be cleaned consistent with terminal room cleaning requirements for the facility. The time to clean is not expected to be longer than a terminal clean. We report the development and findings from a cost-effectiveness model based on evidence synthesized from high-quality sources [15—17].

Methods

The primary outcomes are the expected change to 'total costs' and 'health benefits' measured in 'years of life' gained from a reduced incidence of HAI from a decision to adopt a temporary isolation room into the acute care setting. The perspective for the analysis is the UK National Health Service (NHS), and the baseline comparator against which the new item was compared was current rates of HAI in NHS hospitals.

The structure of the model used was simple, with current rates of HAI outcomes per 100,000 occupied bed-days observed in the NHS used to estimate baseline values for these outcomes: number of patients with an HAI; number of acute care bed-days used to manage the consequences of HAI; monetary value of these bed-days; deaths associated with patients with an HAI; years of life lost to HAI. Information is assembled to show the outcomes for 'all HAI', 'bloodstream infection', 'gastrointestinal infection', 'lower respiratory tract infection', 'pneumonia', 'surgical site infection', 'urinary tract infection', and 'other infections'.

The model was used to evaluate the 'effectiveness' of a decision to adopt a temporary isolation room, with effectiveness defined as a reduction in cases of HAI arising from the isolation of new admissions colonized with multi-resistant organisms. Effectiveness estimates between zero and 100% were used. If there are 250 cases of HAI per 100,000 occupied bed-days (OBD) under baseline conditions, then inputting an effectiveness estimate of 20% would reduce the number of cases by 50—200. The model was used to output new values for the outcomes based on the effectiveness scenario chosen. The model was also programmed to include the cost of purchasing and maintaining the temporary isolation rooms. Because the durations of HAI are relatively short, the use of preference utility weights to show quality-adjusted life-years (QALYs) was deemed unnecessary.

Dividing change to 'total costs' by change to 'total health benefits' yielded an incremental cost-effectiveness ratio, expressed as the cost per life-year gained (LYG). In the UK, most decisions made by National Institute of Health and Care Excellence regarding adoption of new technologies are contingent on a maximum willingness to pay of £20,000 and up to £30,000 [18]. Recent work by Claxton *et al.* suggests that an operational value adopted by the NHS is close to £13,000 [19].

In the present study, uncertainty is described such that the 'probability that an adoption decision is cost-effective' is estimated [20]. Values for this statistic that exceed 50% suggest that adoption is a better decision than remaining with existing practice, although values close to 50% imply large uncertainty in the decision and more information may be required prior to an implementation decision being made [21].

Information used for the model

The data on infection outcomes were obtained from the Evaluation of Cost of Nosocomial Infection (ECONI) study [22]. This two-centre prospective observational incidence study used hospital record linkage to provide full admission and discharge information on non-cases. The participating hospitals were broadly representative of other acute hospitals in Scotland in terms of patient specialties, distribution of elective, emergency and transfers, mean length of stay, previously reported HAI prevalence patient mix, and rurality. The teaching hospital had 831 available acute beds during the reporting period 2018/19 and the general hospital 418. The hospitals served 91% of all specialties served within Scotland in 2016.

During the study period there were a total of 99,018 adult overnight admissions, 31,655 to the general hospital and 67,363 to the teaching hospital. Different patterns of HAI incidence were seen in the two hospital settings. In the general hospital 87 cases of HAI were identified (0.28% of admissions), and there were 996 in the teaching hospital (1.48% of admissions). Overall, 893 patients had one or more HAI during their stay in hospital. A total of 135,831 bed-days were occupied within the general hospital and 298,003 bed-days in the teaching hospital. The median age of patients was 66 years (interquartile range (IQR): 51—78). Median (IQR) LOS for all admissions was 3 (1—8) days. Median (IQR) LOS for admissions with HAI was 30 (14—56)

Table I
Information about incidence rates of healthcare-associated infection (HAI) and prolongation of length of stay

Infection	Rate of HAI per 100,000 occupied bed-days	Extra length of stay due to an HAI
All HAI	250 (7.58)	7.80 (1.10)
Bloodstream	45 (3.19)	11.40 (2.80)
Gastrointestinal	39 (3.01)	6.00 (3.40)
Lower respiratory	42 (3.11)	7.30 (2.80)
Pneumonia	24 (2.32)	16.30 (4.50)
Surgical site	35 (2.86)	9.80 (2.70)
Urinary tract	51 (3.42)	0.00 (0.00)
Other	14 (1.76)	14.00 (9.10)

All values are mean (standard deviation).

days. The incidence rates for HAI under baseline conditions were informed by the data from the ECONI study and represent the baseline comparator of existing practice (Table I).

The extra length of stay due to an HAI was estimated from the same data collected for the ECONI study [23]. A multi-state modelling approach that took account of time varying exposures and the competing risks of death and discharge was used [24]. The probabilities of transitions from admission to discharge or from admission to HAI, and then to discharge during the admission were estimated using the Aalen–Johansen estimator [25]. The mean excess LOS was estimated by calculating the average difference in LOS between patients with and without HAI at each time, weighted by the observed distribution of time to HAI. A total of 50 bootstrap samples were generated and the distributional spread of the excess LOS assessed. Normality was deemed to be followed, allowing estimation of 95% confidence intervals using the standard error calculated from the bootstrap samples. The findings from this analysis are shown in Table I.

For hospital mortality, 649 (74%) HAI-related admissions were discharged alive from hospital and 149 (17%) died in hospital; 58,208 (92.4%) non-HAI-related admissions had been discharged alive from hospital and 2414 (3.8%) died in hospital. The unadjusted relative risk of death for all HAIs is 4.69 (95% CI: 3.94–5.58). Unadjusted relative risks and the 95% confidence interval for the specific types of HAI are shown in Table II.

Life expectancy for those born in the UK in 1954 is 85 years for males and 87 years for females [26]. Future years of life saved are discounted at 3%. One bed-day in an acute hospital is valued at a cost of £799 (standard deviation: £536) [27]. The costs of adopting a temporary isolation room for 100,000 occupied bed-days are estimated by assuming that the capital cost of the cart is £400 per month over a five-year life span, and one canopy costs £300 and will be used for the duration of stay for one isolated patient (A. Pitt, personal communication, Gama Healthcare; 2021).

Table II
Unadjusted relative risks of death due to healthcare-associated infection

Infection	Discharged	Died	RR (95% CI)
Bloodstream	97	44	7.84 (5.50–11.16)
Gastrointestinal	98	24	4.94 (3.17–7.71)
Lower respiratory	115	30	5.20 (3.48–7.75)
Pneumonia	52	19	6.72 (3.98–11.35)
Surgical site	108	12	2.51 (1.39–4.55)
Urinary tract	154	16	2.36 (1.39–4.55)
Other	25	4	3.46 (1.21–9.95)

RR, relative risk; CI, confidence interval.

The proportion of newly admitted patients who would need to be isolated with contact precautions is assumed to be in a range between 3% and 30%. This is based on published data showing that 3.4% of admissions to NHS hospitals are colonized with meticillin-resistant *Staphylococcus aureus* (MRSA), 0.1% with carbapenemase-producing Enterobacterales, 9% with extended-spectrum β-lactamase Enterobacterales [28]. For vancomycin-resistant enterococci (VRE) a systematic review revealed colonization with VRE on admission to the intensive care unit (ICU) was 8.8% (range: 7.1–10.6) [29]. Adding these estimates together shows that 21.3% of patients might require isolation and contact precautions.

The potential for a temporary isolation room to reduce HAI rates

Evidence for the effect of single-room isolation alone on reducing HAI rates is scarce [10]. This study modelled potential reductions in cases at 30% on average with a standard deviation of 5%. As guidelines across the world recommend single-room isolation for a range of multidrug-resistant pathogens and pathogens spread via the droplet route, we assumed that there was a substantial benefit [6–9].

Uncertainty and model evaluation

The uncertainties in the parameters were included in the model by fitting prior statistical distributions, which were then subject to 3000 random samples. This propagated forward uncertainties to output distributions of model outcomes. The parameter estimates and prior distributions for evaluating the cost-effectiveness of adopting a temporary isolation room are shown in Table III.

The number of cases of HAI per 100,000 OBD was fitted to a normal distribution using the information in Table I. The number of bed-days saved per 100,000 OBD was fitted to a gamma distribution also using the information in Table I. The monetary estimates of costs saved from the bed-days released was fitted to a gamma distribution based on mean cost per bed-day of £799 (SD: £536). The number of deaths avoided was estimated with uncertainty by taking the relative risk of death associated with HAI from the 'hospital mortality' data on a logarithmic scale, which was assumed to follow a normal distribution. The exponent of the logarithmic resample was used to update the model outcomes. The discounted life-years gained from the expected reduction to deaths was based on published life tables [26].

Scenario analyses

The issue of the 'unadjusted' relative risk of death from HAI was addressed by halving the risk to show whether model conclusions were robust to a reduced estimate of the health benefits gained. We also reported results against a

Table III
Information used, and uncertainties in the model parameters

Variable	Estimate	Prior distribution	Source
Cases of HAI baseline/100,000 OBD			
Bloodstream	45	Normal (45, 3.19)	[22]
Gastrointestinal	39	Normal (39, 3.10)	
Lower respiratory	42	Normal (42, 3.11)	
Pneumonia	24	Normal (24, 2.32)	
Surgical site	35	Normal (35, 2.86)	
Urinary tract	51	Normal (51, 3.42)	
Other	14	Normal (14, 1.76)	
Excess LOS (days), mean (SD)			
Bloodstream	11.4 (2.8)	Gamma (16.58, 0.69)	[23]
Gastrointestinal	6 (3.4)	Gamma (3.11, 1.93)	
Lower respiratory	7.3 (2.8)	Gamma (6.80, 1.07)	
Pneumonia	16.3 (4.5)	Gamma (13.12, 1.24)	
Surgical site	9.8 (2.7)	Gamma (13.17, 0.74)	
Urinary tract	0		
Other	14 (9.1)	Gamma (2.36, 5.91)	
Log_{10} of relative risk of death			
Bloodstream infection	7.84	Normal (2.06, 0.18)	[23]
Gastrointestinal infection	4.94	Normal (1.6, 0.23)	
Lower respiratory tract infection	5.20	Normal (1.65, 0.2)	
Pneumonia	6.72	Normal (1.91, 0.27)	
Surgical site infection	2.51	Normal (0.92, 0.3)	
Urinary tract infection	2.36	Normal (0.86, 0.26)	
Other	3.46	Normal (1.24, 0.54)	
Other parameters			
Cost per bed-days (mean, SD)	799 (536)	Gamma (2.23, 358.92)	[27]
Mean age of patients (years)	66	Fixed	
Life expectancy		Fixed	[26]
Males	85		
Females	87		
Effectiveness (mean, SD)	30%, 5%	Beta (24.9, 58.1)	
% admissions isolated (range)	3%, 30%	Uniform (0.03–0.3)	

HAI, healthcare-associated infection; OBD, occupied bed-days; LOS, length of stay; SD, standard deviation; RR, relative risk.

lower 'maximum willingness to pay for life-years gained' of £13,000 rather than £20,000. Finally, the minimum mean value was sought for effectiveness at which the probability of cost-effectiveness exceeded 50%, and therefore favoured adoption. Expected change to all outcomes and the expected costs of implementing a temporary isolation room were reported. This enabled expected change to 'total costs' and 'life-years gained' and an estimate of cost-effectiveness.

Results

The distribution of the expected effectiveness estimate is shown in Figure 1. The expected changes to all outcomes arising from this, with uncertainties, are shown in Table IV.

The mean expected cost of implementing a temporary isolation room per 100,000 OBD in an NHS hospital is £1,545,949, the mean change to total costs is expected to be £1,073,645, and the mean change to LYG is expected to be £184.19. The mean incremental cost per LYG is £5,829. The joint distribution of these uncertain outcomes is shown in Figure 2 and the probability that adoption is cost-effective against a £20,000 threshold per additional LYG is 93%, and for £13,000 this is reduced to 87%.

The results of the scenario analysis, where the risk of death with HAI is halved, show the probability that adoption is cost-effective against a £20,000 threshold has reduced to 79%. And when the lower threshold of $13,000 per LYG is used, the probability that adoption is cost-effective is reduced to 67%. Finally, if the mean value for effectiveness were reduced to 16.5%, then the probability that adoption is cost-effective would exceed 50%.

Discussion

Not all strategies to reduce risk of HAI can be fully and simultaneously prosecuted among busy clinical teams. There is a need to identify infection control activities that deliver the largest health return per dollar invested and this is usefully informed by cost-effectiveness studies [30]. An essay on the role of economic evaluation regarding HAI is available and covers the topics of why the discipline of economics is useful for infection control professionals, how measures of economic outcomes should be achieved, how decision-makers should use the results of economic evaluation studies, and importantly, an

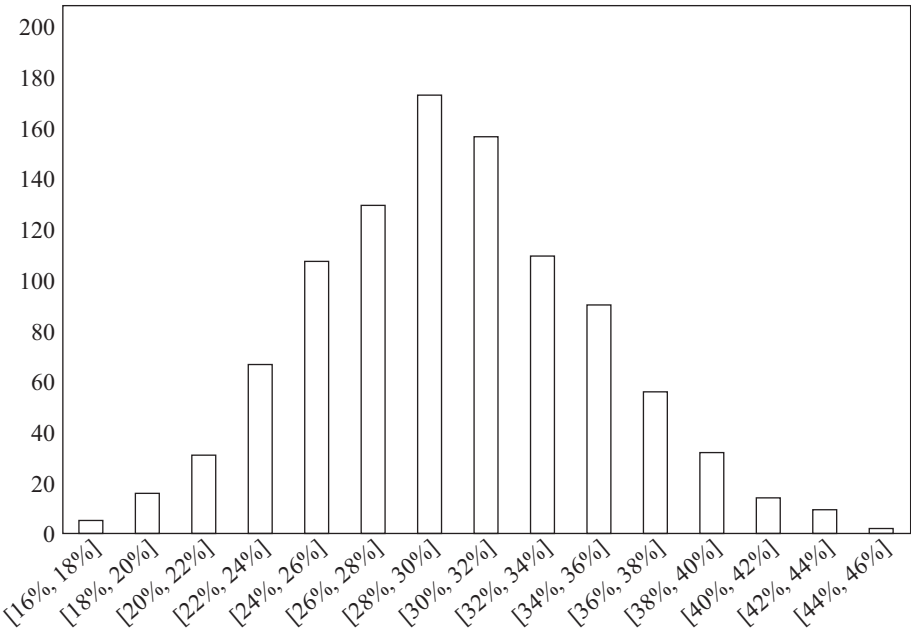

Figure 1. The posterior distribution of the assumed effectiveness parameter.

Table IV
Expected changes to all outcomes arising from this, with uncertainties

Infection	HAI cases avoided	Bed-days saved	Monetary value of bed-days	No. of deaths avoided	Life-years gained
All HAI	75 (13)	584 (348)	£486,280 (£1,297,281)	11.69 (2.38)	184 (38)
Bloodstream	13 (2)	153 (154)	£116,846 (£362,786)	3.71 (1.02)	58 (16)
Gastrointestinal	12 (2)	69 (167)	£53,374 (£216,757)	1.87 (0.65)	29 (10)
Lower respiratory	13 (2)	94 (147)	£76,992 (£252,753)	2.17 (0.68)	34 (11)
Pneumonia	7 (1)	117 (135)	£93,228 (£292,225)	1.71 (0.64)	27 (10)
Surgical site	10 (2)	100 (117)	£81,353 (£255,890)	0.68 (0.36)	11 (6)
Urinary tract	15 (3)	0 (0)	£0,000 (£0,000)	0.88 (0.43)	14 (7)
Other	4 (1)	60 (161)	£48,514 (£200,742)	0.68 (0.43)	11 (7)

All values are mean (standard deviation).

argument is made that good economics can improve the amount of health gained from an infection prevention service working under conditions of scarce resources [5]. A range of narrative and systematic reviews have been done on the economics of competing infection prevention interventions [31–40].

The findings reported here provide some evidence that the adoption of single portable isolation rooms by the NHS will be a cost-effective decision. This conclusion is robust to uncertainty arising from model parameters and to plausible scenarios. The data used for incidence rates, extra stay due to HAI and mortality outcomes are recent, were collected from the NHS setting, and are high quality. We emphasize the fact that risk of death from HAI is unadjusted for other factors that might explain its variation, and so this parameter must be treated with some caution. Those with an HAI might have an elevated risk of death compared to those without an HAI, regardless of the presence of HAI. To address this source of uncertainty the 'risk of death' was halved and the model simulations were re-run. The evidence to support adoption was weaker and the probability that adoption was a good decision was reduced. Reducing the maximum willingness to pay for marginal LYG from £20,000 to an evidence-based figure of £13,000 reduced the probability that adoption was cost-effective. Being robust to this scenario supports our confidence in the adoption decision. The minimum required effectiveness for Redirroom to be cost-effective is 16.5%. Our effectiveness parameter is, however, based on expert opinion and not real data. This is the greatest unknown regarding the decision and a prospective clinical trial of Redirroom in the real-world setting would be useful to address uncertainty in this assumption.

Nonetheless, our treatment of the effectiveness parameter emerges from reasonable assumptions. Guidelines across the world recommend single-room isolation for patients with multidrug-resistant pathogens [41–44]. These same guidelines recommend isolation for patients with infections spread via the droplet route. Recommendations in these guidelines are generally supported by low-quality evidence [45]; however, the theoretical rationale is strong. Similarly, single-room isolation is a key pillar of infection prevention in hospitals and common practice as part of a wider approach to contact precautions. Isolation is of course one element of contact precautions, and it

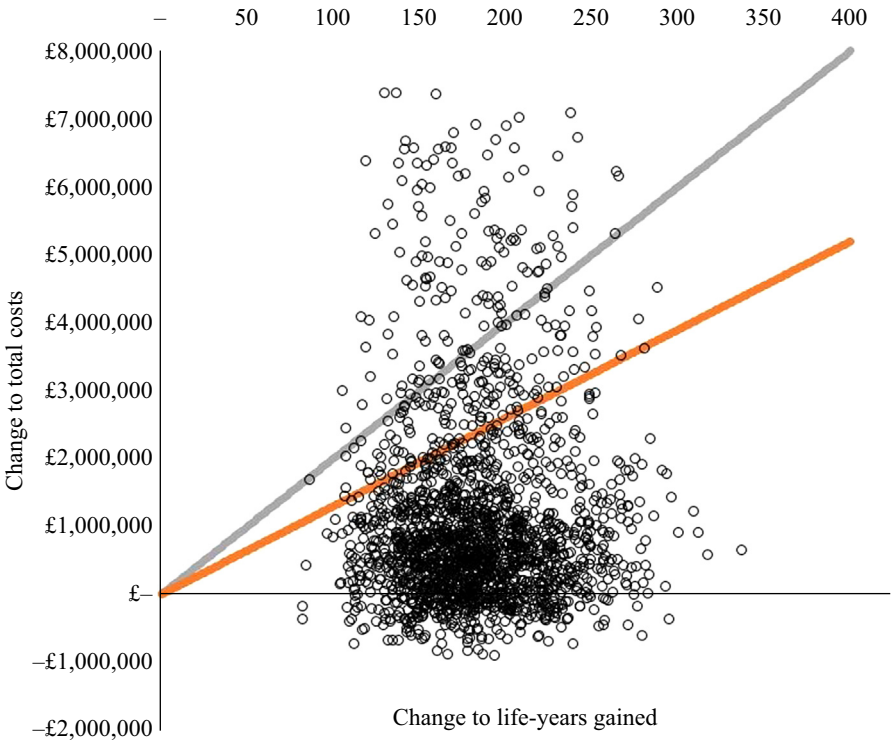

Figure 2. Uncertainty shown for the cost-effectiveness outcomes with two thresholds: £20,000 and £13,000.

is difficult to tease out the specific effectiveness of just one measure. This is particularly the case when the evidence underpinning the use of contact precautions uses a 'bundled' approach, which includes the use of personal protective equipment, different models of cleaning, as well as patient isolation [46]. A study conducted in Korea found that strict isolation was associated with a reduction in incidence density of VRE from 1.45 to 0.74 cases per 10,000 patient-days [47]. Modelling suggests that the probability of acquiring MRSA and vancomycin-resistant enterococcus without isolation increases rapidly, from 5% to 20% in just one week [48]. The longer a patient is not isolated, the greater the risk of cross-infection with other patients and potentially staff. A systematic review [10] included 46 studies on the effectiveness of isolation measures in reducing the incidence of MRSA colonization and infection in hospital patients. The authors found weaknesses and inadequate reporting in studies and concluded that alternative explanations for reductions in MRSA acquisition could not be ruled out; but they did confirm that initiatives featuring isolation interventions can reduce MRSA, even in endemic settings.

A more recent review with a wider scope addressed the question of whether healthcare facility design, including the use of single rooms, is a useful part of infection control [11]. The authors included studies that reported acquisition of colonization or development of infection with HAI when comparing clinical areas with 'single rooms' to clinical areas with 'multi-occupancy' spaces. For the analyses, all bundled interventions were excluded. From the nine studies included, eight were in ICU setting and there were large differences in the study designs. All but one of the studies reported reduction of HAI due to a greater proportion of single rooms. There was a halving of the HAI risk in single-room environments with a risk ratio of 0.55 (95% confidence interval: 0.41–0.74).

Some potentially unmeasured benefits of this intervention could necessitate responding to outbreaks of highly contagious pathogens circulating in the community which then impact patients in hospitals. A review of bed-days lost due to diarrhoea and vomiting between the years 2010–2016 indicated that between 88,000 and 113,000 beds were closed due to gastroenteritis each winter, 19.6–20.4% of which were unoccupied with costs of £5.7–7.5 million [49].

Despite uncertainties about the effectiveness of Redirom for reducing risks of HAI, this study supplies some evidence that an adoption decision is likely to be cost-effective for the NHS setting. Prospective studies will be useful to reduce this source of uncertainty.

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