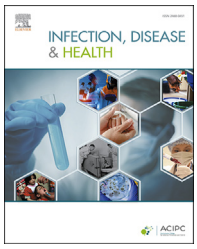
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Research paper

A cost-effectiveness model for a decision to adopt temporary single-patient rooms to reduce risks of healthcare-associated infection in the Australian public healthcare system

Nicholas Graves [a,*], **Martin Kiernan** [b,c], **Brett G. Mitchell** [b]

[a] *Health Services & Systems Research, Duke-NUS Medical School, 8 College Road, Singapore, 169857, Singapore*
[b] *School of Nursing and Midwifery, College of Health, Medicine and Wellbeing, School of Nursing, Avondale University, Cooranbong, NSW, Australia*
[c] *Gama Healthcare Ltd, Hemel Hempstead, UK*

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KEYWORDS
Patient isolation;
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Abstract *Background:* The cost-effectiveness of patient isolation as part of an infection prevention effort is poorly understood. The potential to reduce risks of transmission saving costs and improving health outcomes is strong, yet up front investments in patient isolation are required. We report a cost-effectiveness model to inform adoption of a portable single isolation rooms into Australian publicly funded acute hospitals.
Methods: Information is harvested from a range of contemporary sources to reveal the expected changes to total costs and total health benefits measured by life years gain. An Incremental cost-effectiveness ratio is estimated with uncertainty in all model parameters included by probabilistic sensitivity analysis.
Results: The adoption decision was found to change total costs per 100,000 occupied bed-days by $1,429,011 and generate health benefits of 436 life years. The mean cost per life year gained is $3278. The probability an adoption decision is cost saving is 2.1%.
Conclusion: There is some evidence that adoption of redirooms is likely to be a cost-effective solution for Australian hospitals. Important caveats and assumptions need to be considered when interpreting this conclusion.
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* Corresponding author.
E-mail address: n.graves@duke-nus.edu.sg (N. Graves).
Twitter: @NickDisco.

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Highlights

- Little is known about the cost-effectives of patient isolation for the control of healthcare associated infections.
- Rediroom is a portable single isolation rooms available to Australian hospitals.
- The evidence for effectiveness emerged from expert opinion and is uncertain.
- We estimate that adoption will be cost-effectives, given uncertainty and reasonable assumptions.

Introduction

There are an estimated 165,000 cases of healthcare associated infections (HAI) each year in Australian hospitals. These imply large health and economic burdens [1] and studies have reported the costs arising from urinary tract infections [2], *Clostridioides difficile* infections [3], surgical site infections [4], respiratory infections [5] and hospital-onset *Staphylococcus aureus* bacteraemia [6]. Further large costs are likely to arise from pneumonia [7], gastroenterological [8] and bloodstream infections [9,10].

Current infection control practices include improving hand hygiene compliance, surveillance of selected pathogens, stewardship of antimicrobials, environmental cleaning, use of personal protective equipment and the isolation of high risk patients. Isolation is used to reduce transmission of infectious agents or diseases by reducing contact with individuals or the environment and reducing exposures to droplet or airborne particles [11].

The extent to which all high risk patients can be effectively isolated largely depend on the number of single rooms available. While the number of beds that are in single rooms in Australian acute hospitals is not easy to know, a recent study found that total bed occupancy of single beds did not fall below 99·4%, with infection control cited as the main reason for patients being allocated to a single-bed room [12]. This suggests demand is strong for single rooms and while there is a trend for new build hospitals to have more single rooms it will likely take a long time to provide sufficient capacity.

A potential solution to a shortage of single rooms for isolation is the adoption of temporary 'pop-up' single patient isolation rooms. For this paper we consider 'rediroom' [13], a mobile cart that unpacks into an air-filtered isolation room that offers the users hands-free entry. This technology potentially enables superior isolation capacity and flexibility. The mechanisms of benefit for patients are plausible yet evidence about the potential value of increasing single-room isolation for drug resistant organisms and droplet spread pathogens is limited [14]. No definitive studies exists to support improvements to patient outcomes [15]. What is currently known is reported in systematic reviews for isolation rooms and HAI outcomes [15,16]. There is also evidence of negative aspects of patient isolation from increased adverse events [17].

The cost-effectiveness of any change to infection control practices, such as expanding isolation rooms, should be assessed to support sustainability and the efficiency of health services. Indeed, cost-effectiveness information is becoming more important for decision makers [18].

The aim for this paper is to model the potential economic changes from a decision to adopt 'Rediroom' into Australian public hospitals. A similar study has been done for the NHS and here we extend and build on that work [19]. The proposed intervention is a temporary, single patient, isolation room transformed from an unfolding PPE cart, fully operational in 5 min [20,21]. The baseline comparator against which the adoption of Rediroom will be judged are current rates of HAI in Australian hospitals. The specific objective for this analysis is to develop a cost-effectiveness model to show by how much 'health care costs', 'cases of HAI' and associated 'health benefits' are expected to change from a decision to adopt 'Rediroom' into an Australian publicly funded acute hospital.

Our rationale for this research is that rates of HAI can be reduced in the Australian setting, yet the adoption of single room isolation may be costly to implement. If effective, adoption will reduce rates of infection, save downstream health services costs and increase health benefits. The analysis will reveal whether the change to total costs are adequately compensated by the change to health benefits, and this is important information for decision makers to have.

Methods

The setting is Australian publicly funded principal referral or 'Group A' hospitals. There are currently 30 principal referral and 61 group A hospitals in the Australian health system [22]. The perspective for costs are health services. Because the duration of infection is usually measured in days, with long term consequences rare, we have not used preference utility weights to estimate quality-adjusted life-years. Rather life years gained from reduced risk of death are the measure of health benefit. All outcomes are estimated for 2018 and all costs reported in Australian Dollars. All items for the CHEERS checklist [23] have been addressed for this study.

The cost-effectiveness model we propose will include rates of HAI outcomes per 100,000 occupied bed-days and this defines the existing practice comparator. The model is then used to estimate the following outcomes:

Outcome 1. Expected number of patients with an HAI per year.
Outcome 2. Number of acute care bed-days required to manage the consequences of HAI.

Outcome 3. Monetary value of the bed-days lost.
Outcome 4. Number of deaths associated with patients with an HAI.
Outcome 5. Years of life lost to HAI.

All outcomes are estimated for healthcare acquired bloodstream infection (BSI), Clostridioides difficile infection (CDI), pneumonia (HAP), surgical site infection (SSI) and urinary tract infection (UTI).

The 'effectiveness' of a decision to invest in temporary isolation rooms is shown by a reduction in cases of HAI arising from the isolation of new patients who are colonized by multi-resistant organisms. Estimates of effectiveness between zero and 100% can be applied. The model is used to generate alternate values for the defined outcomes based on a chosen scenario for effectiveness. The model also includes information about the costs of purchasing and maintaining the temporary isolation rooms. An incremental cost-effectiveness ratio is estimated as the 'cost per life year gained' and this will be judged against commonly used thresholds for cost effectiveness of $28,000 [24]. We consider uncertainty in terms of the 'probability that an adoption decision is cost-effective' [25] and values for this statistic greater than 50% provide evidence that adoption is superior to existing practice.

Information used for the model

The data used to show the occurrences of infection outcomes were obtained from a recent Australian prevalence survey [26]. We use information reported from an adjunct modelling study that obtained incidence rates from the observed prevalence's [27]. The prevalence survey [26] was done in 2018 with 2767 patients from 19 hospitals included. The median age of patients was 67, and 52.9% of the sample were male. Presence of a multidrug resistant organism was documented for 10.3% of the patients. We assume the 19 study hospitals included are representative of the other 30 principal referral and 61 Group A hospitals in Australia in terms of clinical specialties, distribution of elective and emergency admissions, patient mix and comorbidities.

In 2018 there were a total of 4,389,805 admissions to acute hospitals that involved an overnight stay, excluding psychiatric admissions [28]. These are the denominator for the number of HAIs derived by the modelling for incidence rates [27]. Seventy per cent of these were in public hospitals and 30% in private. The estimated incidence rates for HAI under baseline conditions are shown in Table 1. The mean length of stay for patients in the prevalence survey was 6.25 days and the number of admissions per 100,000 occupied bed days is 18,522. The number of cases of HAI per 100,000 occupied bed-days is also shown in Table 1.

The extra length of stay due to HAI was estimated from a range of sources. For BSI, HAP and UTI values of 5.33 days, 2.82 days and 1.04 days [29] were used, respectively. For CDI a value of 0.9 days [30] was used and for SSI values in a range between 4 and 8 days were used [31]. All estimates apart from for SSI were derived from Australian data and arose from multi-state modelling, which takes account of time varying exposures and the competing risks of death and discharge [32]. For SSI there were no high-quality Australian estimates available, and so we used findings from a recent systematic review of studies that reported all methods to estimate prolongation to LOS from HAI. Twenty-seven studies reported the excess stay due to HAI, with a minimum value of 4 days and a maximum of 8. For hospital mortality associated with HAI we used information from the UK based ECONI study [33,34]. The parameter estimates and prior distributions for evaluating the cost-effectiveness of adoption Rediroom are shown in Table 2.

Table 1 Incidence rates and cases per 100,000 occupied bed days.

	Annual incidence rate	Cases per 100,000 occupied bed-days
BSI	0.50%	93
CDI	0.11%	20
HAP	1.06%	196
SSI	0.92%	170
UTI	0.88%	164
All	3.47%	642

Including uncertainty

The number of cases per 100,000 occupied bed-days is made uncertain by fitting a normal distribution to the numerator and dividing by the relevant denominator of 4,389,805 admissions. The result is a rate that is applied to the number of cases per 100,000 occupied bed-days. The number of bed days saved per 100,000 occupied bed-days is fitted to statistical distributions using the information in Table 2. The monetary estimates of costs saved from the bed days released is taken as a fixed value of $1667 [35]. The number of deaths avoided is estimated with uncertainty by taking the relative risk of death associated with HAI from the 'hospital mortality' data on a log scale, this is assumed to be follow a normal distribution. The exponent of the log resample is used to update the model outcomes. The discounted life years gained from the expected reduction to deaths is based on Australian life tables [36].

Scenario analysis

The risk of death with HAI was halved to show whether model conclusions were robust to a reduced estimate of health benefits gained.

Results

The effectiveness parameter of a decision to adopt Rediroom is shown in Fig. 1. This reveals the most likely level of effectiveness is ~30% reduction in HAI cases. There is a lower likelihood that adoption of Rediroom will reduce cases by ~14% or by ~51%.

The expected change to all outcomes from a decision to adopt Rediroom is shown in Table 3.

The adoption decision is expected to change total costs per 100,000 occupied bed-days by $1,429,011 and generate health benefits of 436 life years. The mean cost per life year gained is $3278. The joint distribution of the uncertain

Table 2 Parameters and distributions used for cost-effectiveness model.

	Estimate	Distribution	Source
Cases of HAI under baseline conditions	per 100,000 occupied bed-days		
BSI	93/100,000	Normal (21925, 4753)	Table 1
CDI	20/100,000	Normal (4678, 1998)	Table 1
HAP	196/100,000	Normal (46564, 11695)	Table 1
SSI	170/100,000	Normal (40240, 7495)	Table 1
UTI	164/100,000	Normal (38751, 10120)	Table 1
Excess length of stay	Days		
BSI (mean, sd)	5.33 (0.08)	Gamma (4850,0.001)	[29]
CDI (mean, sd)	0.9 (1.38)	Gamma (0.43, 2.10)	[30]
HAP (mean, sd)	2.82 (0.07)	Gamma (1453, 0.002)	[29]
SSI min, max	4, 8	Uniform [4,8]	[31]
UTI (mean, sd)	1.04 (0.17)	Gamma (38.15, 0.027)	[29]
Log of relative risk of death from HAI	Relative Risk		
BSI	7.84	Normal (2.06, 0.18)	[33,34].
CDI	4.94	Normal (1.6, 0.23)	[33,34].
HAP	6.72	Normal (1.91, 0.27)	[33,34].
SSI	2.51	Normal (0.92, 0.3)	[33,34].
UTI	2.36	Normal (0.86, 0.26)	[33,34].
Other parameters			
Cost per Bed Days (mean, sd)	1667	Fixed	[35]
Mean age of patients	66	Fixed	[26]
Life expectancy	85 (m) 88 (f)	Fixed	[36]
Effectiveness of redirooom (mean, sd)	30%, 5%	Beta (24.9, 58.1)	ASSUMPTION
% admissions who are isolated (min, max)	5—15	Uniform	[26]

outcomes is shown in Fig. 2 and the probability that adoption is cost effective against a $28,000 threshold per additional LYG is 100%. The probability an adoption decision is cost saving is 2.1%.

When the risk of death from HAI is halved, reducing the health benefits from fewer cases of HAI from a decision to adopt redirooom, the economic evidence to support adoption is slightly lessened. The mean change to 'total costs' is increased to $1,427,785 and the mean change to 'total health benefits' is lower at 205 life years gained. The mean cost per life year gained is $6982. The probability an adoption decision is cost-effective is 98% and the probability it is cost saving is 1.1%.

Discussion

This analysis provides some evidence that adoption of 'Redirooom' into the Australian public healthcare system will be a cost-effective decision against commonly used thresholds. The results of the initial analyses and the reduced mortality scenario show incremental cost-effectiveness comfortably below the threshold used for decision making in Australia [24,37].

The data used for incidence rates [27] are likely to be accurate as they arose from a recent and high quality prevalence survey conducted in 19 acute hospitals. The estimates of extra stay due to HAI, apart from SSI, arise from Australian data and appropriate analytic methods. The result for BSI is somewhat low at 5.3 days but might well reflect current clinical practice in Australia. The estimates for Pneumonia and UTI are also quite low but make intuitive sense given shortening lengths of stay and a move towards shorter courses of treatments. These potentially low estimates for LOS mean our cost-effectiveness analysis is conservative. As no Australian data were available for SSI we harvested data from 27 international studies that showed small variation in the outcome; a range between 4 and 8 days makes clinical sense. Only one [38] of the 27 estimates arose from methods that accounted for the time varying nature of an exposure to HAI. Even if the rage of estimates used are not valid, it is unlikely to change the conclusions for cost effectiveness.

The risk of death from HAI was taken from the recent UK based ECONI study [33,34] as no suitable estimates could be found from Australian sources. Furthermore, it is unadjusted for other factors that might explain variation in this outcome, so this needs to be treated with some caution. This issue is that those with an HAI might have a greater risk of death that those without an HAI, regardless of the HAI. To address this, the 'risk of death' estimates was halved and the simulations re-run. The evidence to support adoption was minimally affected as the model-predicted cost savings and positive health gains. These parameters are still the cause of a large amount of uncertainty for these conclusions. The effectiveness parameter is not based on data; rather expert opinion was used. Real world effectiveness remains the greatest unknown for this work and a well-designed prospective clinical trial of portable single isolation rooms in the real-world setting would be useful to address the current uncertainty about this assumption.

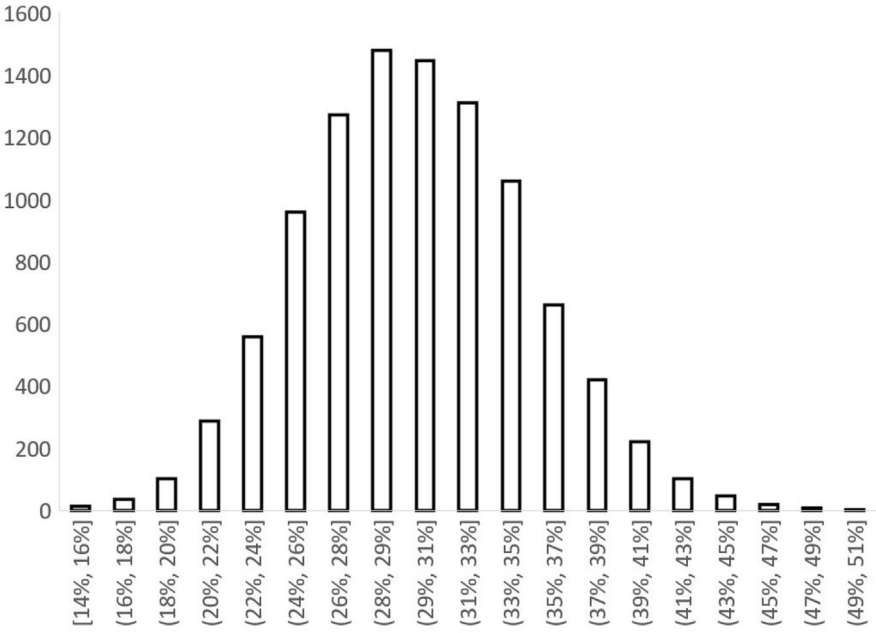


Figure 1 Distribution of the effectiveness parameter.

Table 3 Mean (standard deviation) outcomes per 100,000 occupied bed days from a decision to implement Rediroom.

	Cases of HAI avoided	Bed-days saved	Value of bed days saved	Deaths avoided	Life years
All HAI	192 (40)	674 (156)	$1,123,946 ($260,289)	28.67 (8.24)	436 (125)
BSI	28 (8)	147 (41)	$245,371 ($68,216)	7.67 (2.71)	117 (41)
CDI	6 (3)	5 (9)	$8782 ($15,339)	0.96 (0.54)	15 (8)
HAP	59 (18)	166 (51)	$276,469 ($85,319)	13.94 (6.19)	212 (94)
SSI	51 (13)	305 (105)	$508,243 ($175,780)	3.30 (1.90)	50 (29)
UTI	49 (15)	51 (18)	$85,081 ($30,026)	2.81 (1.57)	43 (24)

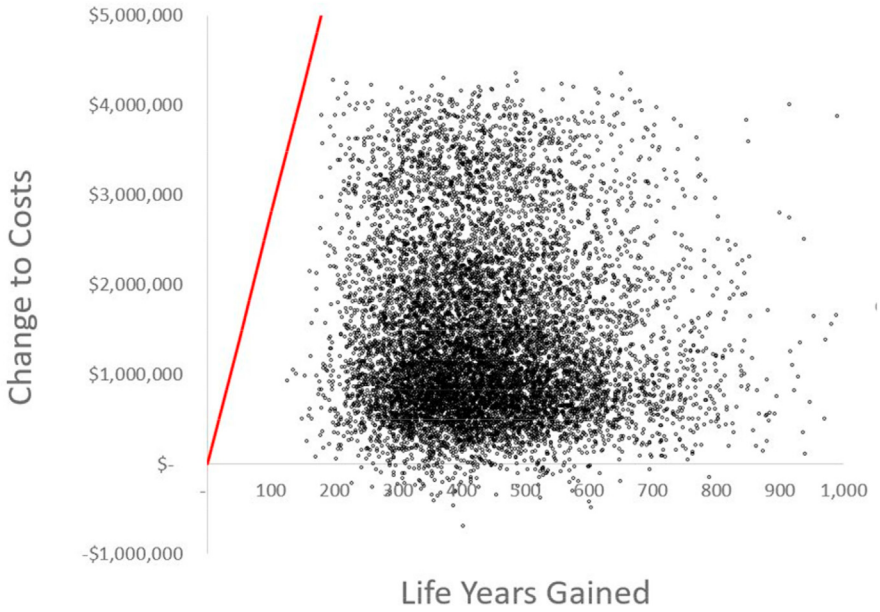


Figure 2 Uncertainty for the cost-effectiveness outcome against a threshold of $28,000, with the diagonal red line indicating a threshold of $28,000 per life year gained. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

There is likely to be variation in the proportion of patients isolated in Australian hospitals. We know that 10.3% of patients had organisms that would require isolation, based on findings from the recent Australian prevalence survey. Our approach was to include a range between 5% and 15% to allow for uncertainties, and the decision-making conclusions were robust to this source of uncertainty.

In Australia, the availability of single rooms does vary. In some new builds, 100% of rooms are single occupancy, whereas other hospitals have very limited single rooms available. Where single rooms are limited, difficult decisions are needed around the allocation of these rooms to manage and balance different infection risks alongside other non-infection related care needs such as palliation and behavioural or the mental health needs of patients [39]. Having a cost-effective portable isolation room facility to flex and respond to needs may help address such issues. A practical consideration is where temporary isolation rooms would be set up. They will take up more space than the average bed space, so new suitable locations would have to be found. There might also be increased staffing requirements to screen patients on admission, set the rooms up and then care for the relevant patients.

We see from previous studies that current isolation rooms usage is close to 100%, implying a need for temporary isolation [12]. We see the rooms as being useful for admissions deemed high risk who cannot be accommodated in an existing single room, they might also be used to control outbreaks within the hospital, or to isolate patients with highly contagious pathogens acquired in the community setting. The deployment of temporary isolation rooms could be based on current recommendations for single-room isolation for infection prevention and control.

Overall we provide some evidence, with our caveats made transparent, that adoption of rediroom is likely to be a cost-effective solution for Australian hospitals.

Ethics

No ethics review was required as all data were publically available and previously published in summary form.

Authorship statement

NG, MB and MK contributed to: conception and design of the study, acquisition of data and analysis and interpretation of data; drafting the article or revising it critically for important intellectual content; and, final approval of the version to be submitted.

Conflict of interest

Neither B.M. nor M.K. received fees from Gama Healthcare for this publication. B.M. has received research funding from Gama Healthcare through a Commonwealth government grant process (Innovations Connections). M.K. is the clinical director of Gama Healthcare.

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Provenance and peer review

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