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Do cost savings from reductions in nosocomial infections justify additional costs of single-bed rooms in intensive care units? A simulation case study

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ABSTRACT

Purpose: Evidence shows that single-patient rooms can play an important role in preventing cross-transmission and reducing nosocomial infections in intensive care units (ICUs). This case study investigated whether cost savings from reductions in nosocomial infections justify the additional construction and operation costs of single-bed rooms in ICUs.

Materials and methods: We conducted deterministic and probabilistic return-on-investment analyses of converting the space occupied by open-bay rooms to single-bed rooms in an exemplary ICU. We used the findings of a study of an actual ICU in which the association between the locations of patients in single-bed vs open-bay rooms with infection risk was evaluated.

Results: Despite uncertainty in the estimates of costs, infection risks, and length of stay, the cost savings from the reduction of nosocomial infections in single-bed rooms in this case substantially outweighed additional construction and operation expenses. The mean value of internal rate of return over a 5-year analysis period was 56.18% (95% credible interval, 55.34%-57.02%).

Conclusions: This case study shows that although single-patient rooms are more costly to build and operate, they can result in substantial savings compared with open-bay rooms by avoiding costs associated with nosocomial infections.

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1. Introduction

The critically ill patients in intensive care units (ICUs) are susceptible to infection, making the risk nosocomial infections much greater in ICUs than in other hospital departments [1-3]. Nosocomial infections are associated with substantial morbidity and mortality [1,4]. Although recent efforts to improve health care quality and safety in the United States and around the world have led to major progress in preventing nosocomial infections, studies continue to show that there is still a considerable room for improvement in preventing the hundreds of thousands of nosocomial infections that occur every year [5-7].

Some efforts to control nosocomial infections focus on changing the behaviors of those involved in patient care; others focus on standardizing the clinical best practices for preventing infections. Examples of behavioral strategies include education and performance feedback [8] as well as teamwork and decision making by physician-led multidisciplinary teams [9,10]. Clinical practices include screening at hospital admission, standard isolation measures (eg, hand hygiene, personal protective equipment, respiratory hygiene and cough etiquette, cleaning and disinfection of equipment and environment, and waste disposal), and transmission-based isolation measures (eg, contact, droplet, and airborne isolation) precautions during hospital stay [11]. In recent years, hospitals have also used decolonization strategies, such as the use of daily chlorhexidine bathing [12-14], and used nasal mupirocin [14,15] for controlling transmission of multidrug-resistant organisms.

However, given the multifactorial nature of these infections, no single intervention is likely to be sufficient. Multiple interventions, including those that focus on the physical environment, are necessary to mitigate risk [16,17]. A growing body of evidence demonstrates that nosocomial infection rates can be reduced through changes in facility design and operation, including the use of single-patient rooms, air filtration devices, antibacterial surfaces, cleanable surfaces, and properly located hand-cleaning rubs and sinks [11,18-20].

Although there are studies that have not demonstrated no significant differences in highly endemic infections between single-patient and open-bay rooms [21,22], many other studies have specifically shown the benefits of single-patient rooms in preventing environmental contamination and interrupting transmission of pathogens in adult [23-30]

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and pediatric [31,32] ICU settings. A recent quasiexperimental study of 176 hospitals found that after controlling for known predictors of nosocomial infection rates, including use of a surgical mask, use of antiseptic soap, enhanced environmental cleaning, admission screening, occupancy rate, and staffing level, the routine use of private rooms for colonized and infected patients was independently associated with a lower rate of nosocomial infections [30]. Overall, the conventional wisdom seems to be in favor of the added benefit of single-patient rooms. In light of such evidence, the current infection control [11] and facility design [33,34] guidelines in the United States recommend single-bed rooms over open-bay rooms, citing better infection control, specifically when transmission-based precautions are necessary. Nevertheless, single-bed rooms require additional space and possibly higher construction costs as well as higher operation and maintenance costs (eg, heating and cooling loads, cleaning, disinfection, and support services). Such costs, however, can potentially be offset by the costs avoided due to lower rates of infection. Contrasting the long-term costs of single-patient vs open-bay room can provide a valuable tool for facility planning, financial evaluations, and resource allocation in hospitals.

Few peer-reviewed studies have investigated the return on investment from improving facility design and operation [35,36], and none have been performed in ICU settings. Therefore, this study aimed to investigate whether, from a hospital perspective, the costs savings from reductions in nosocomial infections can justify the additional construction and operation costs of single-bed rooms in ICUs. We use the reported results from a previous comparative study of nosocomial infections in patients in single-patient and open-bay ICU rooms to estimate the return on investment in such rooms.

2. Materials and methods

This study uses, as an exemplary setting, the assessment by Bracco et al [24] of a medical-surgical ICU in Canada. Bracco et al provided detailed information regarding the specific design and operation features implemented in the facility and a schematic drawing of the floor plan for calculating construction and operating costs. With these data, as well as external evidence on the costs associated with particular ICU design and operation interventions, we performed a probabilistic return-on-investment study. The analysis period was 5 years, the maximum payback period (time required to recover the cost of an investment) commonly expected from health care facility investments in North America [37].

Given the underlying uncertainty in the parameters, the probabilistic approach helps to quantify the financial risks (uncertainties) by expressing them in terms of the mean, SD, and credible intervals for the financial indicator of interest [38]. This requires assigning point estimates and probability distributions to all uncertain parameters (Table 1).

2.1. Description of the case

Bracco et al [24] studied the medical-surgical ICU of a tertiary teaching hospital affiliated with the University of Montreal in Canada. The ICU consisted of 6 rooms, including 2 open-bay rooms of 6 and 2 beds, 2 single-bed rooms, and 1 room with 4 distinct cubicles, which was considered as 4 single-bed rooms. The observation period started in July 2002 and lasted 30 months. The authors observed 2522 cases (903 patients in open-bay rooms and 1619 patients in single-bed rooms), totaling 8811 patient-days (2465 in open-bay rooms and 6346 in single rooms). The standard nurse-to-patient ratio was 1:2 in both types of rooms. Length of stay in the same bed was 2.73 (±6.92) and 3.92 (±3.73) days in open-bay rooms and single-bed rooms, respectively.

The 3 most common nosocomial infections were methicillin-resistant *Staphylococcus* aureus (MRSA), *Pseudomonas* species, and *Candida* species [43]. In open-bay rooms, the incidence density of MRSA acquisition was 4.1 (95% confidence interval [CI], 2.7-6.3) per 1000 patient-days; for *Pseudomonas*, it was 3.9 (95% CI, 2.5-6.1), and for *Candida*, it was 38.4 (95% CI, 33.3-44.1). Together, these pathogens represent most nosocomial infections [43]. After controlling for potential confounding factors (emergency vs elective admission, mechanical ventilation, medical or surgical patient), Bracco et al [24] found that the location of patients in single-bed vs open-bay rooms remained a significant factor associated with infection risk. In a multivariate regression analysis, the adjusted relative risks (RRs) of MRSA, *Pseudomonas*, and

Table 1
Point estimates of baseline values and parameters of the probability distribution assigned to analysis parameters

Analysis parameter	Baseline value	Probability distribution
Additional construction costs of turning bay rooms into single-bed rooms	$364 922 (±$36 492)[a]	γ(102.23, 3649)
Additional annual operating expenses of single-bed rooms versus bay rooms	$198 924 (±$46 960)[b]	γ(62 732, 3.17)
Length of stay in open-bay rooms	2.73 (±6.92) days [c]	γ(140.54, 0.02)
Patient arrival rate (per year)	361[d]	γ(361, 0.03)
MRSA acquisition risk in bay rooms (per 1000 patient-days)	4.1 (2.7-6.3)	lognormal(1.41, 0.22)
Pseudomonas spp acquisition risk in bay rooms (per 1000 patient-days)	3.9 (2.5-6.1)	lognormal(1.36, 0.23)
Candida spp colonization risk in bay rooms (per 1000 patient-days)	38.4 (33.4-44.1)	lognormal(3.65, 0.07)
Adjusted RR of MRSA acquisition in single-bed rooms	0.65 (0.42-0.98)[e]	lognormal(−0.43,0.22)
Adjusted RR of *Pseudomonas* spp acquisition in single-bed rooms	0.61 (0.49-0.67) [e]	lognormal(−0.49,0.08)
Adjusted RR of *Candida* spp colonization risk in single-bed rooms	0.75 (0.60-0.97) [e]	lognormal(−0.29, 0.12)
Costs of each incident of MRSA acquisition	$10 632 [f]	γ(16.00, 664.50)
Costs of each incident of *Pseudomonas* spp acquisition	$31 357 [g]	γ(16.00, 1959.81)
Costs of each incident of *Candida* spp colonization	$37 652 [h]	γ(16.00, 2353.25)

All costs were adjusted to 2002 US dollars (the first year of observation in Bracco et al [24]). The consumer price indices reported by the US Department of Labor's Bureau of Labor Statistics were used to convert infections costs in each reported year to the reference year.
$\gamma(x, y)$, γ Distribution with shape parameter x and rate parameter y. The parameters were estimated using the method of moments approach from the mean and SEM.
Lognormal(x, y), log-normal distribution with mean x and SD y for the log-transformed values of the mean. The parameters were estimated from the point estimate and 95% confidence bounds reported in Bracco et al [24].

[a] Estimated using 2010 cost averages as calculated by a leading health care construction firm in the United States and reported in Sadler et al [36]. Historical construction cost indices [39] were used to adjust for the inflation rate and convert 2010 costs to the approximate costs for 2002. The value in parentheses is the SEM, assumed to be 10% of the point estimate of the cost.

[b] Estimated using ICU operating expenses in the United States reported by Centers for Medicare & Medicaid Services. The value in parentheses is the SD.

[c] The probability distribution was estimated using the Methods of Moments approach from the sample size, mean, and SD reported in Bracco et al [24]. Because it is assumed that patients in open-bay rooms would be admitted to single-bed rooms, the length of stay for open-bay room patients was used to reflect their characteristics.

[d] During the 30 months of study, Bracco et al [24] observed 903 cases in open-bay rooms, equal to 361 patients per year. The probability distribution was estimated using the number of observations per year as the shape parameter and the observation period in years (30/12) as the rate parameter.

[e] We used adjusted RRs to calculate acquisition risks in single-bed rooms because raw risks of infections in single-bed rooms were confounded by differences in patient characteristics such as emergency admissions, mechanical ventilation, and medical/surgical patient. The use of adjusted RRs gave the acquisition risks of 2.60, 2.32, and 28.35 per 1000 patient-days for MRSA, *Pseudomonas* species, and *Candida* species infection, respectively, in single-bed rooms.

[f] $12 880 in 2009 US dollars [40].

[g] $38 121 in 2008 US dollars [41].

[h] $34 123 in 1997 US dollars [42]. The probability distribution for infection costs was estimated using the Method of Moments approach assuming 25% of the point estimate of the cost as the SEM.

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