The effect of a long-stay patient on transmission of a pathogen to shorter-stay patients in a small multi-bed hospital unit: Implications for infection control

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Introduction

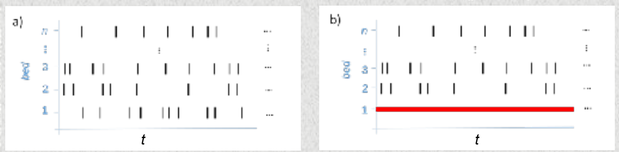
- **Prolonged hospitalization** is a risk factor for colonization with pathogens such as **carbapenem-resistant Enterobacteriaceae (CRE)**[4,11,12,15] ,which has limited treatment options + high mortality
- **Long-stay patients are at higher risk** for hospital-acquired infections[1,2,4,17] than short-stay patients, but **the impact of long-stay patients on *other* patients** in the same unit is unclear
- This **mathematical model of in-hospital pathogen transmission** seeks to answer the question, "How does a single long-stay patient affect the probability that any *other* patient leaves the unit colonized with a pathogen?"

Mathematical Model

Two variants of a discrete-state/continuous-time Markov model (13-bed hospital unit):

Fig 1a: Regular-turnover model - patients enter and exit [*vertical hashes*] a hospital unit with a given average length of stay

Fig 1b: Long-stay colonized patient model - one patient is colonized *[red bar]* with an indefinite length of stay.



*The **state of the unit** is the number of positive patients (i), which can increase / decrease:*

Fig 2: State Transitions

(a) regular turnover (b) with long-stay colonized patient

Three mechanisms of colonization:

- **pre-existing colonization** (φ): endemic within the community[10]
- **prior-to-new patient transmission** (ψ): via contaminated bed linens or fomite transmission from the immediate surroundings[11]
- **patient-patient transmission** (γ): via healthcare providers or other vectors[16]

State Transition Equations

patient-patient transmission rate per colonized patient per day — *turnover rate per day*

Rate of Increase (state *i* -> *i+1*)

$$f_i = \gamma\, i(n-i) + \beta(n-i)\phi$$

pre-existing colonization probability

 # colonized-uncolonized pairs of patients — *# uncolonized patients*

Rate of Decrease (state *i* -> *i-1*)

$$g_i = \beta i(1-\phi)(1-\psi)$$

prior-to-new colonization probability

Model Comparison

Equations	Regular Turnover Model	Long-Stay Colonized Patient Model
Rate of increase (i -> i+1)	f_i	$f_i^{LC} = f_i$
Rate of decrease (i -> i-1)	g_i	$g_i^{LC} = g_{i-1}$

The model addresses only the steady-state situation in which a long-stay patient is colonized and accounts only for length of stay, not the severity of illness

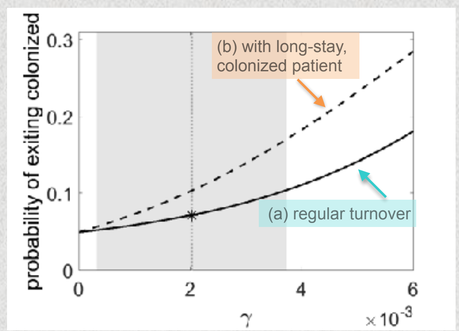
Best-Fit Parameters*

	name	definition	units	value
n	number of beds	number of beds in the hospital unit	beds	13
β	turnover rate (1/average length of stay)	probability per unit time per patient that the patient exits and a new patient enters	1/d	0.071
φ	pre-existing prevalence	probability that an entering patient is colonized	*none*	0.05
γ	patient-patient transmission rate	probability of transmission from colonized to uncolonized patient per colonized-uncolonized patient pair per unit time	1/d	0.002 +/- 0.0017
ψ	prior-to-new colonization probability	probability of transfer of colonization from a bed's prior colonized occupant to the bed's uncolonized incoming patient	*none*	0.0009

Best-fit parameters inferred from surveillance data of a 13-bed NYC hospital unit (Ong et al, PLOS One, in press)

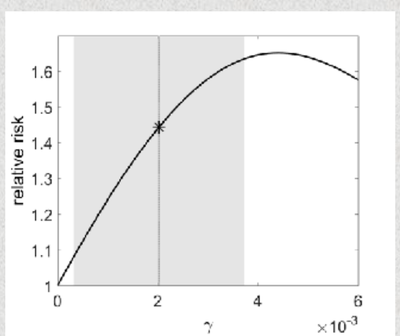
Comparison of Results

Probability of Exiting Colonized from a Unit with a Long-Stay Colonized Patient



——— regular turnover
— — — long-stay, initially colonized patient.
- - - - - γ = 0.002
uncertainty for γ +/- SD (0.000329, 0.003729)
* probability at best-fit parameters (φ, γ, ψ)

Relative Risk of Exiting Colonized from a Unit with a Long-Stay Colonized Patient



Plot of the relative risk of exiting colonized for a patient in a unit containing a single colonized long-stay patient versus one without at different rates of patient-patient transmission (γ *+/- SD, shaded area*).

Results

	Regular Turnover	Hospital Unit with Long Stay Patient
Probability of Exiting Colonized	7.2% (5.7-10%)	10.4% (5.7-16%)
Relative Risk (+/- SD)	—	1.44 (1.08-1.63)

Conclusions

- The presence of **a single CRE-colonized long-stay patient increases** the **risk of colonization of *other* patients** in the unit **by about 44%** (range 8% to 63%)
- **Relative risk** is highly sensitive to the **patient-patient transmission rate**
- **One possible high-yield target** for screening and decolonization of CRE is the **long-stay patient,** who not only has longer exposure time for possible colonization, but who also poses a **disproportionate risk** to other patients within hospital units.
- Focusing efforts on **isolation or decolonization of long-stay patients** may be **an effective intervention for reducing colonization pressure** within a hospital unit, while avoiding some of the possible negative consequences and cost of universal decolonization.

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