

Supplementary Online Content

Scaria E, Barker AK, Alagoz O, Safdar N. Association of visitor contact precautions with estimated hospital-onset *Clostridioides difficile* infection rates in acute care hospitals. *JAMA Netw Open*. 2021;4(2):e210361. doi:10.1001/jamanetworkopen.2021.0361

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This supplementary material has been provided by the authors to give readers additional information about their work.

eAppendix

Representing patient disease state

Patient *Clostridioides difficile* infection (CDI) state is modeled using a discrete-time Markov chain containing nine states, as described in eTable 1. The states of death and non-susceptible are absorbing, from which patients cannot transition to any other state. Possible transitions between disease states are illustrated in the eFigure.

Input parameters for the baseline model configuration

All infection control interventions included in the agent-based simulation model can be implemented at multiple levels representing varying compliance with protocols. Interventions can be implemented at the baseline level, representing minimal (if any) institutional support, and therefore have the least agent compliance. Interventions can also be implemented at an ideal level, representing significant institutional support and agent compliance. The simulation model includes several parameters to describe the baseline state, distribution, and behavior of agents in the model. The parameters that were directly referenced or altered in our study of VCPs de-implementation are described in eTable 2. For a full description of the model's input parameters and their derivations, please see Barker, et al 2018.¹

Detailed description of visitor behavior

Visitors may enter the simulation between the in-model hours of 9:00am and 9:00pm. When visitor agents are initialized, they are assigned a length of stay according to an exponential distribution with a mean of 15 minutes. While the visitor is in the patient room, healthcare workers may enter and interact with the patient and the environment, but not with the visitor. After the visitor has completed their stay, probabilities for patient-to-visitor and environment-to-visitor contamination trials are calculated, depending on the visitor length of stay, frequency of

contact, proportion of the room or patient that may harbor *C. difficile* spores, and the transfer efficiency between surfaces. The proportion of the room or patient harboring *C. difficile* depends on the patient's disease status. If either of these probability trials are successful, the visitor is considered contaminated.

Right before leaving the patient room, Bernoulli trials are used to determine if the patient washed their hands upon exit or was wearing VCPs during their stay. These trials are dependent on the compliance and effectiveness of the two interventions. If either trial is successful, the visitor is no longer considered contaminated. The visitor moves to the ward common ward, where they remain for five minutes. The model then calculates the probability for a visitor-to-environment contamination trial, depending on visitor length of stay, frequency of contact, and transfer efficiency between surfaces. If the trial is successful and the visitor was contaminated, high touch surfaces in the common room are considered contaminated. The visitor is then removed from the model.

Conversion of model from NetLogo to Java

The NetLogo model described in Barker, et al simulates the spread of hospital onset *Clostridioides difficile* infection (HO-CDI) in a generic, 200-bed acute care hospital.¹ Though NetLogo's ease of use and graphical interface are highly useful features in modeling infectious diseases, other programming languages can offer greater flexibility and speed. Java is one such language and lends itself naturally to agent-based modeling because of its object-oriented capabilities. To enable the experiments described in this paper we first converted the model described in Barker et al to an analogous model in Java (version 8); see the Appendix material of Barker et al for detailed logic governing agent and environment interactions.¹

Coding and debugging of the Java model was completed in Eclipse IDE v4.8 (Photon), developed by the Eclipse Foundation. The Java model replicates the agent and environmental variables and behavior, with changes made as necessary to accommodate Java data structures and objects. Both the NetLogo and Java models use the Colt Project's Mersenne Twister algorithm to produce random number generator streams. ETables 3 and 4 compare the output of the NetLogo and Java models for different infection control measures implemented at the enhanced and ideal levels, respectively. Of primary interest was the percent change in HO-CDI per 10000 patient days and colonizations per 1000 admitted patients as a function of different infection control implementation. Absolute percent changes of less than one percent were considered insignificant. Like the NetLogo model, the Java model was face validated by subject matter experts in hospital associated infections and simulation.

To determine stability of results, HO-CDI per 10000 patient days and colonizations per 1000 admitted patients were examined as a function of number of replications, as seen in eTable 5. As the Java model showed a similar stability at 5000 replications to the NetLogo model, we concluded that 5000 replications were sufficient to produce stable results.

Existence of association between VCPs and HO-CDI reduction

In the interest of finding what conditions exist in our model, if any, where VCPs are associated with a greater than 1% reduction in HO-CDI rates, we conducted further experiments using large parameter changes. Of primary interest is if there exists a threshold at of visitor length of stay or rate of contact at which VCPs are associated with HO-CDI reductions. In our model, all probabilities related to visitor *C. difficile* acquisition or deposition are of the form:

$$p = 1 - DRe^{-l\lambda}$$

Where:

p = probability of acquisition or deposition
 D = proportion of environment/patient contaminated with *C. difficile*
 R = transfer probability of *C. difficile* between patient/environment and visitor
 λ = rate of contact between visitor and environment/patient
 l = length of stay with patient/in environment

As visitor length of stay and visitor acquisition/deposition rates increase, the probability of transfer rapidly approaches 1. Once the exponential power is on the order of -10, increasing visitor length of stay or rate of contact more do little to affect the probability of exposure. Therefore, there is little need to investigate lengths of stay or rates of contact that result in a power less than -10. We conducted an additional experiment where we multiplied the rates of contact between visitors and the environment and between visitors and patients by 10, thereby bringing the probability of transmission and deposition near to 1. The rate of HO-CDI per 10,000 patient days with no VCPs was 7.95 (95% CI: [7.91, 7.99]), while the rate with ideal VCPs implementation was 7.99 (95% CI: [7.95, 8.03]). As the difference between these average rates is less than one percent, we are confident that increasing the rate of contact or length of stay any further would not lead to a greater association between VCPs and HO-CDI.

We believe it would be of interest to know if there is any condition where VCPs may be associated with a larger reduction in HO-CDI. We found that under extreme conditions where the only possible transmission pathway was through visitors contaminating the common room, transmission to and from visitors was guaranteed, and surveillance testing was adequately high, VCPs could have a larger association with HO-CDI. Note that surveillance testing represents the scenario that patients are screened for *C. difficile* at admission and then are put in isolation therefore VCPs will be implemented. Experiments varying the surveillance testing parameter

are shown in eTable 6. Averages and confidence intervals were calculated from 5000 replications.

Surveillance likely played an important role in the experiments described in eTable 6 because our model assumes that VCPs may only be used when interacting with patients known to be infected or colonized with *C. difficile*. Therefore, increasing surveillance and testing leads to a greater number of known colonizations and infections and thus increased VCPs use. However, even when all patients entering the hospital are tested (i.e., surveillance compliance of 100%), the association of VCPs and HO-CDI is still relatively small.

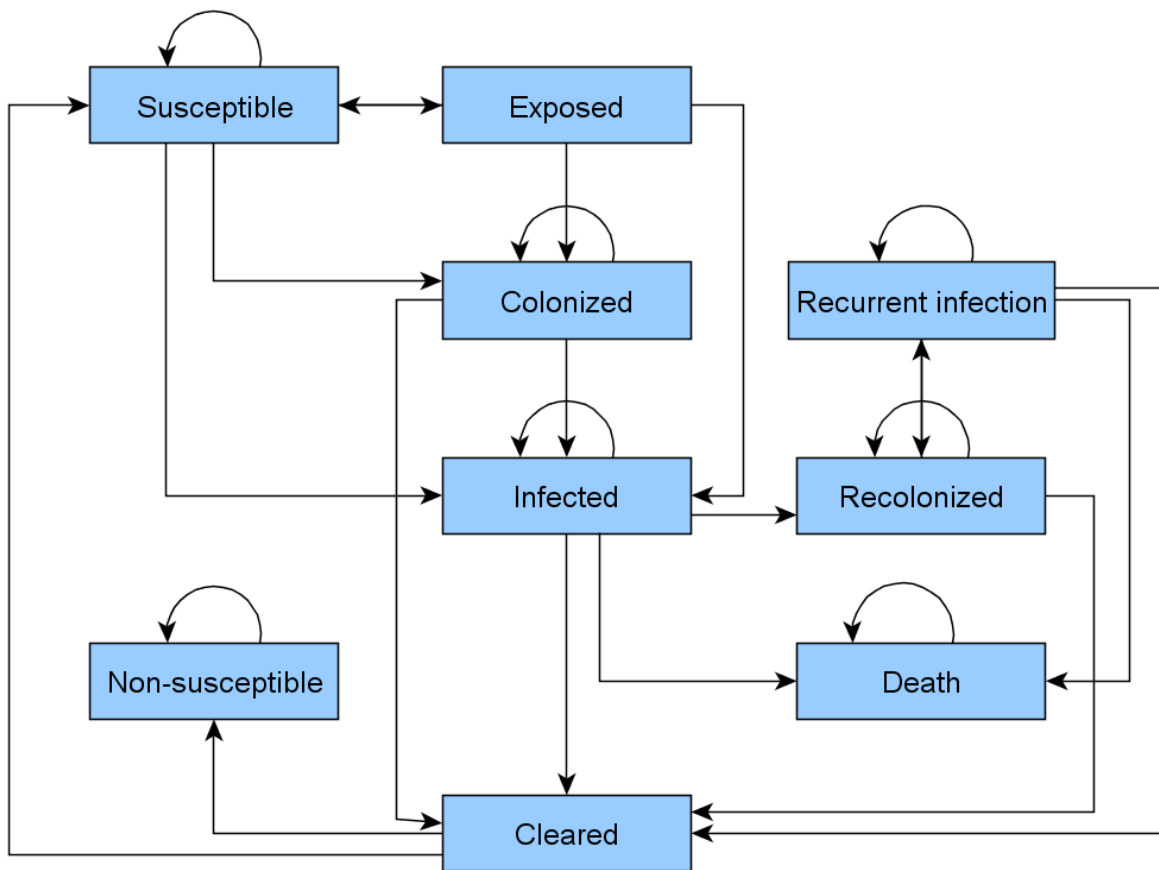
Under baseline conditions, simply expanding use of VCPs to all patients is not significantly associated with a decrease in HO-CDI, as described in eTable 7.

eTable 1: Clinical states of the patients included in the discrete-time Markov chain (adapted from Barker et al 2018)¹

Clinical State	Description
Non-susceptible	Not at risk for colonization or CDI
Susceptible	At risk for <i>C. difficile</i> colonization but no symptoms or disease
Exposed	Exposed to <i>C. difficile</i> but no symptoms or disease
Colonized	Gastrointestinal colonization of <i>C. difficile</i> , but no symptoms
Infected	Clinically diagnosed CDI, symptomatic
Cleared	Experienced infection or colonization but successfully cleared
Recolonized	Recovered from infection, but gastrointestinal colonization remains, no symptoms
Infection recurrence	Recurrence of the infection in a previously infected patient, symptomatic
Death	CDI-related death

Patients in the clinical states that are shaded with gray are contagious, therefore can transmit *C. difficile* to other agents and contaminate the environment, while patients in other clinical states cannot

eFigure: Possible transitions between CDI disease states (adapted from Barker et al 2018)¹



eTable 2: Key Input Parameters (adapted from Barker et al 2018)¹

Interventions Parameters				
Intervention	Baseline Compliance	Ideal Compliance	Source	Source Dates
Hand Hygiene				
Standard Patient				
Patient	33%	84%	2-7	04/03 - 2014
Nurse	60%	96%	8-18	08/2000-2012
Doctor	50%	91%	8-20	2000-12/12
Visitor	35%	84%	5,9,21-26	06/97 - 2016
CDI Patient				
Patient	48%	88%	27-30	10/02-12/12
Nurse	69%	97%	27-30	10/02-12/12
Doctor	61%	93%	27-30	10/02-12/12
Visitor	50%	88%	27-30	10/02-12/12
Environmental cleaning				
Daily Cleaning	46%	94%	31-35	03/01-05/12
Terminal cleaning	47%	98%	31,36-39	10/11-07/14
Admission Parameters				
Parameter	Mean value		Source	Source Dates
Proportion of susceptible patients	39.70%		40-44	01/99-12/12
Proportion of asymptomatic colonized patients	6.10%		45-55	03/06-03/15
Proportion of patients with CDI	0.29%		45,52,56,57	01/09-2016
Proportion of non-susceptible patients	53.90%		-	
Patient arrival rate	26/day		58,59	01/75-12/15
Health care worker behavior and distribution				
Parameter	Value		Source	Source Dates
Patient-nurse contact probability [rate]	0.358 (for 5 minutes) [10.53 contacts/ minute]		60	06/10-08/10
Patient-doctor contact probability [rate]	0.688 (for 5 minutes) [9.25 contacts/ minute]		60	06/10-08/10
Number of nurses per ward	4		60-63	04/98-08/10
Number of doctors per ward	2		58,60	06/10-12/12
Average nurse service time	4.7 minutes		28,60,64,65	06/01-04/13
Average doctor service time	10.8 minutes		28,60,64,65	06/01-04/13
Average number of nurse visits per 6 hours	5		28,60,66,67	06/01-04/13
Average number of doctor visits per 6 hours	1		28,60,66,67	06/01-04/13
Proportion of patients prescribed fluoroquinolones	7.5%		68-70	01/06-09/11
Proportion of patients prescribed other (non-fluoroquinolone) high risk antibiotics	12.5%		68-70	01/06-09/11
Visitor behavior				
Parameter	Mean value		Source	Source Dates
Probability of receiving visitors (per day)	0.5		71,72	06/72-03/04
Number of visitors per visit	2		72,73	2003-03/04
Visitor length of stay	15 minutes		60,72-74	2003-08/10

Visitor-environment contact probability [rate]	0.932 (for 15 minutes) [0.179 contacts/ minute]	60	06/10-08/10
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eTable 3: Performance of infection control measures implemented at enhanced adherence, as quantified by NetLogo and Java simulation

Experiment		NetLogo, 5000 replications (95% CI)	Java, 5000 replications (95% CI)	Percent change relative to baseline, NetLogo	Percent change relative to baseline, Java
Baseline	HO-CDI per 10000 patient days	7.98 (7.95, 8.02)	7.98 (7.94, 8.01)	-	-
	Colonizations per 1000 patients	32.51 (32.45, 32.57)	31.90 (31.84, 31.97)	-	-
Daily cleaning enhanced	HO-CDI per 10000 patient days	2.48 (2.46, 2.50)	2.49 (2.47, 2.51)	68.92%	68.81%
	Colonizations per 1000 patients	7.32 (7.3, 7.35)	7.20 (7.18, 7.23)	77.48%	77.42%
Terminal cleaning enhanced	HO-CDI per 10000 patient days	6.52 (6.48, 6.55)	6.45 (6.42, 6.49)	18.30%	19.11%
	Colonizations per 1000 patients	23.57 (23.51, 23.62)	23.16 (23.11, 23.22)	27.50%	27.40%
Healthcare work hand hygiene enhanced	HO-CDI per 10000 patient days	5.37 (5.34, 5.40)	5.31 (5.28, 5.34)	32.71%	33.43%
	Colonizations per 1000 patients	20.26 (20.21, 20.31)	19.82 (19.77, 19.87)	37.68%	37.87%
Patient hand hygiene enhanced	HO-CDI per 10000 patient days	7.09 (7.05, 7.12)	7.04 (7.00, 7.07)	11.15%	11.80%
	Colonizations per 1000 patients	28.19 (28.14, 28.25)	27.66 (27.6, 27.71)	13.29%	13.31%
Visitor hand hygiene enhanced	HO-CDI per 10000 patient days	7.98 (7.94, 8.02)	7.96 (7.93, 8.00)	0.00%	0.15%
	Colonizations per 1000 patients	32.53 (32.47, 32.59)	31.88 (31.82, 31.94)	-0.06%	0.07%
Visitor contact precautions enhanced	HO-CDI per 10000 patient days	7.97 (7.93, 8.00)	7.96 (7.92, 8.00)	0.13%	0.17%
	Colonizations per 1000 patients	32.51 (32.45, 32.57)	31.90 (31.83, 31.96)	0.00%	0.03%
Healthcare worker contact precautions enhanced	HO-CDI per 10000 patient days	7.89 (7.86, 7.93)	7.84 (7.80, 7.87)	1.13%	1.75%
	Colonizations per 1000 patients	32.07 (32.01, 32.13)	31.45 (31.39, 31.51)	1.35%	1.43%
Patient transfer enhanced	HO-CDI per 10000 patient days	7.64 (7.60, 7.67)	7.60 (7.57, 7.64)	4.26%	4.70%
	Colonizations per 1000 patients	30.34 (30.28, 30.4)	29.75 (29.68, 29.81)	6.67%	6.77%
Surveillance enhanced	HO-CDI per 10000 patient days	5.13 (5.10, 5.16)	5.09 (5.06, 5.13)	35.71%	36.14%
	Colonizations per 1000 patients	19.78 (19.72, 19.83)	19.44 (19.38, 19.50)	39.16%	39.06%

eTable 4: Performance of infection control measures implemented at ideal adherence, as quantified by NetLogo and Java simulation

Experiment		NetLogo, 5000 replications (95% CI)	Java, 5000 replications (95% CI)	Percent change relative to baseline, NetLogo	Percent change relative to baseline, Java
Baseline	HO-CDI per 10000 patient days	7.98 (7.95, 8.02)	7.98 (7.94, 8.01)	-	-
	Colonizations per 1000 patients	32.51 (32.45, 32.57)	31.9 (31.84, 31.97)	-	-
Daily cleaning ideal	HO-CDI per 10000 patient days	2.14 (2.12, 2.16)	2.16 (2.14, 2.18)	73.19%	72.92%
	Colonizations per 1000 patients	5.81 (5.79, 5.84)	5.70 (5.68, 5.73)	82.12%	82.13%
Terminal cleaning ideal	HO-CDI per 10000 patient days	6.08 (6.05, 6.11)	6.06 (6.02, 6.09)	23.84%	24.09%
	Colonizations per 1000 patients	21.23 (21.18, 21.28)	20.87 (20.82, 20.92)	34.69%	34.59%
Healthcare work hand hygiene ideal	HO-CDI per 10000 patient days	3.87 (3.84, 3.89)	3.84 (3.81, 3.86)	51.59%	51.91%
	Colonizations per 1000 patients	13.53 (13.49, 13.57)	13.23 (13.19, 13.27)	58.39%	58.55%
Patient hand hygiene ideal	HO-CDI per 10000 patient days	6.23 (6.20, 6.27)	6.20 (6.17, 6.24)	21.94%	22.24%
	Colonizations per 1000 patients	24.16 (24.11, 24.21)	23.67 (23.62, 23.73)	25.69%	25.80%
Visitor hand hygiene ideal	HO-CDI per 10000 patient days	8.00 (7.96, 8.03)	7.94 (7.91, 7.98)	-0.14%	0.40%
	Colonizations per 1000 patients	32.51 (32.45, 32.57)	31.90 (31.83, 31.96)	0.01%	0.02%
Visitor contact precautions ideal	HO-CDI per 10000 patient days	7.99 (7.96, 8.03)	7.97 (7.93, 8.01)	-0.12%	0.11%
	Colonizations per 1000 patients	32.52 (32.46, 32.58)	31.88 (31.81, 31.94)	-0.03%	0.09%

Experiment		NetLogo, 5000 replications (95% CI)	Java, 5000 replications (95% CI)	Percent change relative to baseline, NetLogo	Percent change relative to baseline, Java
Healthcare worker contact precautions ideal	HO-CDI per 10000 patient days	7.80 (7.76, 7.84)	7.79 (7.76, 7.83)	2.29%	2.31%
	Colonizations per 1000 patients	31.78 (31.72, 31.84)	31.16 (31.1, 31.22)	2.25%	2.33%
Patient transfer ideal	HO-CDI per 10000 patient days	7.47 (7.44, 7.51)	7.47 (7.44, 7.51)	6.40%	6.32%
	Colonizations per 1000 patients	29.39 (29.34, 29.45)	28.85 (28.79, 28.91)	9.58%	9.58%
Surveillance ideal	HO-CDI per 10000 patient days	5.06 (5.03, 5.09)	5.02 (4.98, 5.05)	36.62%	37.12%
	Colonizations per 1000 patients	19.43 (19.38, 19.49)	19.08 (19.02, 19.14)	40.22%	40.19%

eTable 5: Stability of baseline infection outcomes as a function of number of replications, as quantified by NetLogo and Java models

Model		Number of Replications				
		1000	2000	3000	4000	5000
NetLogo	HO-CDI per 10000 patient days	8.12 (8.03, 8.21)	8.06 (7.99, 8.12)	8.01 (7.96, 8.06)	8.01 (7.96, 8.05)	7.98 (7.95, 8.02)
	Colonizations per 1000 patients	32.43 (32.3, 32.57)	32.43 (32.3, 32.57)	32.47 (32.39, 32.55)	32.51 (32.44, 32.57)	32.51 (32.45, 32.58)
Java	HO-CDI per 10000 patient days	7.89 (7.81, 7.98)	7.96 (7.90, 8.02)	7.98 (7.93, 8.03)	7.98 (7.94, 8.02)	7.98 (7.95, 8.02)
	Colonizations per 1000 patients	31.79 (31.66, 31.93)	31.89 (31.79, 31.98)	31.93 (31.85, 32.01)	31.90 (31.83, 31.97)	32.51 (32.45, 32.57)

eTable 6: HO-CDI per 10,000 patient days as a function of compliance with surveillance, under maximal visitor transmission

Compliance with surveillance	VCPs de-implemented HO-CDI/ 10,000 patient days (95% CI)	VCPs Ideal HO-CDI/ 10,000 patient days (95% CI)	Change
50%	30.03 (29.96, 30.1)	29.77 (29.7, 29.84)	0.89%
60%	29.83 (29.76, 29.9)	29.54 (29.47, 29.62)	0.97%
70%	29.7 (29.63, 29.78)	29.47 (29.4, 29.54)	0.80%
80%	29.59 (29.52, 29.66)	29.17 (29.1, 29.24)	1.42%
90%	29.46 (29.39, 29.53)	28.92 (28.85, 28.99)	1.85%
100%	29.29 (29.22, 29.36)	28.63 (28.56, 28.7)	2.25%

eTable 7: HO-CDI per 10,000 patient days with VCPs in use for all patients

Description	VCPs de-implemented HO-CDI/ 10,000 patient days (95% CI)	VCPs Ideal HO-CDI/ 10,000 patient days (95% CI)	Change
Baseline conditions, VCPs available for use with all patients	7.95 (7.91, 7.98)	7.95 (7.91, 7.99)	<1%

eTable 8: Changes in hand hygiene and cleaning compliance associated with reduction in HO-CDI/10,000 patient days on par with that of VCPs ideal intervention

Intervention	Baseline (no VCP use)		Improved		Absolute percent reduction in HO-CDI rate
	Compliance (%)	HO-CDI/10,000 Patient days	Compliance (%)	HO-CDI/10,000 Patient days	
Visitor contact precautions	0	7.94 (7.91, 7.98)	93.5	7.97 (7.93, 8.01)	< 1%
Nurse hand hygiene	60	7.94 (7.91, 7.98)	61	7.82 (7.78, 7.86)	2.01%
Physician hand hygiene	50	7.94 (7.91, 7.98)	51	7.90 (7.86, 7.94)	1.00%
Daily cleaning	46	7.94 (7.91, 7.98)	47	7.86 (7.82, 7.90)	1.50%
Terminal cleaning	47	7.94 (7.91, 7.98)	50	7.88 (7.84, 7.92)	1.25%

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