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Evaluating Policies to Decrease the Risk of Introducing SARS-CoV-2 Infections to Nursing Home Facilities

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Abstract

We used an individual-based microsimulation model of North Carolina to determine what facility-level policies would result in the greatest reduction in the number of individuals with SARS-CoV-2 entering the nursing home environment from 12/15/2021–1/3/2022 (e.g., Omicron variant surge). On average, there were 14,287 (Credible Interval [CI]: 13,477–15,147) daily visitors and 17,168 (CI: 16,571–17,768) HCW coming from the community into 426 nursing home facilities. Policies requiring a negative rapid test or vaccinated status for visitors resulted in the greatest reduction in the number of individuals with SARS-CoV-2 infection entering the nursing home environment with a 29.6% (26.9%–32.0%) and 24.0% (CI: 22.2%–25.5%) reduction, respectively. Policies halving visits (21.2% [20.0%–28.2%]), requiring all vaccinated HCW to receive a booster (7.8% [CI: 7.4%–8.7%]), and limiting visitation to a primary visitor (6.5% [CI: 3.5%–9.7%]) reduced infectious contacts to a lesser degree.

Brief summary:

Using a microsimulation model of nursing home facilities, we found that a policy requiring all visitors to test negative on a rapid SARS-CoV-2 antigen test before each visit resulted in the greatest reduction in potential transmission events.

Keywords

nursing homes; SARS-CoV-2; simulation modeling

INTRODUCTION

During the first 12 months of the COVID-19 pandemic, more than a quarter of all deaths due to SARS-CoV-2 in the United States occurred among nursing home residents or nursing home staff (Times, 2020). Early in the pandemic, nursing homes frequently lacked personal protective equipment and access to testing, and experienced challenges with adequate

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staffing (McGarry, Grabowski, & Barnett, 2020; Reinhardt, Franzosa, Mak, & Burack, 2022). Accordingly, nursing home residents were prioritized to receive vaccinations and additional support from local, state, and federal agencies once vaccination was possible (CDC, 2020). By January 2022, approximately 86% of nursing home residents had received two doses of a COVID-19 vaccine (Centers for Medicare). However, even with widespread vaccination, nursing homes are at particular risk for future outbreaks as congregate settings with a high proportion of immunocompromised individuals and frequent healthcare worker (HCW) and patient interactions with the risk of transmission from asymptomatic carriers (Holmdahl, Kahn, Hay, Buckee, & Mina, 2021). For example, even with a high vaccination rate among residents, North Carolina experienced 111 outbreaks within nursing home facilities in August 2021 related to the surge of the Delta variant (B.1.617.2) ("Outbreaks at nursing homes shine light on disparate staff, resident vaccination rates :: WRAL.com,"). The most recent surge of infections related to the Omicron (B.1.1.529) variant resulted in the closures of facilities and staffing shortages (Chatterjee, 2022). At the same time, increased awareness of the physical, emotional, and mental cost of restrictive measures, in particular visitor limitations, requires careful thought when evaluating the cost and benefits of COVID-19 prevention measures.

Testing and vaccination strategies are essential components of COVID-19 mitigation for nursing home facilities. However, questions remain regarding which strategies best reduce the likelihood of introducing SARS-CoV-2 infection into the nursing home environment. Policies have ranged in the eligibility for COVID-19 testing (e.g., only testing those with symptoms, only testing residents) or vaccination requirements (e.g., requiring staff to be up-to-date on vaccinations) (Geeraedts et al., 2022; McGarry et al., 2020). Observational studies have found that long-term care facilities implementing more liberal testing strategies reported lower excess mortality compared to facilities with higher threshold (i.e., only testing those with certain symptoms) testing early in the pandemic (Geeraedts et al., 2022; Zollner-Schwetz et al., 2021). However, a recent study found that predictors of COVID-19 outbreaks in nursing homes in the southeastern United States varied significantly in later stages of the pandemic (Lane, Sugg, Spaulding, Hege, & Iyer, 2022). There is a critical need to evaluate what policies are most effective in decreasing the introduction of SARS-CoV-2 infections into nursing home facilities, particularly in response to potential new variants and waning immunity.

Using a geospatially explicit individual-based microsimulation model of North Carolina, we sought to determine what facility-level policies would result in the greatest reduction in the number of individuals with SARS-CoV-2 entering the nursing home environment.

Methods

Analytic Overview

Using an agent-based model of North Carolina, the Modeling Infectious Diseases in Healthcare Network (MInD-Healthcare) model, we simulated the movement of people into healthcare facilities and SARS-CoV-2 infections to compare policies available to nursing home facilities over a 1-month time horizon representing December 15, 2021, to January 13, 2022. We selected a 30-day period as it reflected a period of quick exponential growth in SARS-CoV-2 transmission related to the Omicron variant. We sought to identify optimal strategies during a period of increased community transmission to provide guidance to nursing facilities on how to prepare for future periods of increased transmission related to new variants or increased immune escape.

For this analysis, we evaluated five policies that were implemented within nursing home facilities: (1) ensuring that all vaccinated HCW are up to date on SARS-CoV-2 vaccinations (i.e., received third dose or booster); (2) requiring visitors to have received at least two doses of a COVID-19 vaccine; (3) requiring a negative rapid (antigen) SARS-CoV-2 test for all nursing home visitors; (4) reducing visitation to only one primary visitor; and (5) halving the number of in-person visits. Policies were compared on the following model outcomes: the number of SARS-CoV-2 infected HCW or visitors, the percent of visits or HCW daily shifts with potential SARS-CoV-2 transmission, the percent of visits or HCW daily shifts with potential SARS-CoV-2 transmission from an asymptomatic carrier, and the estimated number of infectious contacts that could lead to a transmission. To illuminate potential strengths or weaknesses of each policy under varying model assumptions, we compared the policies under different model scenarios including (a) increased booster uptake (from 37% to 74%) within the community for the vaccinated population and (b) lowering the ratio of reported cases to the estimated actual number of true infections (i.e., the case multiplier) from 8x to 4x and 6x.

Model Overview

Originally built to evaluate interventions to prevent healthcare-associated infections within a regional health system, (MInD-Healthcare) MInD-Healthcare was adapted in 2020 to assess the potential strain on hospital capacity for North Carolina hospitals during the COVID-19 pandemic. Agent-based models are particularly well suited to capture the underlying network structure of complex systems such as hospitals and nursing homes by simulating the detail and heterogeneity of movement into facilities by patients, staff, and visitors. To simulate SARS-CoV-2 cases for each county, we incorporated Susceptible-Exposed-Infectious-Recovered-Susceptible (SEIRS) compartmental models for each county to inform the level of infections based on publicly available data from COVID ActNow. Using RTI's SynthPop™ for a baseline synthetic population, we simulated the population of North Carolina (n = 10.6 million individuals). The simulated population includes community members, patients within hospitals, nursing home residents, and HCW. Only residents of North Carolina were modeled (i.e., residents admitted from other states were not simulated). Historical reported case counts by county from December 15, 2021, to January 13, 2022, were smoothed using a 10-day rolling average to account for lack of reporting on weekends and holidays. Case counts were multiplied by 8x to account for underreporting. Individuals within the ABM were assigned SARS-CoV-2 infection and SARS-CoV-2 case status (susceptible, asymptomatic, symptomatic, or recovered) based on Bayesian equations accounting for age and vaccination status data from the North Carolina Department of Health and Human Services (NC DHHS). SARS-CoV-2 symptomatic infections were further classified into mild/moderate, severe (requiring an inpatient admission for COVID-19), or critical (requiring inpatient admission and ventilation). The probability of hospital admission for COVID-19 used a Bayesian specification based on age and comorbidity status (Hadley et al., 2022). Individuals with asymptomatic infections do not seek hospitalization and have no change in behavior. Individuals with mild to moderate infection also do not seek hospitalization but will have a probability of isolating (i.e., 80% will not go to work if a HCW and 60% will not visit a nursing home facility). Our analysis focused on the entry of SARS-CoV-2 into the nursing home environment and therefore, we did not model transmission within facilities. A previous agent-based modeling study of viral dynamics within nursing home environments reported a 2% probability of infection per infectious contact (Kahn et al., 2021) and assumed that each staff member has daily contact with six residents. We used these parameters and assumed that each visitor has daily contact with 2 residents to estimate infectious contacts per day. We do not model death due to SARS-CoV-2 within the model due to the short time frame (1 month) and changing therapeutics available to reduce the likelihood of mortality.

We assume that antigen (i.e., rapid) testing has a test sensitivity of 67.4% and 72% for detecting Omicron infection in asymptomatic and symptomatic individuals, respectively (Dinnes et al., 2021; Drain, 2022; Goodall, LeBlanc, Hatchette, Barrett, & Patriquin, 2022; Michelena et al., 2022; Schrom et al., 2022). We assumed a test specificity of 98%, the negative percent agreement required for approval by the FDA (Drain, 2022). Key parameters and data sources are summarized in Table 1, full details are included within the supplementary materials.

Vaccination—Within the model, vaccination decreases the likelihood of infection, increases the likelihood of asymptomatic infection, and decreases the likelihood of hospitalization. By modeling vaccination, we account for differing vaccination rates and test the impact of policies related to vaccination on transmission dynamics.

Vaccination rates were informed by an individual’s characteristics: 86% of nursing home residents, 75% of nursing home visitors, and 80% of HCWs were assumed to be vaccinated compared to 53% of the general population based on January 2022 estimates (Centers for Medicare). Data on the percent of HCW, visitors, and nursing home residents receiving the booster were not available; therefore, we assumed that 37% of those vaccinated had received a booster (the percentage for the general vaccinated population).

Receipt of a vaccine decreased the likelihood of infection. We implemented a single value for vaccine effectiveness against infection to serve as a population average. The model does not account for the type of vaccine received or vaccination schedule (i.e., timing of boosters). Vaccine effectiveness against infection with the Omicron variant was informed by data published by the UK Health Security Agency and preprints (Agency, 2021; Buchan, Chung, Brown, Austin, Fell, Gubbay, Nasreen, Schwartz, Sundaram, Tadrous, Wilson, Wilson, Kwong, & Investigators, 2022; Spensley et al., 2022). These analyses report that, although receipt of a booster dose confers around 50% vaccine effectiveness against infection with the Omicron variant, marked waning of immunity against infection was seen for those without a booster and on average, there was only 7% protection against infection. As of January 5, 2022, 37% of the vaccinated population of North Carolina had received a booster dose. Therefore, we implemented a weighted vaccine effectiveness against infection parameter (24%). Additional details on sources and calculations are in the supplemental materials.

Vaccinated individuals have an increased likelihood of being asymptomatic, if infected. Based on recent studies, we assumed that 25% of vaccinated individuals with SARS-CoV-2 will be asymptomatic compared to 5% of unvaccinated individuals for reported cases (CDCMMWR, 2021; Fowlkes et al., 2021). With a case multiplier of 8x, 12.5% of cases are assumed to be reported. For unreported cases, we assumed that 50% of vaccinated individuals and 25% of unvaccinated cases are asymptomatic. Vaccination also decreases the likelihood of hospitalization. We replicated historical hospital admissions based on data from NC DHHS that reported the majority of individuals (69%) hospitalized with COVID-19 were unvaccinated.

Community-to-Healthcare Facility Movement—To accurately reflect the movement of individuals, the simulation employs length-of-stay values, individual facility capacities, transfers to different facilities, and patient demographics. Individuals can enter two main types of healthcare facilities as patients: short-term acute care hospitals (n = 104) and nursing home facilities (n = 426). Healthcare facilities are defined by bed count (i.e., capacity) and geospatially (i.e., county).

At each daily timestep within the model, agents have a probability of entering a healthcare facility. Community members enter the healthcare environment as patients or as visitors (to nursing home facilities only). Agents classified as HCW enter the healthcare environment as patients or as workers.

Healthcare Workers—Based on the Payroll Based Journal (PBJ) dataset published by the Centers for Medicare & Medicaid Services, 25,831 individuals in North Carolina work within nursing home facilities (Centers for & Medicaid). We included both full- and part-time employees who work at a single site or multiple sites and contract workers. Each HCW is assigned to a specific facility or facilities and is assumed to fulfill a certain number of hours per week based on PBJ data. We assume that HCWs will work at facilities within certain geographic limitations (for example, primary facilities worked are typically within the county of residence).

Nursing Home Visitation—Based on the peer-reviewed literature on the social networks of nursing home residents, we assume that 15% of nursing home residents have no visitors, 45% have one, 25% have two, and 15% have three visitors during their stay (Gaugler, 2005; Ross, Rosenthal, & Dawson, 1997; Tornatore & Grant, 2002). These visitors represent spouses, primary caregivers, children, relatives, and friends and are assigned upon admission to a nursing home facility. To inform the probability of visitation, we mapped the frequency of visit and age distribution to the likely type of visitor. These distributions approximate a spouse or primary caregiver (older age, visits every other day), a child (younger, visits once a week), and a friend, child, or grandchild (youngest, visits about once a month). We assume that visitors are from the same county of residence as the patient.

Each model scenario was run 100 times using 10.6 million agents to represent the population of North Carolina. The MInD-Healthcare model was approved by RTI International's Institutional Review Board and programmed using Python. The full model code is available online (https://doi.org/10.5281/zenodo.6463789) and is accompanied by scripts and instructions for recreation of all model results.

RESULTS

Each model scenario initialized with agents representing the population of North Carolina: 48% male with 63% of the total population younger than 50 years old, 21% between 50 and 65 years old, and 16% 65 and older. Over 1 month within the baseline scenario (i.e., reflecting conditions from December 15, 2021, to January 13, 2022), there were on average 14,287 (Credible Interval [CI]: 13,477–15,147) daily visitors and 17,168 (CI: 16,571–17,768) HCW coming from the community into the 426 nursing home facilities modeled (Table 2). Of all visitors and HCW entering per day, 776 (CI: 585–1000) or 2.5% (CI: 1.9%–3.0%) were SARS-CoV-2 infected. On average, 330 (CI: 227–460) or 2.3% (CI: 1.7%–3.0%) of daily visitors had SARS-CoV-2 infection, of whom, 54.1% (CI: 53.9%–54.7%) had asymptomatic infection. On average, 446 (CI: 359–541) or 2.6% (CI: 2.2–3.0) of daily HCW shifts were with a HCW with SARS-CoV-2 infection of whom 75.7% (CI: 73.2%–78.8%) were asymptomatic.

When implementing a policy requiring that all vaccinated HCW are up to date on their booster, the average number of daily HCW shifts with SARS-CoV-2 infection decreased to 385 (CI: 306–471) or 2.2% (1.8%–2.6%) (Figure 1). A policy requiring visitors to have at least two doses of a COVID-19 vaccine decreased the number of daily visitors with SARS-CoV-2 infection to 144 (CI: 96–205) or 1.3% (0.9%–1.8%). A policy requiring a negative rapid test from visitors decreased the average number of daily visitors with SARS-CoV-2 infection to 101 (CI: 69–140) or 0.7% (CI: 0.5%–0.9%). With rapid antigen testing, 69.5% visitors with SARS-CoV-2 were identified and there were 279 false positives (i.e., individuals identified as positive for SARS-CoV-2 who were not infected) per day. The policy restricting visitation to a primary visitor decreased the number of visits from 14,287 to 12,212 per day and decreased the number of visits with a SARS-CoV-2-positive individual (280 [CI: 206–362]) but did not change the percentage of visits with SARS-CoV-2 infection. Halving the number of visits also decreased the number of visits and number of visits with the potential for SARS-CoV-2 transmission to 7,144 (CI: 6,571–7,755) and 164 (CI: 110–231) per day, respectively.

Overall, the policies requiring all visitors to be vaccinated and have a negative rapid test resulted in the greatest reduction in the number of individuals with SARS-CoV-2 entering the nursing home environment with a 24.0% (CI: 22.2%–25.5%) and 29.6% (CI: 26.9%–32.0%) reduction, respectively (Figure 1). The policies halving visits (21.2% [CI: 20.0%–28.2%]), requiring all vaccinated HCW to receive a booster (7.8% [7.4%–8.7%] averted), and limiting visitation to a primary visitor (6.5% [CI: 3.5%–9.7%]) had a lesser impact.

A policy requiring a negative rapid test result from visitors led to the fewest number of infectious contacts that could lead to transmission (Table 2). On average, there were 59

(46–75) infectious contacts per day compared to 67 (52–83) per day without an intervention policy or 14 averted infectious contacts per day (Table 3). Because HCW have contact with an average of six residents per day (vs. 2 for visitors), policies decreasing the number of HCW with SARS-CoV-2 infection had an impact equivalent to that of requiring all visitors to be fully vaccinated (11% of infectious contacts averted). Policies restricting visitation to a primary visitor or halving visits averted fewer infectious contacts per day.

Scenario analyses increasing the uptake of the booster within the community from 37% to 60% resulted in 12.3% (CI: 10.1%–14.0%) fewer SARS-CoV-2 exposures in the nursing home environment per day. Decreasing the case multiplier led to fewer SARS-CoV-2 exposures but did not qualitatively change outcomes of the simulated policies.

DISCUSSION

In an individual-based microsimulation of North Carolina nursing home facilities, we found that 2.3% of visits and 2.6% of daily HCW shifts could potentially lead to a SARS-CoV-2 transmission event during a month-long period replicating historical trends in infections and hospitalizations seen during the Omicron wave. Our model findings suggest that requiring a negative rapid antigen test for entry is the most effective policy to decrease the risk of SARS-CoV-2 transmission within nursing home facilities. Doing so did not meaningfully change the overall number of visits but it did decrease the proportion of visits that could result in a transmission. Policies requiring a booster from all vaccinated HCW and requiring all visitors to be vaccinated were also effective in decreasing the risk of transmission. Policies restricting visitation to a primary visitor and halving the number of visits did not result in as great of a reduction.

Visitation by friends and families is critical to maintaining the physical and mental health of nursing home residents. Particularly in the early months of the pandemic, nursing homes closed their doors to visitation from friends and families. Although this likely saved many lives there was a significant cost to the mental health and social vulnerability of nursing home residents. Public health researchers must weigh the cost of limiting or prohibiting visitation against the benefit of reducing the risk of COVID transmission. Our analysis found that policies requiring visitors to be vaccinated or to present a negative rapid antigen test resulted in greater reductions in overall potential infectious contacts than any of the other policies simulated, including the halving of visits. This suggests that robust screening protocols can allow for the same level of visitation with lesser risk than policies that limit visitation.

The Supreme Court recently upheld the mandate for healthcare facilities that receive federal funding, including nursing homes, to require COVID-19 vaccination for their staff. Mandatory vaccination may increase staff shortages. Only around a third of nursing home workers have received a booster, increasing their risk of acquiring SARS-CoV-2. During one week in mid-January during the Omicron surge, over 50,000 nursing home staff nationally reported testing positive for SARS-CoV-2 and 70 died (Chatterjee, 2022). Within our study, we found that increasing the percentage of nursing home staff receiving the booster would decrease potential infectious contacts but to a lesser degree than requiring a negative antigen of visitors. However, it should be noted that staff often work at multiple sites. Future work with this model will explore the impact of staff shortages, staff working at multiple sites, different employee types (e.g., certified nursing assistant vs. licensed practical nurse), as well as high staff turnover on the probability of a nosocomial outbreak. Findings from this analysis likely underestimate the benefit of requiring staff to be up to date on their vaccinations. Increasing the number of vaccinated and boosted staff at nursing home facilities will have benefits for the individual staff members and decrease the probability of transmission within the facility.

This study is subject to several limitations. Our model simulates individuals with SARS CoV-2 entering the nursing home environment and estimates the number of infectious contacts per day but does not simulate transmission to nursing home residents. Accordingly, we did not model interventions that decrease the risk of transmission within the nursing home environment such as masking, social distancing, and cohorting of residents. Other studies have examined these within-facility interventions in detail (Holmdahl et al., 2021; Love et al., 2021; Nguyen et al., 2021). Estimating the extent of resultant outbreaks from these contacts was not the focus of this analysis and therefore, we did not model the full chain of transmissions. We did not simulate the impact of sociodemographic variables such as race/ethnicity or rural residence on the probability of vaccination or nursing home visitation as the synthetic population currently does not include these agent-level variables. We also assumed that all nursing home residents were 65 years of age or older. While a growing percentage of nursing home residents are younger (Ne'eman, Stein, & Grabowski, 2022), we lacked this information for the simulated nursing homes in North Carolina. Future work will seek to incorporate additional sociodemographic variables within the model.

Next, we did not account for changes in vaccine effectiveness against infection due to differing vaccine schedules or immunosuppression and implemented a weighted average vaccine effectiveness based on reports during the Omicron surge. A more effective vaccine may result in policies that increase the percentage of staff or the community with a booster being more impactful compared to the other modeled policies. Finally, like all simulation studies, this analysis is subject to the inherent biases and limitations related to the sources used to parameterize the model. A formal probabilistic sensitivity analysis was not performed as methodological guidance for how to conduct PSA for agent-based models is still in development (Borgonovo, Pangallo, Rivkin, Rizzo, & Siggelkow, 2022; Ten Broeke, Van Voorn, & Ligtenberg, 2016). Therefore, parameters with greater uncertainty such as the probability of visiting a nursing home while experiencing mild symptoms of COVID-19 or the number of nursing home residents attended to by a single healthcare worker may not be fully accounted for within the main analyses. However, we conducted several scenario analyses to explore the potential impact of selected uncertain parameters including the case multiplier and vaccine effectiveness against infection.

Simulation analyses like this one could be powerful decision aids in future waves of the COVID-19 pandemic or in future epidemics. Our North Carolina model has a modular design, so different experiments and disease models can be built on the agent-based modeling foundation. To replicate this analysis in response to a future COVID-19 wave, a new vaccine or test, or other scenarios, we could adjust parameters and intervention scenarios, returning results in a matter of days. However, for information generated by the model to realize their potential impact on future crises, two obstacles remain. First, simulation models rely on real-world data to inform their parameters. Turnaround time can only be as fast as the time it takes to reliably estimate parameters. Second, practitioners and public health decision-makers must be involved in framing and dissemination. Our work with the NC Department of Health and Human Services provides an example of such collaboration (Endres-Dighe et al.; Preiss et al.). Traditional epidemiologic approaches including prospective cohort studies and surveillance-based analyses are often limited in their ability to account for interference (i.e., where one person's outcome such as COVID-19 infection impacts another person's exposure). Using an agent-based model, we can successfully account for interference, multiple exposures (i.e., exposure through visitation as well from HCW) and generate causal effect estimates (Marshall & Galea, 2014). An additional advantage of this simulation model is the ability to estimate the number of asymptomatic carriers who may test negative but are still capable of transmitting SARS-CoV-2. Observational studies are typically unable to accurately estimate asymptomatic carriers due to a reliance on testing data.

CONCLUSIONS AND IMPLICATIONS

This study presents information to help nursing home facilities evaluate which policies may be most effective in preventing potential SARS-CoV-2 infectious contacts during a period of increased community spread. The policy requiring visitors to provide a negative rapid test resulted in the greatest decrease in the number of potential infectious contacts. A policy which increases the proportion of staff boosted will likely have greater impact than that reported due to staff working at multiple sites. Facilities should consider prioritizing these strategies when preparing for the next period of increased SARS-CoV-2 transmission.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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What this paper adds

- A policy requiring a negative SARS-CoV-2 rapid test from all visitors resulted in the greatest decrease in the number of potential transmissions.
- Policies which required visitors to be vaccinated with at least two doses and requiring vaccinated healthcare workers to be boosted were also effective in decreasing the risk of transmission.
- Even if visitors or healthcare workers exhibiting SARS-CoV-2 symptoms isolate, asymptomatic or presymptomatic individuals will enter the nursing home environment during periods of increased community spread.

Applications of study findings

- During periods of increased community spread of SARS-CoV-2, nursing home facilities should consider requiring a negative rapid test from all visitors.

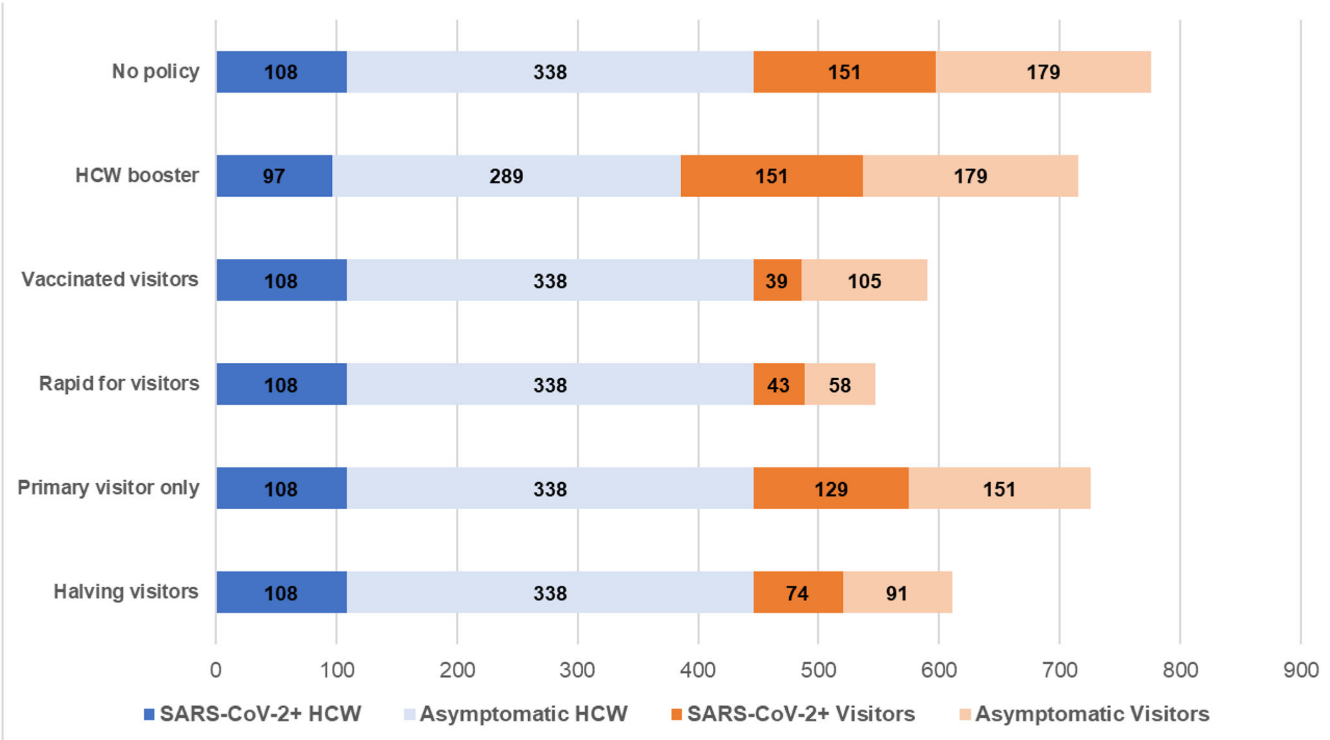

Figure 1.

Average number of SARS-CoV-2 infected healthcare workers (HCW) or visitors entering nursing home facilities per day by policy.

Table 1.

Estimates for Key Model Parameters NC MInD-Healthcare Agent-based Model

Parameter	Value, Range/Distribution	Source
Initializing population		
Sex	48.1% male, 51.9% female	RTI SynthPop™ 2017 dataset
Age group	63.1% <50, 21.0% 50–65, 15.8% 65+	RTI SynthPop™ 2017 dataset
County of residence	100 counties	RTI SynthPop™ 2017 dataset
Comorbidities	23.74% of agents 50–64 years old, 54.97% of agents 65+ years old classified as having a comorbidity	Medicare Marketscan data 2016–2017
Occupation as a healthcare worker	25,831 (0.24% of total population)	Medicare Care Compare CMS Provider Information, (Ferguson et al., 2020)
Visitor to a nursing home facility	52,600 over one month	(Gaugler, 2005), (Tornatore & Grant, 2002), (Ross et al., 1997)
SARS-CoV-2		
Incubation period	5 days until Dec. 2021, 3 days starting in Dec. 2021 (Omicron dominant)	(Ferguson et al., 2020), (Jansen, 2021)
Period of infectiousness	7 days	(Hay et al., 2022)
Target case count for reported infections	384,868 (actual reported Dec. 15, 2021-Jan. 13, 2022)	COVID Act Now (www.covidactnow.org)
Case multiplier	8x (varied in sensitivity analyses)	Assumed
Vaccination		
Vaccine effectiveness against infection	24% (assumes vaccine effectiveness of 50% with booster and 7% for two doses or unvaccinated)	(UK Health Security Agency, 2022) (Buchan, Chung, Brown, Austin, Fell, Gubbay, Nasreen, Schwartz, Sundaram, Tadrous, Wilson, Wilson, Kwong, & Investigators on behalf of the Canadian Immunization Research Network Provincial Collaborative Network, 2022) preprint: (Spensley et al., 2022)
SARS-CoV-2 asymptomatic status based on vaccination status	*For reported cases (12.5% of total):* Unvaccinated: 5% asymptomatic Vaccinated: *25% asymptomatic *For unreported cases (87.5% of total):* Unvaccinated: 25% asymptomatic Vaccinated:* 50% asymptomatic	(Fowlkes et al., 2021),(Centers for Disease Control & Prevention, n.d.),(Tartof et al., 2021) (Espenhain et al., 2021) (Ferguson, 2021), (Oran & Topol, 2021) NC DHHS Report (accessed Nov. 30, 2021)
SARS-CoV-2 severity based on vaccination status	Varies by age group, informed by hospital inpatient data	NC DHHS Report (accessed Nov. 30, 2021)
Vaccination rate (two doses)	53% (as of Jan. 15, 2022)	NC DHHS COVID Data Dashboard
Booster rate (third dose)	25.6% of total population and 37% of vaccinated population (as of Jan. 15, 2022)	NC DHHS COVID Data Dashboard
Vaccination rate for nursing home visitors	75% (as of Jan. 15, 2022)	Informed by NC DHHS COVID Data Dashboard
Vaccination rate for healthcare workers	80% (as of Jan. 1, 2022) for two doses	CMS COVID-19 Nursing Home Data, (Centers for Medicare)
Vaccination rate for nursing home residents	86% (as of Jan. 3. 2022) for two doses	CMS COVID-19 Nursing Home Data, (Centers for Medicare)
Agent movements		
Community to acute care setting as patient		NC short-term acute care hospital discharge data from (Cecil G. Sheps Center for Health Services Research)

Parameter	Value, Range/Distribution	Source
Length of stay (hospital)	Non-COVID admission: varies by hospital COVID admission: mean 3 days, standard deviation 5 days, range 1–50 days	NC short-term acute care hospital discharge data from (Cecil G. Sheps Center for Health Services Research)
Probability of transfer, hospital to nursing home		NC short-term acute care hospital discharge data from(Cecil G. Sheps Center for Health Services Research)
Community to nursing home facility as patient		NC short-term acute care hospital discharge data from (Cecil G. Sheps Center for Health Services Research)
Community to nursing home facility as healthcare worker		Medicare Care Compare CMS Provider Information, (Ferguson et al., 2020)
Community to nursing home facility as visitor		(Gaugler, 2005), (Tornatore & Grant, 2002), (Ross et al., 1997)
Acute care settings		
Number of acute care settings	104 short-term acute care hospitals	NC short-term acute care hospital discharge data from (Cecil G. Sheps Center for Health Services Research)
Number of beds by facility	1–1,000+	
Location	100 counties	Centers for Medicare & Medicaid Services data (Centers for Medicare)
Proportion of non-ICU beds filled at model initiation	65%	Expert opinion
Proportion of ICU beds filled at model initiation	50%	Expert opinion
Nursing home facilities		
Number of nursing home facilities	426 nursing homes	NC short-term acute care hospital discharge data from (Cecil G. Sheps Center for Health Services Research)
Number of beds by facility	Average: 104, range (4–248)	Medicare Care Compare CMS Provider Information
Frequency of nursing home visitation	Primary visitor: 15 times per month, second visitor: 5 times per month, third visitor: once per month	(Gaugler, 2005), (Tornatore & Grant, 2002), (Ross et al., 1997)
Testing parameters		
Sensitivity for polymerase chain reaction (PCR) testing	77% for asymptomatic, 85% for symptomatic	(Butler-Laporte et al., 2021) (Hellewell et al., 2021)
Sensitivity for point-of-care antigen testing	67.4% for asymptomatic, 72% for symptomatic	(Ontario COVID-19 Science Advisory Table et al., n.d.) preprint: (Goodall et al., 2022)(Goodall et al., 2022), preprint: (Schrom et al., 2022) preprint: (de Michelena et al., 2022), (Drain, 2022),(Dinnes et al., 2021)
PCR persistent positivity (positive test for agents within the "recovered" state)	30%	(Landi et al., 2021), (Yahav et al., 2021), (Aldhaeefi, Tahir, Cote, Izzy, & El Khoury, 2021), (Stehlik et al., 2021)
Specificity for PCR and point-of-care antigen testing	98%	FDA threshold

* Vaccination is modeled as a time-invariant agent state and does not differ by vaccine manufacturer, number of received doses, or time since last dose.

Table 2.

Simulated Outcomes for SARS-CoV-2 Intervention Policies for Nursing Home Facilities[a]

Testing Policy	Total Daily Attendance (HCW+ visitors)	Number of Daily SARS-CoV-2 Infected HCW or Visitors	Percent of			
			Visits with SARS-CoV-2	Visits with Asymptomatic Infection	HCW Daily Shifts with SARS-CoV-2	SARS-CoV-2+ HCW Shifts with Asymptomatic Infection
No intervention policy						
A. Main analysis	31,456 (30,048–32,914)	776 (585–1000)	2.3% (1.7–3.0%)	54.1% (53.8–54.4%)	2.6% (2.2–3.0%)	75.7% (73.2–78.8%)
B. Community booster uptake	31,518 (30,153–32,930)	678 (497–884)	2.1% (1.5–2.8%)	52.5% (52.4–52.6%)	2.2% (1.8–2.6%)	74.6% (72.5–78.1%)
C. Case multiplier 6x	31,613 (30,266–33,045)	575 (412–769)	1.7% (1.1–2.3%)	53.4% (53.1–53.9%)	1.9% (1.5–2.3%)	75.1% (72.3–79.0%)
D. Case multiplier 4x	31,781 (30,346–33,192)	375 (245–534)	1.1% (0.6–1.6%)	51.4% (51.4–51.7%)	1.3% (0.9–1.6%)	73.4% (70.4–77.9%)
Requiring that all vaccinated HCW are up to date with booster						
A. Main analysis	31,494 (30,143–32,945)	716 (534–926)	2.3% (1.7–3.0%)	54.1% (53.5–54.3%)	2.2% (1.8–2.6%)	75.0 (72.3–78.1%)
B. Community booster uptake[b]	31,518 (30,153–32,930)	678 (497–884)	2.1% (1.5–2.8%)	52.5% (52.4–52.6%)	2.2% (1.8–2.6%)	74.6% (72.5–78.1%)
C. Case multiplier 6x	31,656 (30,269–33,128)	528 (370–718)	1.7% (1.1–2.3%)	53.2% (52.7–53.6%)	1.6% (1.3–2.0%)	73.9% (71.1–77.7%)
D. Case multiplier 4x	31,805 (30,462–33,187)	345 (220–504)	1.1% (0.7–1.6%)	51.4% (51.5–51.7%)	1.1% (0.8–1.4%)	72.4% (69.6–77.0%)
Requiring visitors to be fully vaccinated (i.e., two doses)						
A. Main analysis	27,863 (26,785–28,967)	590 (455–745)	1.3% (0.9–1.8%)	69.0% (66.3–72.6%)	2.6% (2.2–3.0%)	75.7% (73.2–78.8%)
B. Community booster uptake	27,919 (26.892–28,970)	492 (366–632)	1.1% (0.7–1.5%)	69.0% (65.8–74.6%)	2.2% (1.8–2.6%)	74.6% (72.5–78.1%)
C. Case multiplier 6x	27,982 (26.961–29,067)	441 (325–576)	1.0% (0.7–1.4%)	68.3% (65.7–72.2%)	1.9% (1.5–2.3%)	75.1% (72.3–79.0%)
D. Case multiplier 4x	28,101 (27,072–29,185)	290 (195–403)	0.7% (0.4–1.0%)	66.3% (63.4–71.1%)	1.3% (0.9–1.6%)	73.4% (70.4–77.9%)
Requiring a negative rapid for visitors						
A. Main analysis	31,226 (29,890–32,595)	547 (428–681)	0.7% (0.5–0.9%)	57.8% (57.6–58.2%)	2.6% (2.2–3.0%)	75.7% (73.2–78.8%)
B. Community booster uptake	31,309 (30,765–32,638)	469 (388–592)	0.7% (0.6–0.9%)	56.3% (56.2–57.4%)	2.2% (1.8–2.6%)	74.6% (72.5–78.1%)
C. Case multiplier 6x	31,445 (30,865–32,798)	407 (330–523)	0.5% (0.5–0.7%)	57.2% (56.8–57.6%)	1.9% (1.5–2.3%)	75.1% (72.3–70.0%)
D. Case multiplier 4x	31,671 (31,131–33,021)	266 (203–363)	0.3% (0.3–0.5%)	55.5% (55.2–56.6%)	1.3% (0.9–1.6%)	73.4% (70.4–77.9%)
Restricting visitation to primary visitor						

Testing Policy	Total Daily Attendance (HCW+ visitors)	Number of Daily SARS-CoV-2 Infected HCW or Visitors	Percent of			
			Visits with SARS-CoV-2	Visits with Asymptomatic Infection	HCW Daily Shifts with SARS-CoV-2	SARS-CoV-2+ HCW Shifts with Asymptomatic Infection
A. Main analysis	29,380 (28,246–30,533)	726 (565–903)	2.3% (1.8–2.8%)	54.1% (53.8–54.4%)	2.6% (2.2–3.0%)	75.7% (73.2–78.8%)
B. Community booster uptake	29,441 (28,351–30,543)	632 (481–794)	2.1% (1.6–2.6%)	52.6% (52.5–52.7%)	2.2% (1.8–2.6%)	74.6% (72.5–78.1%)
C. Case multiplier 6x	29,526 (28,447–30,654)	538 (400–692)	1.7% (1.2–2.2%)	53.4% (53.1–54.1%)	1.9% (1.5–2.3%)	75.1% (72.3–70.0%)
D. Case multiplier 4x	29,683 (28,601–30,800)	351 (240–476)	1.1% (0.7–1.5%)	53.1% (52.7–53.2%)	1.3% (0.9–1.6%)	73.4% (70.4–77.9%)
Reducing visitation frequency by 50%						
A. Main analysis	24,312 (23,312–25,523)	611 (455–800)	2.3% (1.5–3.3%)	54.1% (53.6–55.1%)	2.6% (2.2–3.0%)	75.7% (73.2–78.8%)
B. Community booster uptake	24,367 (23,248–25,546)	527 (379–702)	2.1% (1.3–3.1%)	52.4% (51.7–52.5%)	2.2% (1.8–2.6%)	74.6% (72.5–78.1%)
C. Case multiplier 6x	24,441 (23,321–25,626)	454 (322–617)	1.7% (1.0–2.6%)	53.4% (53.2–53.8%)	1.9% (1.5–2.3%)	75.1% (72.3–70.0%)
D. Case multinlier 4x	24.575 (23.475–25.737)	296 (191–434)	1.1% (0.5–1.9%)	51.4% 151.3–51.8%)	1.3% (0.9–1.6%)	73.4% (70.4–77.9%)

[a]Mean and credible interval shown

[b]Equivalent to the community booster uptake scenario under the "no intervention policy" model runs as the proportion of vaccinated HCW and community members with booster is set to same percentage (74%).

Table 3.

Estimated number of infectious contacts per day for SARS-CoV-2 Intervention Policies for Nursing Home Facilities[a,b]

Testing Policy	Number of daily infectious contacts by HCW	Number of daily infectious contacts by visitors	Total number of daily infectious contacts	Number and percent of infectious contacts averted compared to "No intervention"
No intervention policy				
E. Main analysis	54 (43–65)	13 (9–18)	67 (52–83)	n/a
F. Community booster uptake	45 (35–56)	12 (8–17)	57 (43–73)	n/a
G. Case multiplier 6x	40 (31–50)	10 (6–14)	50 (37–64)	n/a
H. Case multiplier 4x	26 (19–35)	6 (4–10)	32 (22–44)	n/a
Requiring that all vaccinated HCW are up to date with booster				
E. Main analysis	46 (37–57)	13 (9–18)	59 (46–75)	8 (10.9%)
F Community booster uptake[c]	45 (35–56)	12 (8–17)	57 (43–73)	0 (0 0%)
G. Case multiplier 6x	34 (26–44)	10 (6–14)	44 (32–58)	6 (11.4%)
H. Case multiplier 4x	22(16–31)	6(4–10)	29(19–41)	3 (11.3%)
Requiring visitors to be fully vaccinated (i.e., two doses)				
E. Main analysis	54 (43–65)	6 (4–8)	59 (47–73)	8 (10.9%)
F. Community booster uptake	45 (35–56)	5 (3–7)	50 (38–62)	7 (13.0%)
G. Case multiplier 6x	40 (31–50)	4 (3–6)	44 (34–56)	5 (10.8%)
H. Case multiplier 4x	26 (19–35)	3 (2–5)	29 (20–39)	3 (10.5%)
Requiring a negative rapid for visitors				
E. Main analysis	54 (43–65)	4 (3–6)	58 (46–70)	9 (13.8%)
F. Community booster uptake	45 (35–56)	4 (4–5)	49 (39–61)	8 (14.6%)
G. Case multiplier 6x	40 (31–50)	3 (3–4)	43 (34–54)	7 (13.6%)
H. Case multiplier 4x	26 (19–35)	2 (2–3)	28 (21–38)	4 (13.5%)
Restricting visitation to primary visitor				
E. Main analysis	54 (43–65)	11 (8–14)	65 (51–79)	2 (3.0%)
F. Community booster uptake	45 (35–56)	10 (7–13)	55 (43–69)	2 (3.2%)

Testing Policy	Number of daily infectious contacts by HCW	Number of daily infectious contacts by visitors	Total number of daily infectious contacts	Number and percent of infectious contacts averted compared to “No intervention”
G. Case multiplier 6x	40 (31–50)	8 (6–11)	48 (37–61)	1 (3.0%)
H. Case multiplier 4x	26 (19–35)	5 (3–8)	31 (22–42)	1 (3.0%)
Reducing visitation frequency by 50%				
E. Main analysis	54 (43–65)	7 (4–10)	60 (47–75)	7 (9.9%)
F. Community booster uptake	45 (35–56)	6 (3–9)	51 (39–65)	6 (10.5%)
G. Case multiplier 6x	40 (31–50)	5 (3–8)	45 (34058)	5 (9.8%)
H. Case multiplier 4x	26 (19–35)	3 (1–6)	29 (20–40)	3 (9.7%)

[a] Mean and credible interval shown

[b] Assumes a 2% probability of transmission per infectious contact, that HCW have daily contact with 6 residents, and visitors have daily contact with 2 residents

[c] Equivalent to the community booster uptake scenario as the proportion of vaccinated HCW and community members with booster is set to same percentage (74%).