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A Simulation-Based Cost-Effectiveness Analysis of Severe Acute Respiratory Syndrome Coronavirus 2 Infection Prevention Strategies for Visitors of Healthcare Institutions

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ABSTRACT

Objectives: The aim is to quantitatively evaluate different infection prevention strategies in the context of hospital visitor management during pandemics and to provide a decision support system for strategic and operational decisions based on this evaluation.

Methods: A simulation-based cost-effectiveness analysis is applied to the data of a university hospital in Southern Germany and published COVID-19 research. The performance of different hospital visitor management strategies is evaluated by several decision-theoretic methods with varying objective functions.

Results: Appropriate visitor restrictions and infection prevention measures can reduce additional infections and costs caused by visitors of healthcare institutions by 90%. The risk of transmission of severe acute respiratory syndrome coronavirus 2 by visitors of terminal care (ie, palliative care) patients can be reduced almost to 0 if appropriate infection prevention measures are implemented. Antigen tests do not seem to be beneficial from both a cost and an effectiveness perspective.

Conclusions: Hospital visitor management is crucial and effectively prevents infections while maintaining cost-effectiveness. For terminal care patients, visitor restrictions can be omitted if appropriate infection prevention measures are taken. Antigen testing plays a subordinate role, except in the case of a pure focus on additional infections caused by visitors of healthcare institutions. We provide decision support to authorities and hospital visitor managers to identify appropriate visitor restriction and infection prevention strategies for specific local conditions, incidence rates, and objectives.

Keywords: cost-effectiveness analysis, severe acute respiratory syndrome coronavirus 2, simulation, visitor management.

Introduction

The World Health Organization declared COVID-19 to be a pandemic on March 11, 2020. Since then, the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has placed a burden on healthcare systems, economies, and individuals. The high number of hospitalized patients, especially in critical care units, has been an increasing challenge to hospitals and healthcare workers. In-hospital outbreaks and affected staff by the virus and the outbreaks have aggravated the problem.

Carter et al found that up to 12.5% of hospitalized patients with COVID-19 acquire the infection in the hospital; Bhattacharya et al reported up to 5.3%. Therefore, hospitals must implement prevention strategies to reduce nosocomial transmission to the lowest number possible and minimize transmission to staff. Strict hygiene measures, including wearing surgical face masks, have decreased the nosocomial infection rate. Visitor restriction has been another standard tool since the first peak phase of the pandemic. So far, there are only a few recommendations by health authorities or researchers concerning appropriate infection control measurements and visitor restrictions (eg, Bayerisches Staatsministerium für Gesundheit und Pflege, Wakam et al). Short visiting hours and as few visitors as possible have been proposed. Nevertheless, these restrictions should be balanced with the patients’ mental health and quality of life. Studies show, for example, the importance of visitation for patient outcome or the reduction of anxiety in intensive care patients. Consequently, until the start of the pandemic, most hospitals were accessible to visitors at almost any time without any regulation, and a new management task on visitation in hospitals came up with SARS-CoV-2. Hospital visitor management includes several steps such as an admission control, registration activities, or testing. The regulations, thereby, are a particular burden to terminal care and critically ill patients, and especially from an ethical perspective, visitor restrictions to those groups of patients may be difficult to enforce.

Besides hospital visitor admission, several similar challenges associated with COVID-19 appeared throughout the pandemic.
Among others, these include the management of endoscopic units during pandemics or the evaluation of social distancing strategies. Simulation techniques and cost-effectiveness analyses are frequently applied in literature to challenges as mentioned before (see, eg, Chhatwal et al,12 Dawoud and Soliman,13 Ebibgo et al,14 Kriegel et al,15 or Shlomai et al16).

Our study aims to analyze whether visitor management is an adequate tool to effectively prevent infections while maintaining hospital visits in a pandemic situation based on broad simulation studies. We elucidate various infection prevention measures concerning their effectiveness and cost-benefit ratio depending on different hypothetical incidence rates. In addition, we assess the impact of all terminal care patients having visitors almost without restrictions.

Methods

Model Assumptions

We analyzed and compared additional costs $c_{m}$ and additional infections $n_{i,m}$ of various infection prevention measures $m = \{1, \ldots, M\}$ and incidence rates $inc_i$ with $i \in \{1, \ldots, I\}$ and thereby calculated a cost-effect ratio. We included costs for surgical face masks, N95 face masks, antigen tests, different polymerase chain reaction (PCR) tests, symptom screening, personnel, equipment, and quarantine costs for visitor management. Quarantine costs included the economic loss due to home quarantine for one affected healthcare worker (average of 1 resident/doctor, 1 nurse, and 1 nursing student) and 2 patients from the working population. The latter indicated the consequence of an infection and the related quarantine due to the definition of risk contacts (see below). Personnel and equipment costs of €10 140 per week were deterministic and were only assumed in the case of actual infection prevention measures with $m \neq 1$, that is,

$$c_{m} = \begin{cases} 0 & m = 1 \\ 10 140 & m \in \{2, \ldots, M\} \end{cases}$$

$c_{m}$ for $m \neq 1$ summarized costs for employees deployed at the entrance area, discounted technical devices, partition walls, floor markings, etc. The costs were calculated by interviews with the hospital visitor manager at the University Hospital of Augsburg (UKA). For the calculations, we evaluated different hypothetical infection rates $inc_i$ with $i \in \{1, \ldots, I\}$ and defined these as the ratio of currently infectious individuals with an infectivity of 7 days, that is, the number of new infections per 100 000 residents per week. We used a worst-case scenario and defined 3 risk contacts per visitor and an infection rate of 100% in the case of no preventive measures. Risk contacts included 2 patients (ie, the visited patient and the room neighbor) and 1 healthcare worker. In the case of complete hospital staff vaccination, we excluded healthcare workers from being risk contacts as proposed by the Robert Koch Institute (see Robert Koch Institut17). The latter case with 2 risk contacts might also function as an alternative to the worst-case scenario with lower infectivity.

The transmission rate $t_1 = 1$ for $m = 1$ (ie, no infection prevention measures) might be reduced by several measures such as face masks or testing with $m \in \{2, \ldots, 8\}$. This reduction was calculated based on existing publications, manufacturer's information, or studies at the UKA on the (clinical) sensitivity per measure. According to manufacturer’s information, the sensitivity of the PCR test with $m = 7$ is 97%. Consequently, in 3 of 100 cases, an infected subject was not identified by the PCR test and will enter the hospital. The associated transmission rate for $m = 7$ was $t_2 = 0.03$. Based on the meta-analysis by Chu et al,18 we calculated the transmission rate per risk contact with surgical face masks to be $t_2 = 0.16$ and with N95 face mask to be $t_3 = 0.01$, accordingly. Although the calculations are strongly supported by recent studies of the Max Planck Institute,19,20 we researched the influence of a misjudgment of $t_2$ by a sensitivity analysis.

Regarding symptom screening, we considered and averaged the information of the German Robert Koch Institute on the ratios of patients infected with SARS-CoV-2 with well-known symptoms such as cough. By, in addition, incorporating the findings by Nogrady11 on asymptomatic COVID-19 infections, we assumed the transmission rate for $m = 8$ to be $t_8 = 0.66$. For the evaluation of combined infection prevention strategies with $m \in \{9, \ldots, M\}$, for example, surgical face mask, PCR test, and symptom screening, we calculated the transmission rates under an independence assumption:

$$t_m = \begin{cases} t_t & m \in \{1, \ldots, 8\} \\ t_t \times t_7 & m \in \{9, \ldots, M\} \end{cases}$$

where $t_t$ is the transmission rate for surgical face masks ($j = 2$) and PCR test ($k = 7$), for example, was calculated by $t_2 \times t_7$. For a combination of surgical face masks ($j = 2$), PCR test ($k = 7$), and symptom screening ($l = 8$), the transmission rate was given by $t_2 \times t_7 \times t_8$. Note that not all combinations, for instance, surgical face masks ($m = 2$) and N95 face masks ($m = 3$), are useful from an infection prevention perspective and the independence assumption. Besides $M = 18$ base and useful combined infection prevention strategies, we evaluated visitor restrictions $r$, with $r \in \{1, \ldots, R\}$ per bed and week. Thereby, a maximum number of visitors allowed was set to 1, 3, or 10, respectively, while we assumed a thereupon symmetric triangular distribution. A maximum number of 10 visitors per bed and week might be interpreted as no visitor restrictions. Given that the average hospitalization time in Germany is 1 week (see Statista25) and this is exactly the denominator of the incidence rate, the reference size of all calculations was 1 week.

A special consideration of this article is hospital visitor management of terminal care patients during pandemics. We researched the results of no visitor restrictions (ie, 10 visitors) for terminal care patients only. To conclude from this, we retrospectively averaged the relative number of terminal care patients in the UKA per week from August to December 2020. Appendix Table 1 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.04.1736 provides an overview of our assumptions and sources (eg, Chu et al,18 Leielveld et al,19 or Nogrady11). The parameters and indices are summarized in Appendix Table 2 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.04.1736.

Data Generation Process

A Monte Carlo simulation with software R while input parameters are specified by literature and data of the UKA is used to evaluate visitor restrictions and preventive measures. We run 1000 simulations per incidence rate and visitor restriction with >30 000 000 random numbers all in all. A hospital size of the main building of the UKA with approximately 1000 beds is assumed. To investigate the generalizability of our results, we also run simulations for the mean hospital size in Germany with approximately 250 beds (calculated from Destatis26). Appendix Figure 1 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.04.1736 presents a flowchart of our simulation routine.
### Performance Metrics

The R output consists of additional infections $n_i$ and additional costs $c_i$ caused by hospital visitor management per visitor restriction, infection prevention measure, vaccination status, and incidence rate. We evaluate the performance of different measures for a given visitor restriction and vaccination rate using decision-theoretic methods. In particular, 4 objective functions are minimized here: (1) minimize the additional infections $m^{\text{infections}}_i = \operatorname{argmin}_m n_i \forall i \in \{1, \ldots, I\}$, (2) minimize the additional costs $m^{\text{costs}}_i = \operatorname{argmin}_m c_i \forall i \in \{1, \ldots, I\}$, (3) minimize the additional costs subject to an infection threshold $m^{\text{order}}_i = \operatorname{argmin}_m c_i \text{ s.t. } n_i \leq 0.1 \forall i \in \{1, \ldots, I\}$, or (4) minimize a function of standardized additional costs and additional infections $m^{\text{GP}_i} = \operatorname{argmin}_m \left( \frac{n_i - 0 + \frac{n_i}{c_{i,m}}} {c_{i,m}} \right) \forall i \in \{1, \ldots, I\}$ with $c_{i,m}^{\text{max}} = \max_r c_{i,m}$. Table 1 and Figure 1 show the results of these optimizations.

### Research Ethics

The study was conducted in accordance with the Declaration of Helsinki Ethical Principles and Good Clinical Practices and was reported to the local ethics committee (21-0832 KB).

### Results

For a single, randomly selected simulation run, 4945 different people visit the hospital with 1000 beds per week in the case of 10 visitors per bed restriction (see Table 1). Visitors provoke approximately 5 or 30 risk contacts for an incidence of 35 or 200, respectively. These figures are dramatically reduced by introducing a visitor restriction, for example, 1 visitor per bed and week, alone. If visits are restricted to terminal care patients, the number of visitors and risk contacts are strictly below the 1 visitor per bed restriction.

For the simulation study with 1000 runs per setting, the risk of additional infections and additional costs correlate with the incidence in the catchment area. Assuming an incidence of 100 and having no visitor restrictions, additional 15 infections would be caused. Implementing visitor restriction to 1 visitor per bed, additional infections would be reduced to 1.5. Mandatory surgical face masks and a visitor restriction to 1 visitor per bed would further decrease the number of additional infections to 0.24 (see Fig. 1). Taking no measures causes additional costs of €173,413 per week, having an incidence of 500. Accomplishing infection prevention measures in terms of visiting restrictions alone or with mandatory surgical masks decreases costs to €17,329.36 and €13,057.69, respectively (see Fig. 2).

Assuming that visits are restricted to terminal care patients and no other prevention measures are taken, there are costs of €1525.62 and 0.66 additional infections for an incidence of 100. If mandatory N95 face masks are also introduced, there are costs of €1011.4 and 0.01 additional infections. For other incidences, this logic of the conclusions remains unchanged (see Appendix Fig. 2 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.04.1736). Sensitivity analyses regarding the robustness of our results in view of the assumed transmission rate $t_2 = 0.16$ for surgical face masks show that although a slight imprecisionness regarding the assumed transmission rate, that is, $t_2 = 0.10$ or $t_2 = 0.20$, has a minor influence on additional infections, a misjudgment of the transmission rate at a larger scale, ie, $t_2 = 0.01$ or $t_2 = 0.40$, has a significant impact on additional infections (see Appendix Fig. 3 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.04.1736).

When it comes to optimal measures to minimize additional infections, regardless of incidence or restriction, a combination of N95 masks, PCR testing, and symptom screening might always be beneficial. For a plain cost evaluation, only with high incidence rates and loose visitor restrictions, a combination of face masks and symptom screening is preferable to no measures. The lexicographic ordering also initially does not include tests and relies on face masks and symptom screening instead of tests and no other measures.

| Visitor restrictions | Number of visitors | Risk contacts with an incidence of 35 | Risk contacts with an incidence of 200 |
|----------------------|--------------------|--------------------------------------|---------------------------------------|
| 10 visitors (per bed and week) | 4944.60 | 5.19 | 29.67 |
| 3 visitors (per bed and week) | 1524.87 | 1.60 | 9.15 |
| 1 visitor (per bed and week) | 502.26 | 0.53 | 3.01 |
| No visitors at all | 0 | 0 | 0 |

Visitors only allowed for terminal care patients

219.82 | 0.23 | 1.32 |
As before, PCR tests alone are part of optimal alternatives and no antigen tests, especially.

For the traffic light system, all measures are ordered based on the additional infections induced. Interestingly, this order is always the same, no matter which incidence rate or vaccination status is assumed. Nevertheless, what changes are the measures assigned to one of the 3 categories red, yellow, and green. For example, the surgical face mask is in category green for a low incidence rate and strict visitor restrictions. For other constellations, surgical masks might also be part of category yellow or red. Here, again, it is evident that strict visitor restrictions cause fewer measures and vice versa. Complete vaccination of healthcare workers equivalently influences both visitor restrictions needed and measures.

For all incidence rates, visitor restrictions, and vaccination status, 2 combined strategies are in category green: N95 masks × PCR tests and N95 masks × PCR tests × symptom screening. If the number of visitors is restricted to 3 visitors, N95 masks × antigen tests, surgical masks × PCR tests × symptom screening, and N95 masks + antigen tests + symptom screening are part of the green category. Our decision support system for all vaccination status, incidence rates, and visitor restrictions studied on is presented in Appendix Tables 4 to 9 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.04.1736. Corresponding costs are

![Figure 1](image1)

**Figure 1.** Additional infections \( n_{(i,m)} \) caused by visitors to a 1000-bed hospital without secondary infections for various incidences, no infection prevention strategies, a visitor restriction, and mandatory surgical masks.

![Figure 2](image2)

**Figure 2.** Additional costs \( c_{(i,m)} \) caused by visitors to a 1000-bed hospital without secondary infections for various incidences, no infection prevention strategies, a visitor restriction, and mandatory surgical masks.
Because of this conclusion and tests. This is not surprising, considering recent articles on the basic procedure of evaluating specific infection prevention measures based on a worst-case scenario with 3 risk contacts and 100% transmission. In reality, the actual transmission may not occur in all 3 contacts. In contrast, there is a certain dark figure of undetected infections, the problem of super spreaders and new mutations with varying incidence rates and infectivity, which may justify our proceeding. In addition, the scenario with fully vaccinated hospital staff and 2 risk contacts functions as an alternative.
to the worst-case scenario with lower infectivity. Finally, the incidence rate for determining current infectivity in a population should at least be mentioned critically.

Conclusions

In this work, we apply a simulation-based cost-effectiveness analysis to hospital visitor management in Germany during the COVID-19 pandemic. The model is based on data from a university hospital in Southern Germany and published COVID-19 research. We find visitor management involving both visitor restrictions and infection prevention measures is crucial and effectively prevents many infections while maintaining cost-effectiveness. For terminal care patients, visitor restrictions that may apply to usual patients can be omitted from a model perspective if appropriate infection prevention measures are taken. Testing, especially antigen testing, plays a subordinate role, except in the case of a pure focus on additional infections caused by visitors of healthcare institutions. We provide hospital visitor managers with a decision support tool to identify appropriate visitor restrictions and infection prevention strategies for the specific local conditions and incidence rates. In addition, we discuss different objectives regarding hospital visitor management, for example, minimizing costs, in detail.

Supplemental Materials

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.jval.2022.04.1736.

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