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Management of nurse shortage and its impact on pathogen dissemination in the intensive care unit☆

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ABSTRACT

Introduction: Studies provide evidence that reduced nurse staffing resources are associated to an increase in health care-associated infections in intensive care units, but tools to assess the contribution of the mechanisms driving these relations are still lacking. We present an agent-based model of pathogen spread that can be used to evaluate the impact on nosocomial risk of alternative management decisions adopted to deal with transitory nurse shortage.

Materials and methods: We constructed a model simulating contact-mediated dissemination of pathogens in an intensive-care unit with explicit staffing where nurse availability could be temporarily reduced while maintaining requisites of patient care. We used the model to explore the impact of alternative management decisions adopted to deal with transitory nurse shortage under different pathogen- and institution-specific scenarios. Three alternative strategies could be adopted: increasing the workload of working nurses, hiring substitute nurses, or transferring patients to other intensive-care units. The impact of these decisions on pathogen spread was examined while varying pathogen transmissibility and severity of nurse shortage.

Results: The model-predicted changes in pathogen prevalence among patients were impacted by management decisions. Simulations showed that increasing nurse workload led to an increase in pathogen spread and that patient transfer could reduce prevalence of pathogens among patients in the intensive-care unit. The outcome of nurse substitution depended on the assumed skills of substitute nurses. Differences between predicted outcomes of each strategy became more evident with increasing transmissibility of the pathogen and with higher rates of nurse shortage.

Conclusions: Agent-based models with explicit staff management such as the model presented may prove useful to design staff management policies that mitigate the risk of healthcare-associated infections under episodes of increased nurse shortage.

Background

In the recent decades, policies promoting higher patient throughput in hospitals have led to many wards operating near full capacity, leading to increasingly frequent staff shortage situations, which challenge hospitals to continuously provide safe, quality care to acute and critically ill patients (Clarke, 2009). In this context, efficient management of hospital staffing resources is imperative.

In particular, hospital-acquired infections are important indicators of the quality of care in the intensive-care unit (ICU), where highly-specialized healthcare-workers (HCWs) are in close contact with fragile and highly susceptible patients, and where antibiotic pressure readily favors the selection of resistant pathogens

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(Fukuda et al., 2011). Several factors associated with transitory understaffing may contribute to pathogen spread in the ICU, including increased mobility of staff and patients between hospital wards, reduced levels of cohorting, and decreased compliance with infection control measures (Stone et al., 2004; Clements et al., 2008; West et al., 2009).

However, assessing the relative impact of alternative staffing policies in infection control is a complex issue (Pittet et al., 2006; Griffiths et al., 2009; Schwab et al., 2012), because significant evidence cannot be simply extracted from the analysis of administrative and surveillance data due to the abundance of confounding factors: demographic characteristics, condition, exposure to invasive life-support devices and to drug treatments of patients, as well as organizational culture, interdisciplinary collaboration, equipment facilities and documentation burden of the service (Hugonnet et al., 2007; Needleman et al., 2007). Mathematical models provide a complementary research tool that reduces the complexity of the systems under study, making them more accessible to specific questions (Grundmann and Hellriegel, 2006; van Kleef et al., 2013). Agent-based models are bottom-up computational models that describe individual behaviors and interactions in order to reproduce emergent properties of the population. They are well adapted to study the spread of pathogens in the ICU because they can capture the small size of the population, the diversity among individuals, the heterogeneity of the contact network and the stochasticity in staff-patients interactions (Hotchkiss et al., 2005; Hornbeck et al., 2012).

Using an agent-based approach, the objectives of this article were to address the following three questions regarding the management of transitory nurse shortage in the ICU: (1) How may management decisions adopted in response to a temporary nurse shortage significantly affect the prevalence of pathogens in the ICU? (2) How does the relative impact of these decisions vary with the type of pathogen transmitted? And (3), how does it vary with the severity of nurse shortage?

Methods

Data collection

A study undertaken by the French National surveillance network of ICU-acquired infections REA-RAISIN in five volunteer ICUs collected weekly data on bed occupancy, staffing conditions for registered nurses and nurse's aides and incidence of hospital-acquired infections among patients over a period of 26 weeks between January and June 2012.

The average severity of patients entering the ICU, indicated by the Simplified Acute Physiology Score (SAPSII, range 1:163), was 40 [95%CI: 15–71]. The average length of stay of patients was 12.0 days [95%CI: 2–41.7] days. The average bed occupancy rate was 0.97 [95%CI: 0.71–1.17]. It was defined as the number of patient hospital days in a week divided by the number of open bed-days in the same week, and it could adopt values greater than one because some patients remained in the ICU for less than one day. The percentage of nurse substitution was around 9.4% [95%CI: 0–21.4%] for registered nurses, and around 10.9% [95%CI: 0–32.4%] for nurse's aides. It was defined as the number of hours per week covered by substitute staff divided by the total number of weekly working hours. We used this data to define realistic scenarios in our modeling study, in which we explored nurse shortage situations with up to 40% of missing nurses. The average probability of bacterial infection per patient per week was 7% [95%CI: 0–21%] the average ratio of VRE to MRSA cases was 1.91 [95%CI: 0–3], and the average incidence of pneumonia was 7% [95%CI: 3–38%]. No significant correlations were found between incidence of infections and bed occupancy, nor between incidence and staffing conditions, due to the lack of statistical power. Prevalence of pathogen carriage among patients or HCWs was not explicitly measured.

Modeling ICU organization

Based on the data collected, we adapted an existing agent-based model for pathogen spread in the ICU (Temime et al., 2009) to include a realistic framework for the management of patients and staff (Ferrer Savall et al., 2013). We considered a 12-bed ICU in which new patients could be admitted daily, assuming a 100% bed occupancy ratio (Barado et al., 2012). We modeled the duration of patient stay in the ICU using a long-tailed distribution with mean = 4.2 days and median = 2.1 days, in line with reported data that show 80% of patients staying for less than five days and 5% of the patients staying more than 10 days (Kramer and Zimmerman, 2010).

We established the ICU workforce, comprising two types of HCWs (physicians and nurses), in accordance with staffing practices common in the European Union and assuming in-ward staff-to-patient ratios of 1:2 for nurses and 1:6 for physicians. In a 12-bed ICU, this translated as 6 nurses and 2 physicians required round the clock, which entailed the recruitment of 20 nurses and of 14 physicians working 35 h per week in 12 h shifts. Realistic rosters for each staff member were created using the software Shift Plan Assistant©, developed by the company Ximes (Ximes GMBH). At the beginning of each work duty, patients were randomly assigned to working HCWs to model cohorted care delivery.

During the work duty, each nurse paid three 30-min visits to each assigned patient, while each physician made a single round of 25-min visits. In addition, 10-min emergency calls randomly coupling a nurse and a patient could occur at any time but during the planned visits. On average, we simulated 6 emergency calls per patient per day. Visits were scattered throughout the shift and scheduled so that only one-to-one contacts took place. Fig. 1a provides a schematic description of the modeled ICU and the network of contacts between patients and HCWs. Table 1 provides a list of model parameters and their assumed values.

Modeling pathogen spread

We described the spread of carriage of three common pathogens in the ICU: bacteria found on human skin such as methicillin-resistant *Staphylococcus aureus* (MRSA), bacteria with higher transmissibility and environmental endurance, such as vancomycin-resistant enterococci (VRE), and pathogens that can be transmitted either through droplets or via the airborne route, such as influenza. Pathogen spread was modeled exclusively via patient – HCW contagions occurring during visits and implicitly taking into account the application of hygiene measures with limited compliance.

Introduction of a pathogen in the ICU occurred at patient admission or at the arrival of HCWs. 10% of patients were assumed to be carriers at ICU admission, but this probability was varied from 5 to 20% in sensitivity analyses, in line with reported rates in the literature (Ziakas et al., 2013a, 2013b). Patients who acquired pathogen carriage usually remained carriers until their discharge from the ICU, as the average assumed carriage duration was ten days (reflecting for instance weekly screenings plus a 3-day wait for test results). In HCWs, we modeled transient contamination with the pathogen, with a duration following an exponential distribution of mean 10 h, to implicitly take into account hypothetical 80% effective hygiene measures followed by the staff with 65% compliance (Temime et al., 2009). This distribution ensured a 50% probability of pathogen removal between two consecutive nurse visits and allowed for a