

AHRQ Final Progress Report

Title: Developing an Integrated Engineering-Based Model to Reduce Infections in the ICU

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Abstract

Purpose: To develop an engineering-based, systems-level methodology that models the likelihood of infection transmission within pediatric ICUs. *Scope:* Hospital-associated (HA) infections are an important cause of morbidity and mortality, especially for ICU populations. Because a mechanism to understand the dynamics of a system oriented toward abating infection transmission is unavailable, the goal for this research is to develop such a model. *Methods:* We took an integrated approach, concentrating on catheter-related bloodstream infections, ventilator-associated pneumonia, respiratory virus infections, urinary tract infections, and rotavirus infections in pediatric, cardiac, and neonatal ICUs. Rather than attempting to tackle each type of infection individually, we developed a composite endpoint of the most important hospital-associated infections as the primary outcome of the model. *Results:* Development of a risk model for the assessment of hospital-associated infections created a mechanism to compare interventions. The findings show that combinations of interventions are more effective than individual interventions at reducing the risk of HA infections when compared to the effectiveness of individual interventions. They also show that interventions oriented toward reducing the risk of HA infection due specifically to CVCs, mechanical ventilation, PICCs, Foley catheters, patient length of stay, hemodialysis/CRRT, and Broviac lines are more likely to succeed in reducing the overall risk of HA infections.

Key Words: Systems modeling, simulation, risk analysis, infection transmission.

Purpose & Scope

Hospital-associated infections are major problems that not only affect patient health

but also result in increased treatment costs and strained healthcare resources.

This problem persists despite the fact that the best practices to reduce the occurrence

for common hospital-associated infections are well documented in the literature. This research utilized a complex system modeling framework to tackle this problem.

The framework enables one to look beyond the traditional infection control practices of concentrating on a single infection affecting a limited patient population. Instead, this research considers the 5 most common types of hospital-associated (HA) infections affecting the entire patient population in a pediatric ICU. This framework encompasses a variety of engineering techniques, such as simulation modeling, risk analysis, and statistical analysis. Simulation modeling is utilized to model an ICU work environment from the perspective of infection transmission. The model depicts patient population, invasive procedures performed on the patients, and primary staff functions. Risk analysis is then utilized to evaluate the effect of different patient physiological factors and the invasive procedures performed on the patients to determine a "risk-of-infection" model. Using the simulation and the risk model, different interventions are then modeled, and their effectiveness at reducing the risk of infection is evaluated and compared. Experimental design is then used to identify the factors that contribute significantly toward reducing infections.

The findings show that a combination of interventions is more effective at reducing the risk of HA infections compared with the effectiveness of individual interventions. They also show that interventions oriented toward reducing the risk of HA infection due to CVCs, mechanical ventilation, PICCs, Foley catheters, patient length of stay, hemodialysis/CRRT, and Broviac lines are more likely to succeed at reducing the overall risk of HA infections.

Although it is inconceivable to try these interventions in a real ICU to test their effectiveness, the complex system modeling framework allows one to do just that. The framework is flexible and can accommodate additional factors that may be discovered in the future as ones affecting the risk of HA infections.

Methods

This research combines engineering techniques into a system-level complex model to address the problem of the most commonly sighted HA infections affecting pediatric ICU patient populations. This section describes the development of such a model. A variety of factors, e.g., patient physiological attributes and medical functions performed on the patient that affect the spread of HA infections, are considered. In addition, an ICU environment consists of multiple types of care providers – doctors, nurses, and dietitians, to name a few. For this environment, the study mechanism should enable assessment of the effect of different factors on the spread of infections and the effect of interventions on the risk mitigation of infections. Most importantly, the safety of the patients may not be jeopardized. In order to meet all the challenges and to factor in the constraints, complex system modeling (CSM) is a relevant mechanism.

Complex systems are composed of a number of interacting entities, processes, or agents, the understanding of which requires the development or the use of new scientific tools, nonlinear models, out-of-equilibrium descriptions, and computer simulations. ICU work environments can certainly be termed as complex systems due to a variety of factors, including existence of multiple types of care providers, large number of medical procedures performed on ICU patients, etc. In order to concentrate on HA infections, it is necessary to take into account relevant components from an ICU work environment system. The objective is accomplished via the research tasks depicted in Figure 1.

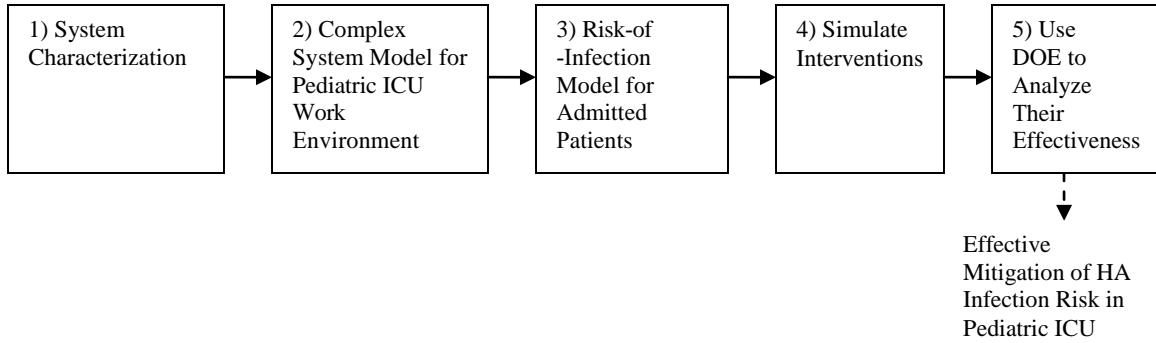


Figure 1. Integrated methodology.

1. Characterize the current system in the ICU.
 The primary aim of this task was to identify main care providers in the ICU work environment, important functions carried out by them during the course of their shift, and the approximate frequency and sequence of the functions. Data sources used: infection control surveillance data, patient demographic data, and observational data.

2. Create a complex systems model of the ICU.
 Models are useful for understanding the working of a system and predicting the outcome of a change. The use of simulation models is recommended when there are multiple variables that potentially can produce a large number of results, especially in the case of complex systems. Simulation models were used to represent the interventions and assess their effectiveness; the basic structure is shown in Figure 2.

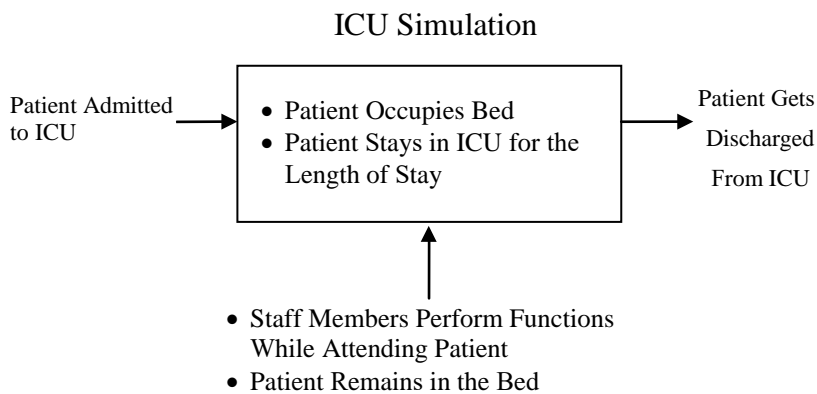


Figure 2. Conceptual simulation model.

Patients were generated as per a schedule obtained from the historical data. Every patient generated in the ICU had 3 physiological parameters – age, length of stay (LOS), and PIM2 score. In addition to the physiological conditions, the simulation also assigned up to 10 different invasive procedures to patients.

Sixty different types of invasive procedures were performed on the patients admitted. Because this research focused on specific hospital-associated infections, it concentrated on the following procedures, which were most likely to be responsible for these infections: central venous catheter (CVC), peripherally inserted central catheter (PICC), Broviac/Hickman type, port-a-cath/mediport/infusaport, extra corporeal membrane oxygenation (ECMO), hemodialysis/CRRT, mechanical ventilation (conventional), mechanical ventilation (HFOV), arterial lines, and Foley catheter.

Verification and validation of the model were completed in order to make sure that the model represents true system behavior reasonably well and can be used in place of experimentation.

3. Use risk analysis to develop a "risk-of-infection" measure and incorporate the risk measures into the simulation model to create a risk model of infection transmission for the existing ICU conditions.

Figure 3 shows the development of a risk index. The aim of this step was to create a baseline risk model depicting the current infection levels within the ICU.

These contribution values were used to calculate the risk score in the simulation.

Age, risk score, length-of-stay risk score, PIM2 score risk score, and the invasive procedure risk scores were calculated at the end of a simulation run. Then, 30% of the age risk score, 20% of the length-of-stay risk score, 5% of the PIM2 risk score, and 45% of the invasive procedure risk score were added in order to obtain the combined composite risk of HA infection score for 1 quarter.

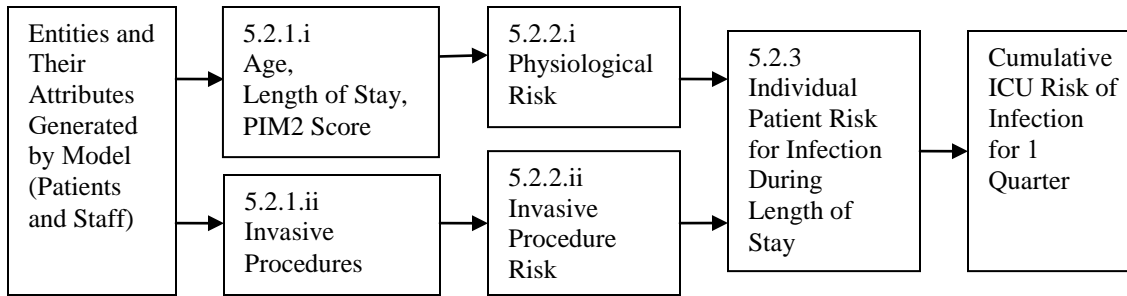


Figure 3. The development of an ICU-specific risk-of-infection score.

At this point, the research created a simulated ICU work environment from the existing data and observations. It also incorporated the technique of risk analysis to generate a composite risk score for 5 types of HA infections in the existing work environment.

4. Simulate interventions suggested in the medical literature for reducing the risk of HA infection transmission and evaluate risk of infection associated with these interventions using the risk model.

The interventions investigated were as follows:

- a. Use of antimicrobial-impregnated CVCs (Khare et al., 2007; Rupp et al., 2005; Veenstra et al., 1999)
- b. Limiting the use of Foley catheters (Saint et al., 2005)
- c. Use of oral care kits with cetylpyridium antiseptic rinse agent (Tollover et al., 2007)
- d. Combinations of 2 or more interventions.
- e. Antimicrobial-impregnated PICC, Broviac lines

The risk scores obtained with different interventions were compared with the existing risk scores by 1-way hypothesis testing: Is the risk of infection with intervention(s) in place

significantly less than the current risk of HA infections? A significant risk reduction with 95% confidence was found for the following:

- Antimicrobial CVC, PICC, Broviac + limited Foley
- Antimicrobial CVC, PICC, Broviac + enhanced oral care
- Antimicrobial CVC, PICC, Broviac + limited Foley + enhanced oral care

A significant risk reduction with 90% confidence was found for the following:

- Antimicrobial CVC, PICC, Broviac
- Antimicrobial CVC + limited Foley
- Antimicrobial CVC + enhanced oral care

The following were not significantly different from the current risk scores:

- Antimicrobial CVC
- Limited use of Foley catheters
- Enhanced oral care
- Limited Foley + enhanced oral care

5. Evaluate the interventions using statistical techniques of design of experiments (DOE) to suggest a set of interventions most effective at reducing the risk of infection transmission in the ICUs.

The response variable was risk-of-infection scores, and the effects were the interventions performed. Assumptions made included that each effect was 2 levels: low-risk reduction (-1) or high-risk reduction (+1); risk reductions for hemodialysis, ECMO, arterial lines, and length of stay; no risk reductions for patient age or PIM2 scores. This design resulted in a $2^{(11-5)}$ fractional factorial design.

Results

The research introduced a risk model for the assessment of HA infections. Different factors affecting the spread of HA infections are identified in the literature. This research combined these factors and suggested their composition utilizing the statistical mixture design technique. The composite risk score proposed by the risk model is a prediction of the HA infections per 1000 patient days for an entire ICU for 1 quarter.

This research makes it possible to assess the impact of an intervention in terms of reduction in HA infection rates in an ICU, because the CSM framework enables projection of the effect of an intervention on the ICU population in general.

Another contribution of this research is that it provides the ability to compare different interventions. It is not possible to perform different interventions and compare their effectiveness in a real-life ICU. The CSM framework allows one to do just that without harming the safety of a patient. The framework also analyzes the effect of more than 1 intervention simultaneously, and the results show that combinations of interventions are more likely to cause a significant reduction in HA infection rates. These results confirm the initial assumption that looking at this problem from a systems perspective may be more effective than considering individual infections separately. The research also enables characterization of different interventions using the DOE technique. Such characterization can suggest factors on which interventions should be focused in order to obtain maximum reduction in the risk of HA infections.

Thus, this research suggests combining simulation modeling, risk analysis, and statistical analysis techniques together into a CSM framework for assessing the risk of HA infections and determining the impact of interventions aimed at mitigating their risk.

Publications

Conferences:

6th International Conference on Health Policy Research at Boston, MA, Oct 28-30, 2005.

INFORMS Annual Meeting at Pittsburgh, PA, Nov 5-8, 2006.

INFORMS Annual Meeting at Seattle, WA, Nov 4-7, 2007.

Conference Proceedings at the 19th Annual Society for Health Systems Conference at New Orleans, LA, Feb 2007.

Publications:

Limaye, S., Mastrangelo, C., Zerr, D., Jeffries, H. (2008) A statistical approach to reduce hospital-associated infections. *Quality Engineering*, 20:4,414-25.

Limaye, S., Mastrangelo, C., Zerr, D. (2008) A case study in monitoring hospital-associated infections with count control charts. *Quality Engineering*, 20:4,404-13.

Two more in progress.