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## Major Article

## You get back what you give: Decreased hospital infections with improvement in CHG bathing, a mathematical modeling and cost analysis



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## Key Words:

Hospital-acquired infections  
Chlorhexidine gluconate bathing  
Infection prevention

**Background:** Multiple studies have shown that bathing with chlorhexidine gluconate (CHG) wipes reduces hospital-acquired infections (HAIs). We employed a mathematical model to assess the impact of CHG patient bathing on central line-associated bloodstream infections (CLABSIs), catheter-associated urinary tract infections (CAUTIs), and hospital-onset *Clostridium difficile* (*C diff*) infections and the associated costs.

**Methods:** Using a Markov chain, we examined the effect of CHG bathing compliance on HAI outcomes and the associated costs. Using estimates from 2 different studies on CHG bathing effectiveness for CLABSI, CAUTI, and *C diff*, the number of HAIs per year were estimated along with associated costs. The simulations were conducted, assuming CHG bathing at varying compliance rates.

**Results:** At 32% reduction in HAI incidence, increasing CHG bathing compliance from 60% to 90% results in 20 averted infections and \$815,301.75 saved cost.

**Conclusions:** As CHG bathing compliance increases, yearly HAIs decrease, and the overall cost associated with the HAIs also decreases.

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Hospital-acquired infections (HAIs) are one of the leading causes of death in the United States.<sup>1</sup> The Centers for Disease Control and Prevention National Healthcare Safety Network defines HAIs as central line-associated bloodstream infections (CLABSIs), catheter-associated urinary tract infections (CAUTIs), select surgical site infections (SSIs), hospital-onset *Clostridium difficile* (*C diff*) infections, and hospital-onset methicillin-resistant *Staphylococcus aureus* (MRSA) bacteremia (bloodstream infections). Prevention strategies, such as improving catheter insertion techniques, following contact precautions, monitoring hand hygiene, disinfecting caps for intravenous lines, and bathing patients, especially near the site of device insertion, are most effective in reducing the number of HAIs in hospital units.<sup>1–3</sup> About 1 in 25 hospitalized patients will acquire an HAI during their hospital stay,<sup>4</sup> although some sources report at least 1 in 10 hospitalized patients gaining an HAI during their stay.<sup>5</sup> The World Health Organization suggests that HAIs continue to plague

even the most advanced hospital systems owing to intrinsic patient factors, including compromised immunity.<sup>6</sup> Devices and wounds serve as a portal of entry for bacteria, increasing the risk of a patient acquiring an HAI.<sup>7</sup>

Chlorhexidine gluconate (CHG), an antiseptic solution, resides on the skin of a patient longer than regular soap and other antiseptics,<sup>8</sup> and, therefore, continues to protect patients long after they are bathed. In a meta-analysis study, Frost et al<sup>9</sup> estimated the reduction of HAI risk with daily CHG bathing for bloodstream infections, CLABSI, vancomycin-resistant Enterococcus (VRE), CAUTI, MRSA, ventilator-associated pneumonia (VAP), and *C diff*. They reported a 56% decreased risk of CLABSI and a 7% decreased risk of *C diff* with daily CHG bathing. In addition, Huang et al<sup>10</sup> conducted a meta-analysis study on CHG data and reported a 32% decreased risk of acquiring CAUTI.

To study the effect of CHG bathing on HAIs, a Markov chain was employed to simulate daily patient dynamics. This model used daily transition probabilities between different patient states to estimate the trajectories of patients. The probabilities of transitioning between states were estimated,<sup>2,9,10</sup> and this model was

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simulated under different bathing compliance rates to estimate the effect on HAIs and overall costs.

**METHODS**

*Model structure*

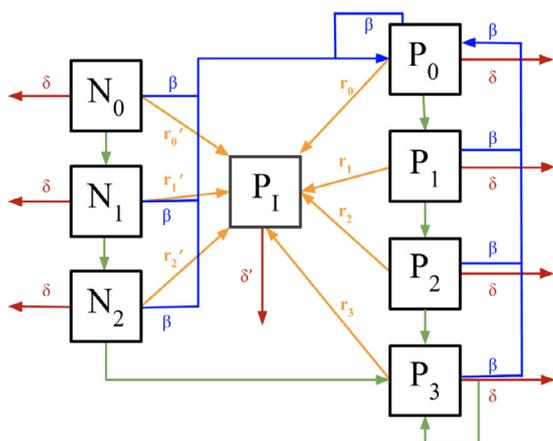
A discrete-time Markov Chain was developed to model the movement of individuals between different patient states. These states include:  $N_i$ , newly admitted patients who have not yet received a CHG bath in  $i$  days ( $i = 0, 1, 2$ ),  $P_i$ , patients whose most recent CHG bath was  $i$  days ago ( $i = 0, 1, 2, 3$ ), and patients with an HAI,  $P_I$ . We define the state vector  $X(n) = [N_0(n), N_1(n), N_2(n), P_0(n), P_1(n), P_2(n), P_3(n), P_I(n)]^T$  to be the number of patients in each state at day  $n$ .

The distribution of patients on any given day depends on what state they were in the day before. In particular, the distribution of patients on day  $n + 1$  is given by:

$X(n + 1) = B \cdot I \cdot D \cdot X(n)$ , where  $B$ ,  $I$ , and  $D$  represent the transition matrices for being bathed, infected, and discharged respectively. Once a patient acquires an HAI and enters the  $P_I$  class, the patient will remain there until discharged. We do not consider additional HAIs beyond the first one acquired.

As shown in Figure 1, each class has a discharge rate of  $\delta$ , except for the  $P_I$  class, which has a lower rate,  $\delta' < \delta$ , owing to acquiring an HAI. If a patient is discharged, then a new patient is replaced in the system into the  $N_0$  class, which maintains a constant population size. If a patient is not discharged, then the patient may acquire an HAI or be CHG bathed. Each class of patients has a specific probability of infection and is denoted  $r'_i = \eta \cdot r_i$  ( $i = 0, 1, 2$ ) for the  $N_i$  classes, and  $r_i = (1 - \frac{(3-i)\alpha}{3})r$  ( $i = 0, 1, 2, 3$ ) for the  $P_i$  classes, where  $\alpha$  is the CHG bathing effectiveness and  $\eta$  ( $0 < \eta < 1$ ) is a newly admitted patient's resistance to infection with their unaltered microbiome, as seen in Figure 1. A patient's microbiome regenerates 72 hours after an injury (such as invasive surgery or an accident).<sup>10,11</sup> Therefore, we considered a patient who has been in the hospital for 3 days to have the same probability of acquiring an HAI with a patient who has been in the hospital for  $>3$  days.

If a patient receives a CHG bath, as denoted by  $\beta$  in Figure 1, the patient is moved into the  $P_0$  class. Then, for each day that a patient does not receive another CHG bath, the effectiveness of the CHG solution on the skin decreases by  $\frac{\alpha}{3}$ . If a patient is not discharged, infected or CHG bathed, then the patient moves as follows: patients in  $N_i$  transition to  $N_{i+1}$  ( $i = 0, 1$ ),  $N_2$  transitions to  $P_3$ ,  $P_k$  transitions to  $P_{k+1}$  ( $i = 0, 1, 2$ ), and  $P_3$  stays in  $P_3$ .



**Fig 1.** The classes of patients ( $N_0, N_1, N_2, P_0, P_1, P_2, P_3, P_I$ ) with discharge rates  $\delta, \delta'$ , CHG bathing compliance rate  $\beta$ , and daily probability of infections ( $r'_0, r'_1, r'_2, r_0, r_1, r_2, r_3$ ). CHG, chlorhexidine gluconate.

**Table 1**  
Parameter values used in the simulations

Parameter	Symbol	Value
Daily probability of infection	$r$	0.00134 (32% effectiveness)
CHG bathing effectiveness	$\alpha$	0.32 HAIs per day
Unaltered microbiome resistance	$\eta$	0.95 per day
Discharge rate for all classes except $P_I$	$\delta$	0.2 Patients per day
Discharge rate for $P_I$	$\delta'$	0.1 Patients per day

CHG, chlorhexidine gluconate; HAIs, hospital-acquired infections.

*Model inputs*

The probability of becoming infected was based on the average observed incidence rate of 1.025 cases per 1,000 patient days for CLABSI, CAUTI, and *C diff* at Virginia Commonwealth University Medical Center in 2017 and 2018.<sup>2</sup> Virginia Commonwealth University Medical Center is an 865-bed academic medical center, with 65,000 patient discharges estimated annually and records with an average of 318 CAUTI, CLABSI and *C diff* between 2017 and 2018. The total number of patients in our specific simulation was 850 patients.<sup>2</sup> An average reduction in the probability of acquiring an HAI,  $\alpha = 32\%$ , was based on the reductions of risk of HAIs in Frost et al and Huang et al. The  $r$  was calculated with a baseline compliance rate of 60% and the effect of CHG bathing on the reduction of incidence of CLABSI, CAUTI, and *C diff*.<sup>9,10</sup> Simulation results were based on 365 days at steady state and the model was simulated in MATLAB\_R2017b. Table 1 lists the parameter values used in the simulation.

One CHG bath costs \$5.71, K. Gurney (personal communication, October 18, 2018). Each specific HAI has an individual cost to the hospital. On average, however, an HAI costs the hospital \$45,000.<sup>12</sup> Patients who do not receive a CHG bath on a given day are assumed to receive a bath with non-CHG wipes, which costs \$1.16 per bath, K. Gurney (personal communication, October 18, 2018). The total cost calculation included costs related to bathing materials and the costs associated with HAIs.

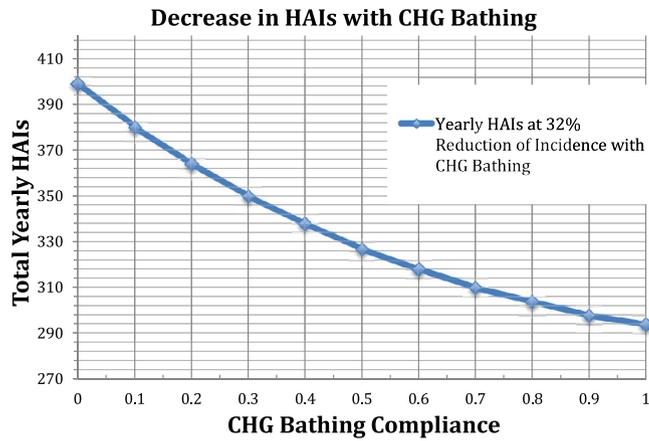
**RESULTS**

As the CHG bathing compliance rate increases, the number of yearly HAIs decreases and the overall health care-associated costs decrease (Fig 2). Increasing the CHG bathing compliance from 60% to 90% incurs an additional cost of \$106,291.65 spent on CHG bathing wipes. However, at 32% reduction in HAI incidence, increasing the compliance rate from 60% to 90% results in 20 averted infections and \$815,301.75 saved cost. Further, based on the HAI mortality rate of 15%-25%,<sup>13</sup> approximately 5 lives would be saved.

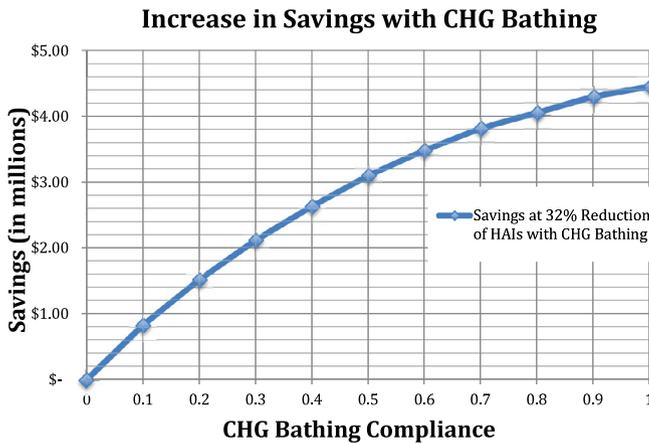
**DISCUSSION**

We employed a Markov chain to study the reduction of HAIs and the associated costs of HAIs by varying the CHG bathing compliance rate. Previous literature<sup>2,3,8-10</sup> support the use of CHG bathing as a preventative and cost-saving practice. Our results show how the effectiveness of CHG bathing impacts the overall return of health care savings. Our results are based off an 850 patient medical center with an incidence rate of 1.025 cases per 1,000 patient days for all HAIs. The infection probability was estimated using a baseline CHG bathing compliance of 60% and an average of 318 yearly HAIs.

Savings are primarily owing to the reduction of HAIs, and there is a larger impact on the reduction of HAIs when CHG bathing is more consistent. Figures 2 and 3 show that overall, every increase in CHG bathing compliance prevents total yearly HAIs and also results in savings. At 32% reduction in HAI incidence, increasing CHG bathing



**Fig 2.** The decrease in yearly HAIs, with an increase in CHG bathing. CHG, chlorhexidine gluconate; HAIs, hospital-acquired infections.



**Fig 3.** The increase of overall savings by increasing CHG bathing compliance from 0%. CHG, chlorhexidine gluconate.

compliance from 60% to 90% results in 20 averted infections and \$815,301.75 in saved cost.

## CONCLUSIONS

Using a mathematical model to understand CHG bathing compliance is novel. This model allows for predicting consequences of varying compliance rates without experimentation that would be unethical. Mathematical models are based on assumptions made.

Here, daily deviations from the parameters were not accounted for, although we assumed that over the course of 1 year that the daily deviations would not be significant. Although the recently reported ABATE trial<sup>14</sup> did not find that CHG use in non-ICU settings was associated in reduced MRSA or VRE acquisition, there are likely subpopulations that do benefit from CHG bathing and it has been proven to be effective in reducing HAIs overall in numerous studies.<sup>2,3,8-10,12</sup> Additionally, increasing the compliance rate and/or training health care workers to properly use CHG bathing increases its effectiveness and can result in saving lives and hospital costs. In the future, we will investigate the impact of implementation barriers and delays on HAIs and cost.

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