ABSTRACT
Bacterial meningitis is a very serious life-threatening illness; that left untreated has a fatality rate of 70 percent. It is an especially serious illness on college campuses where the infection rate is approximately four times greater than the rate for the general population of 18-23 year olds. In 2008, the University of Central Florida (UCF) implemented an inoculation and education policy. This research was interested in determining the effect of the meningitis policy with respect to safeguarding the UCF community. In order to research this issue, deterministic models for meningitis outbreaks on the UCF campus were created and run as simulations using base and alternate input variables. Results from the simulations showed significant benefits could be achieved when inoculation and education programs are combined. More importantly, it demonstrated that simulation could be an effective tool for analyzing healthcare issues and formulating healthcare policy.

Keywords: meningitis, campus outbreak, medical simulation, modeling

1. INTRODUCTION

1.1. Meningitis
Bacterial meningitis (meningitis), a very serious life-threatening illness, can be transmitted through air droplets of respiratory secretions and direct contact with an infected person. Patients with the disease will develop flu-like symptoms and unfortunately, these symptoms can lead to misdiagnosis and lack of treatment. There can also be a rapid progression from the onset of symptoms to death. Sometimes this occurs in as little as 24 to 48 hours. Therefore, any delay in treatment only serves to magnify difficulties in treating the illness. According to the literature, when untreated the disease has a fatality rate of 70 percent, and 11 to 19 percent of the survivors will experience significant side effects. These side effects include hearing loss, loss of limbs, arthritis, and neurological defects. The neurological defects include issues such as memory loss, difficulty learning and remembering, headaches, speech impairment, and loss of sight (Collins, Dupont, and Nagie 2003).

1.2. Initial Research
Meningitis is an especially serious issue on college campuses where the infection rate is approximately four times (5.1 per 100,000 versus 1.4 per 100,000) the rate of the general population of 18-23 year olds (Collins, Dupont, and Nagie 2003). Key factors in the higher infection rates among college students are their lifestyle choices that significantly increase their risk (Kuenzi 2004). According to Kuenzi, these lifestyle choices include active and passive smoking, bar or nightclub patronage, sharing cigarettes and beverage containers, intimate contact with others, and excessive alcohol consumption.

Recognizing these risks, health professionals from more than 35 states have helped to enact varying types of legislation with regards to inoculating students against meningitis or mandating education programs in order to confront this issue among college students (Castel, Reed, Davenport, Harrison and Blythe 2007).

1.3. UCF Policy on Meningitis
The University of Central Florida (UCF) is a university that is the fifth largest in the nation and the second largest in the State of Florida. The main campus sits on approximately 1,415 acres in Orlando Florida. With a growing enrollment rate, enrollment data and statistics indicate that the student population for Fall 2008 was in excess of 50,000 students, including 42,912 undergraduate students and 7,342 graduate students (UCF Office of Institutional Research, 2008-2009). According to UCF, the on-campus and off-campus housing capacity for locations managed by UCF was approximately 10,098 students.

In 2008, the University of Central Florida (UCF) joined the ranks of other colleges when it implemented a policy that requires new college freshmen to either be inoculated against meningitis or sign a waiver with an education statement on it. This research was interested in determining the effect of UCF’s meningitis policy with respect to safeguarding UCF’s community. In order to provide the data necessary to understand the
effects the policy has, the authors have created a base model showing an on-campus outbreak of meningitis. Next, based upon a literature review and research, model variables were manipulated in order to explore various mitigation strategies. These variables include inoculation, education, and combined inoculation and education programs.

The results of the simulations were then analyzed and the conclusions from this analysis were presented to health officials at UCF. By simulating a meningitis outbreak, emergency response procedures, response training, and reaction to outbreaks in real time can be improved (Wu, Shuman, Bidanda, Kelley, Sochats, and Balaban 2008). Conclusions can be drawn from the simulations as to the rate of the disease spreading throughout the UCF population among those who may have been exposed to infected individuals and what appropriate action should be taken to reduce further infections. It is expected that UCF health officials will be able to use the conclusions to review their current policies and, if necessary, revise their program to ensure they have a comprehensive program for reducing the meningitis risk to the general UCF college population.

2. METHOD
This research consisted of developing both base and alternative models for the spread of meningitis then running simulations using those models.

2.1. Base Model Development
This model began as a basic SIR model (Kermack and McKendrick 1927) that utilizes three compartments (susceptible, infectious, and removed). According to Caugant, et al. (1994), the infection of meningitis can result in two possibilities: those infected who show symptoms and those who do not show symptoms. Due to this characteristic of the disease, the model was modified by the inclusion of a non-symptomatic compartment to become an SI\(\bar{R}\) model. As in the SIR model, the population (whose size we represent with the variable \(N\)) is partitioned into the classes susceptible \(S(t)\), infected showing symptoms \(I_S(t)\), infected asymptomatic \(I_{\bar{R}}(t)\), and removed \(R(t)\), where \(S + I_S + I_{\bar{R}} + R = N\). Individuals in the susceptible compartment are subjected to an infected host with a contact rate of \(\beta\). Those contracting the disease enter the infected classes at a rate of \(p\) into the symptomatic class, or \((1 - p)\) entering the asymptomatic class. Individuals with the symptomatic form of the disease can recover from the infection and enter the removed compartment at a rate of \(\gamma\) (the mean recovery rate for meningitis) or die from the disease with a rate of \(\mu\) (the death rate due to the disease). Those within the asymptomatic compartment exit into the removed category at the rate of \(\gamma\). Individuals enter the removed category resistant to the disease for a period of time, \(\alpha\), then become susceptible again. The following ordinary differential equations (ODEs) were derived to represent this model:

\[
\begin{align*}
\frac{dS}{dt} &= \alpha R - \beta S(I_S + I_{\bar{R}}) \quad (1) \\
\frac{dI_S}{dt} &= p \beta S(I_S + I_{\bar{R}}) - I_S(\mu + \gamma) \quad (2) \\
\frac{dI_{\bar{R}}}{dt} &= (1 - p) \beta S(I_S + I_{\bar{R}}) - \gamma I_{\bar{R}} \quad (3) \\
\frac{dR}{dt} &= \gamma(I_S + I_{\bar{R}}) - \alpha R \quad (4)
\end{align*}
\]

These ODEs give continuous average rates for each of the population compartments, susceptible, infected – symptomatic, infected – asymptomatic, and removed. A summary of this notation can be seen in Table 1.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\alpha)</td>
<td>Average Resistance Period</td>
<td>0.1</td>
</tr>
<tr>
<td>(\beta)</td>
<td>Contact Rate</td>
<td>varies with scenario</td>
</tr>
<tr>
<td>(\gamma)</td>
<td>Average Recovery Rate</td>
<td>0.1</td>
</tr>
<tr>
<td>(\mu)</td>
<td>Average Death Rate Due to Meningitis</td>
<td>5% – 15%</td>
</tr>
</tbody>
</table>

The SI\(\bar{R}\)R system parameters were determined using several methods. These methods require the formulation of several assumptions, however. First, since the simulation is to take place on the UCF main campus, the host population is taken to be constant, i.e. no births (incoming students) or deaths due to causes other than meningitis were considered. Secondly, the model considers homogeneous mixing of the campus population resulting in all individuals having an equal opportunity to contract the disease. Finally, this representation of meningitis assumes a recovery from the asymptomatic disease with no lasting immunity.

Contact rate, \(\beta\), was determined for the specified campus area using the equation (5) derived by Rhodes and Anderson (2008).

\[
\beta = \frac{8 R q \overline{v}}{\pi A} \quad (5)
\]

This formula considers a moving population where the transmission rate of the disease is a factor of the density of the individuals. Here \(A\) is the area in which the population is constrained. The value used here is the area of UCF’s main campus, 1,415 acres (5.73 km\(^2\)). The parameter \(R\) is the radius within which an infected individual must pass a susceptible person in order to transmit the disease. One centimeter was used as the value for this parameter. This distance was assumed, as transmission of meningitis is a result of touching or sharing very close spaces. In accordance with the U. S. Department of Transportation (DOT), 4 ft/sec (4.39 km/hr) was utilized as the population average speed, \(\overline{v}\) (DOT 2003). The value for the probability of an
infective transmitting the infection, \( q \), was changed within each scenario to be considered, allowing the creation of different levels of meningitis education within the population.

Table 1 also lists other parameter values specific to meningitis found through our research, they include:

- Rate at which a resistant host becomes susceptible (\( \alpha = 0.1 \)) and the mean recovery rate from the disease (\( \gamma = 0.1 \)) are the same used by Stollenwerk and Jansen (2003).
- Death rate due to the disease (\( \mu = 5 \text{ to } 15\% \)) was found in the article by Paneth, et al. (2000).
- Proportion of infectives developing the symptomatic form of meningitis (\( p = 11\% \)) was derived by Caugant, et al. (1994).

2.2. Alternate Models

Three different alternative scenarios were considered in an effort to relate education and vaccination rates to a potential outbreak of meningitis on our closed college campus. These scenarios are presented in Table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Base Model</th>
<th>Education</th>
<th>Vaccination</th>
<th>Education &amp; Vaccination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability of Transmitting Infection ( q )</td>
<td>0.1</td>
<td>0.05</td>
<td>0.1</td>
<td>0.05</td>
</tr>
<tr>
<td>Number Vaccinated ( v_0 )</td>
<td>0</td>
<td>10%</td>
<td>51%</td>
<td>75%</td>
</tr>
<tr>
<td>Calculated Contact Rate ( \beta )</td>
<td>0.017</td>
<td>0.0085</td>
<td>0.017</td>
<td>0.0085</td>
</tr>
</tbody>
</table>

Three assumptions were made in the formulation of these alternate scenarios. First, a program including education would reduce the probability of transmitting an infection by half through increasing the awareness of students with respect to the sharing of personal items and improved hygiene. This educational program, while not requiring vaccination, would however, increase the rate of vaccination within the student population by 10\% due to an increased awareness of the risks associated with contracting meningitis. Secondly, due to the fact that we were unable to acquire actual statistics for vaccinations at UCF, we used the student vaccination rates determined by Paneth et al. (2000). They determined that a vaccination program similar to that already in place at UCF would result in 51\% of the student population under the age of 30 being inoculated for the disease. Finally, that an educational awareness program would boost vaccination rates to equal 75\% for use in that alternative model. Similar research on the effectiveness of an educational program that reached students prior to arriving on campus coupled with a vaccination program ultimately delivered significant improvements over time in the rates of vaccinated students. The increase ranges from 10\% in the first year to 20\% in the second year. “The total number of students immunized before or after arrival on campus increased from 40\% in the baseline group to 50\% in the class of 2004 (increase of 258 students) and to 60\% in the class of 2005 (increase of 454 students when compared with baseline group). The authors concluded that education about the benefits of meningococcal vaccine before students’ arrival on campus increased both the number of immunized students and the overall immunization rate among students” (Butler 2006).

3. RESULTS

The total number of dead and the number of days to reach that level for each of the various simulations are presented in Table 3. These numbers reflect the results of the simulation of the base model and the three alternative SI\( _S \)I\( _N \)R models.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Base Model</th>
<th>Education</th>
<th>Vaccination</th>
<th>Education &amp; Vaccination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number Dead</td>
<td>4,437</td>
<td>3,963</td>
<td>2,165</td>
<td>1,095</td>
</tr>
<tr>
<td>Number of Days</td>
<td>7.45</td>
<td>14.75</td>
<td>13.58</td>
<td>45.44</td>
</tr>
</tbody>
</table>

It is important to note that these values assume that from the onset of the disease, no action is taken to prevent further cases of the disease. In other words, mitigating actions (such as closing the campus or inoculations) by health officials do not occur. In the base model, there is less than eight days to recognize that an outbreak is occurring and take appropriate measures before more than 4,400 people are dead. Figure 1 graphically presents the results of the simulations.
number of deaths and the increased amount of time available before the total number of deaths occurs. Examination of the table reveals that the greatest decrease in the number of deaths occurs with a combined education and vaccination program (3,342 fewer deaths than in the base model). This also provided the greatest increase in time to react to the outbreak (45.44 more days than in the base model).

Table 4: Effect of Meningitis Reduction Programs from Base Model Results

<table>
<thead>
<tr>
<th></th>
<th>Education</th>
<th>Vaccination</th>
<th>Education &amp; Vaccination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect on Deaths</td>
<td>-474</td>
<td>-2,272</td>
<td>-3,342</td>
</tr>
<tr>
<td></td>
<td>(-11%)</td>
<td>(-51%)</td>
<td>(-75%)</td>
</tr>
<tr>
<td>Effect on Days</td>
<td>+7.3</td>
<td>+6.13</td>
<td>+37.99</td>
</tr>
<tr>
<td></td>
<td>(98%)</td>
<td>(82%)</td>
<td>(510%)</td>
</tr>
</tbody>
</table>

4. Discussion and Comments
While the significance of the total number dead should not be overlooked, analysis of the simulation results should also consider the time it takes to achieve those deaths. Medical care in the United States is such that meningitis is diagnosed before these high numbers are reached. With that in mind, the results of the models need to be discussed in terms of the number of deaths and the time required for the disease to run its course.

4.1. Base Model
The first scenario, the base model was created using no consideration of vaccination or education. It involves the introduction of one infected individual into a totally susceptible and (by our assumptions) uneducated population. By that we mean, a population of 18 to 24 year olds living in close quarters not taking precautions against disease transmission, i.e. binge drinking, smoking, lack of physical activity, etc (Keeling 2002). Left unattended, this situation would be disastrous, resulting in over 4,400 students dead within an eight-day period. However, with the current state of health care we know that this outcome is extremely unlikely on a U.S. college campus.

4.2. Education Program
An important finding from the research is that an education program (one designed to change student’s attitudes, and therefore lifestyle choices around the high-risk factors that increase the chances for contracting meningitis) has a significant effect on the transmission pattern of the disease (Figure 1). The results from the alternate model, which represented the use of an effective education program to minimize the risks associated with a meningitis outbreak, showed approximately a 10 percent decrease in deaths. However, possibly more important to health officials, it provided almost a 100 percent increase in the number of days available to health officials to react to a meningitis outbreak. It seems reasonable to assume that this increased time would be invaluable for agencies responsible for developing a response to an outbreak.

The current UCF “education program” is a statement on their health services website and waiver form informing students that engaging in high risk activities “… may make a person more likely to contract meningococcal disease include lifestyle factors, such as crowded living situations, bar patronage, active or passive smoking, irregular sleep patterns, and sharing personal items” (UCF 2007). Research indicates a warning statement is not an effective training strategy for an attitudinal goal such as changing one’s lifestyle and will have little or no effect on student’s lifestyle choices (Gagne, Briggs, and Wagner 1992). Therefore, for practical purposes it can be assumed that UCF does not have an education program to minimize the risk of meningitis disease and will not benefit from the increased time available to react to a meningitis outbreak (as depicted in Table 4). Programs such as Mr. 5th Guy on the UCF campus (encouraging all students to wash their hands and practice better hygiene) are a good start and can be useful components of an education program, but by themselves they do not provide a comprehensive anti-meningitis education program (Sander 2008).

4.3. Vaccination Program
The most effective single impact on a meningitis outbreak is the use of vaccination. Actual data quantifying the total number of students vaccinated, \(v_o\) as a result of the new immunization requirement that was implemented in July 2008 was unavailable for this research. The only available data was the number of students who were vaccinated, \(v_o\) by the UCF health center in 2007 through 2009. This information is shown in Table 5.

Table 5: Meningitis vaccination administered by the UCF Health Services Dept.

<table>
<thead>
<tr>
<th>Year</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Totals</td>
<td>398</td>
<td>281</td>
<td>20</td>
</tr>
</tbody>
</table>

In the fall of 2008 there were 50,254 students enrolled resulting in a 0.55% (< 1%) vaccination rate. The data clearly did not provide the statistical confidence when compared to previous research regarding vaccination programs on college campuses. To establish a baseline, the number of vaccinated, \(v_o\) was estimated at 51% from previous research on undergraduate vaccination for college students under 30 years old (Paneth et al. 2000). The simulation input values were then chosen based on campus size and other critical parameters, they are: \(q = 0.1\), \(v_o = 51\%\), and \(\beta = 0.017\).

The simulation indicated that an effective vaccination program is able to significantly reduce the number of fatalities by limiting them to 2,165. Additionally, the number of days to a full outbreak was nearly two times longer than the base model, but only approximately one-third the time of a combined education and vaccination program. Similar research on meningitis and the positive impact of a vaccination...
program has proven that “This approach could eventually lead to a 53% reduction in meningococcal incidence and a 65% reduction in meningococcal deaths among persons aged 0–22 years” (Harrison 2000).

The cost for each vaccination at UCF is $103.00; however, that cost could be lowered significantly if the University contacted the appropriate state and federal health officials, and negotiated with the vaccine manufacturers to support an on campus inoculation program. Affordability is always a decision factor for most college students, therefore, it is expected that lowering the cost for a vaccination would increase the number of students who are vaccinated. “CDC officials analyzed the benefit and cost-effectiveness of immunizing college students with the licensed quadrivalent polysaccharide vaccine, and found immunization of all 1st year-students living in dorms would result in administration of 300,000 to 500,000 doses each year and would be estimated to prevent 15 to 30 cases of meningococcal disease and one to three deaths each year” (Butler 2006).

4.4. Vaccination and Education Programs
As expected, a program including education and vaccination proved to provide the most response time and least number dead. The data in Table 4 shows that this combination of policies significantly lowered the death rate by 75 percent (3,342 fewer deaths) and lengthened the time available to react to an outbreak by 510 percent, a net gain of 37 days. According to UCF Health Center officials, their meningitis outbreak protocol involves communicating with the Orange County Health Epidemiology Department (ORCHD), notifying the UCF Administrator and Medical Director of Health Services regarding the infection. Next, the records of the infected student are reviewed to determine whom he or she has been in contact with so that decisions can be made to treat the exposed with medication. Finally, if necessary they will set up a medication-dispensing center in the UCF Health Center. This protocol requires time and the increased time to react to an outbreak, which is afforded by a combination program, can be a significant benefit to health officials and provide UCF with the time necessary to properly implement its protocol.

Combining a vaccination program with education program about lifestyle choices, sanitary precautions (e.g., washing hands), proper nutrition, as well as learning about the signs of meningitis can be a significant benefit to the reduction of the meningitis death rate and increasing the time available to respond to the outbreak.

4.5. Future Research
This research demonstrated that deterministic simulations can be an effective tool for analyzing campus health concerns and examining the impact of various changes to health policy. Data obtained from simulations can then be utilized by campus health officials to review and/or revise meningitis prevention policies. Since the simulations are only as accurate as the data used in the models, health officials should work closely with the developers in order to provide them with the most accurate data possible. Future research could be made using stochastic models that can represent the uncertainty inherent in a meningitis outbreak. Future research should also explore the other contagious diseases this tool can model.

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REFERENCES
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