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Cost-effectiveness of prophylactic antibiotic use to prevent catheter-associated urinary tract infections

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Abstract

Purpose: We evaluate the cost-effectiveness of prophylactic antibiotic use to prevent catheter-associated urinary tract infections.

Materials and Methods: A decision tree model was used to assess the cost-effectiveness of prophylactic antibiotics in preventing catheter-associated urinary tract infections for patients with a short-term indwelling urinary catheter. The model accounted for incidence of urinary tract infections with and without the use of prophylactic antibiotics, incidence of antibiotic-resistant urinary tract infections, as well as costs associated with diagnosis and treatment of urinary tract infections and antibiotic-resistant urinary tract infections. Costs were calculated from the healthcare system's perspective. We conducted one-way sensitivity analyses.

Results: The base case analysis showed that the use of prophylactic antibiotics is cost saving in preventing catheter-associated urinary tract infections. The use of prophylactic antibiotics resulted in lower costs and higher quality-adjusted life-years compared to no prophylactic antibiotics. Sensitivity analyses showed that the optimal strategy changes to no prophylactic antibiotics when the incidence of urinary tract infections after prophylactic antibiotics exceeds 22% or the incidence of developing urinary tract infections without prophylactic antibiotics is less than 12%. Varying the costs of prophylactic antibiotics, urinary tract infection treatment, or antibiotic-

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resistant urinary tract infection treatment within a reasonable range did not change the optimal strategy.

Conclusions: Prophylactic antibiotic use to prevent catheter-associated urinary tract infections is cost effective under most conditions. These results were sensitive to the likelihood of developing catheter-associated urinary tract infections with and without prophylactic antibiotics. Our results are limited to the cost-effectiveness perspective on this clinical practice.

Brief Summary:

Using a decision tree model, prophylactic antibiotic use to prevent short-term indwelling catheter-associated urinary tract infections is cost effective under most conditions.

Keywords

Costs and Cost Analysis; Cost-Benefit Analysis; Antibiotic Prophylaxis; Urinary Tract Infections; Catheter-Related Infections

INTRODUCTION

Catheter-associated urinary tract infections are quite common. Among hospital-acquired urinary tract infections, 70–80% are associated with the use of urinary catheters [1–3], and the daily risk of bacteriuria with catheterization is 3–10% [4]. The cost of catheter-associated urinary tract infections in surgical patients has been estimated to be \$558 to 676 per case [2, 5]. A Cochrane review of randomized controlled studies showed that receiving prophylactic antibiotics reduced the incidence of bacteriuria, pyuria, febrile morbidity and gram-negative isolates among surgical patients [6]. However, there are concerns about development of antibiotic-resistant urinary tract infections if antibiotic treatments are overused. Currently, there is no consensus on the use of prophylactic antibiotics in patients with short-term indwelling urinary catheters and no analysis of the cost effectiveness of such interventions.

Cost-effectiveness analysis uses decision tree models in the form of decision trees to evaluate the costs and effects of alternative strategies. A decision tree model is intended to account for all the probabilities, costs, and effects of different strategies in order to determine specific conditions where strategies are cost effective.

The objective of this study was to evaluate the cost effectiveness, in terms of cost per quality-adjusted life-year, of prophylactic antibiotic use to prevent short-term catheter-associated urinary tract infections. We also aimed to investigate the factors that affect the cost-effectiveness of this strategy.

MATERIALS AND METHODS

Model overview

We developed a decision tree model that integrated empirical data from the published literature to estimate the impact of prophylactic antibiotic use to prevent catheter-associated urinary tract infections in patients with short-term indwelling urinary catheters (Figure 1).

The model was constructed using SilverDecisions [7]. The input parameters of the model and assumptions are discussed below and listed in Table 1.

Patients who required short-term postoperative indwelling urinary catheters entered the model and received either prophylactic antibiotics while the catheter was in place or no prophylaxis (Figure 1). Table 1 shows the base case scenario input parameters. These base case numbers were taken from the literature, assuming an average of 3–5 days of catheterization, with catheter-associated urinary tract infection defined as bacteriuria $> 1,000$ to 100,000 colony forming units per mL. For those in the prophylactic antibiotics group, there was an additional upfront cost of prophylactic antibiotic treatment, estimated as the cost of a prescription for 3–5 days of antibiotics. In the base case, 5% of patients still developed urinary tract infections, while 95% did not. Among those who did develop urinary tract infections, 85% were successfully treated, while 15% developed antibiotic-resistant urinary tract infections. Compared to patients who received prophylactic antibiotics with catheters, among patients who did not receive prophylactic antibiotics, a larger proportion (30%) developed a urinary tract infection. Among the 30% who did develop a urinary tract infection, 92% were successfully treated, and a lower proportion (8%) developed an antibiotic-resistant urinary tract infection compared to the prophylactic antibiotics group given no prior exposure to prophylactic antibiotics. The cost of treating an uncomplicated case of urinary tract infection is estimated to be \$40, which includes testing and antibiotic treatment. The cost of treating a case of antibiotic-resistant urinary tract infection is estimated to be higher, at \$200, to account for repeated testing, office visits, and the need for second or third-line antibiotic treatments. Based on published data, we varied the incidences, costs, and utilities for the sensitivity analyses; the ranges used are shown in Table 1.

Costs

We estimated costs from the health care system's perspective, with all costs in 2018 US dollars. The calculations included direct medical costs (e.g., cost of urinalysis and urine culture, cost of a course of antibiotic treatment). The cost parameters are listed in Table 1 and were based on public national databases from the Fair Health Consumer and Healthcare Bluebook [8, 9]. We did not include indirect costs due to the unavailability of data on productivity losses and transportation costs. For each strategy, we calculated the expected costs by taking a weighted average of the costs incurred through each pathway in the tree and the proportion of the cohort of patients that followed that pathway.

Health utilities

We measured health benefits in terms of quality-adjusted life-years (QALYs). We calculated QALYs based on health state utilities, ranging from 0 to 1, with 0 representing a health state equivalent to death and 1 representing perfect health for one year. In the base case scenario, patients who did not receive prophylactic antibiotics and did not develop urinary tract infections were assigned a utility of 1. Patients who received prophylactic antibiotics and did not develop urinary tract infections were assigned a utility of 0.97 to reflect a small decrease in quality of life, including allergic responses, due to the prophylactic antibiotics [10]. Patients who did not receive prophylactic antibiotics and developed urinary tract infections that were successfully treated were assigned a utility of 0.85 [11–15]. Those who did receive

prophylactic antibiotics and developed urinary tract infections that were successfully treated were assigned a slightly lower utility of 0.82 [10, 16], again to reflect the small decrease in quality of life from the prophylactic antibiotics. Patients who did not receive prophylactic antibiotics and developed antibiotic-resistant urinary tract infections were assigned a utility of 0.75 [16], while those who developed antibiotic-resistant urinary tract infections following prophylactic antibiotics were assigned a utility of 0.72 [16]. We calculated the expected number of QALYs for each strategy by taking a weighted average of the utility of each pathway in the tree and the proportion of the cohort of patients that followed that pathway. We then calculated the corresponding QALYs over a one-week period because costs and health benefits were calculated over a one-week time horizon, as our model aimed to evaluate short-term postoperative urinary catheterization.

Cost-effectiveness analysis

We expressed the outcomes as cost per QALY. A strategy was defined as cost saving if it incurred a lower cost and at the same time a higher QALY compared to another strategy. Otherwise, the incremental cost-effectiveness ratio (ICER) was calculated, and defined as the additional cost divided by the additional health benefit associated with one strategy compared with the next-less-costly strategy. Then, the most cost-effective strategy was identified by comparing the ICER against the threshold value of \$100,000/QALY, which reflects the decision maker's willingness to pay for an additional unit of effect (QALY). Strategies below a specific willingness to pay threshold represent cost-effective strategies. Willingness to pay values of \$50,000–150,000/QALY are commonly used for cost-effectiveness analyses conducted in the U.S. [17].

To assess the impact of the uncertainty in the model input parameters on the cost-effectiveness results, we conducted one-way sensitivity analyses. This study was based solely on de-identified, published data; thus, our institutional review board determined that it did not meet the definition of human subject research.

RESULTS

Cost-effectiveness analysis

The base case analysis showed that the expected average cost of using prophylactic antibiotics was \$13.20, while the expected cost of not using prophylactic antibiotics and treating only after diagnosing a catheter-associated urinary tract infection was \$15.84. At the same time, the expected effect was higher for the strategy of using prophylactic antibiotics (0.0185 QALY) compared to not using prophylactic antibiotics (0.0183 QALY). These results show that, under the base case conditions, prophylactic antibiotic use was the cost saving strategy (less costly and more effective) while a short-term postoperative indwelling urinary catheter was in place.

Sensitivity analyses

Table 1 shows the results of the one-way sensitivity analyses. The sensitivity analyses show whether the strategy of using prophylactic antibiotics remains the cost saving or cost effective strategy when each input parameter is varied over its pre-determined range. As

discussed above, cost saving means a strategy is less costly and more effective than the alternative strategy. Cost effective means the ICER comparing a strategy to its alternative is below the willingness to pay threshold of \$100,000/QALY. The input parameters with the most impact were the probability of developing a urinary tract infection without prophylactic antibiotics, the utility of receiving prophylactic antibiotics and not developing a urinary tract infection, and the utility of not receiving prophylactic antibiotics and developing a urinary tract infection. The base case scenario estimates the probability of developing urinary tract infections without prophylactic antibiotics using studies of postoperative patients with indwelling urinary catheters for an average of 3 to 7 days using symptomatic and asymptomatic bacteriuria as the outcome. If the duration of catheterization is expected to be shorter than 3 days and the definition of catheter-associated urinary tract infections is stricter, so that the probability of developing catheter-associated urinary tract infections without prophylactic antibiotics decreases to below 12%, then not using prophylactic antibiotics would become the cost effective strategy. The model is also sensitive to the QALY associated with receiving a course of prophylactic antibiotic treatment. In the base case, the health state of not receiving prophylactic antibiotics is assigned 1 and the health state of receiving a course of prophylactic antibiotics is assigned 0.97. However, if the latter decreases below 0.96, then not using prophylactic antibiotics becomes the cost effective strategy. Of note, the cost of treating antibiotic-resistant urinary tract infections does not significantly impact the model results. The base case estimates the cost of treating antibiotic-resistant urinary tract infections at \$200, but this can be varied between \$0 and \$2,880 without changing the optimal strategy.

DISCUSSION

Using a decision tree model that accounted for relevant clinical events in the management of short-term postoperative indwelling urinary catheters, we compared the cost effectiveness of prophylactic antibiotic use to prevent urinary tract infections during short-term postoperative catheterization. Our findings showed that prophylactic antibiotics can be cost effective and even cost saving in this context. A sensitivity analysis showed that the incidence of catheter-associated urinary tract infections without prophylactic antibiotics and the quality of life associated with taking prophylactic antibiotics had the greatest impact on the cost-effectiveness of prophylactic antibiotics. One of the main concerns in the use of prophylactic antibiotics is the development of antibiotic-resistant urinary tract infections. In our model, the cost of treating antibiotic-resistant urinary tract infections does not affect the results substantially, despite being varied across a wide range in the sensitivity analysis. This is because, in both strategies, some patients develop antibiotic-resistant urinary tract infections, albeit with different probabilities and from different sources (having received prophylactic antibiotics or treatment antibiotics).

Existing literature has shown that antibiotic prophylaxis for short-term postoperative catheterization reduces catheter-associated urinary tract infections, but highlights the lack of cost-effectiveness data [6, 18]. There have been attempts at delineating the economic consequences of catheter-associated urinary tract infections [2, 5], but none have evaluated the cost effectiveness of strategies to reduce short-term catheter-associated urinary tract infections using a decision tree model.

The major strength of this study was the use of decision-analytic modeling, which provided a framework for informed decision making under conditions of uncertainty. In addition, we used published national data for the vast majority of probabilities, costs, and utilities in our model, thus maximizing the generalizability of our results. Furthermore, our sensitivity analyses allowed us to vary uncertain parameters over a broad range of values and investigate factors that might have a significant influence on the results. For example, our data does not directly account for patients with pre-existing UTIs or history of recurrent UTIs; however, our sensitivity analyses include a range of rates of post-op UTIs, and in this particular population, the risks of post-op UTIs would be expected to be higher. According to our sensitivity analyses, this would mean that prophylactic antibiotics would be even more cost effective.

Inherent to the nature of modeling, we were limited by the availability of data and the accuracy of our assumptions. Hence, we used sensitivity analyses across reasonable ranges of values and presented our results in the context of these sensitivity analyses. We defined catheter-associated urinary tract infection as bacteriuria $>1,000$ to $100,000$ colony forming units per mL for our base case analyses. Some definitions require symptomatic bacteriuria and to address this, our sensitivity analyses tested a range of incidences to account for this. There also are varying rates of antibiotic resistance in the literature, and for this, our sensitivity analyses tested a range of rates of antibiotic resistance. Finally, we presented a simplified version of the comprehensive management options, potential outcomes, and other issues related to postoperative indwelling urinary catheters. We recognize that there was a tradeoff between allowing sufficient complexity to accurately model the real world situation in a decision tree and having enough simplicity to make the model transparent.

Given that we used population-level data to inform the model input parameters, the results can help inform decision-making on a population level. However, the results should be used only as a guide in the context of existing clinical guidelines in decision-making for individual patients. That process should also account for other factors, such as medical history, comorbidities, and patient preference. Future research on the probabilities and costs will help decrease the uncertainty in the model input parameters and thus improve the precision of the findings.

In this study, we created a decision analysis model to evaluate the cost-effectiveness of prophylactic antibiotics in preventing catheter-associated urinary tract infections for post-operative patients with a short-term indwelling urinary catheter. We show that the use of prophylactic antibiotics is cost-effective and can be cost saving under most conditions, but are sensitive to the likelihood of developing catheter-associated urinary tract infections with and without prophylactic antibiotics. Our results are limited to the cost-effectiveness perspective on this clinical practice and should only be interpreted in the context of existing clinical guidelines when making patient care decisions.

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Figure 1.
Decision tree analyzing cost-effectiveness of prophylactic antibiotic versus no prophylactic antibiotic use to prevent catheter-associated urinary tract infections

Table 1.

Input parameters and sensitivity analysis for decision tree model

Probabilities	Base case Sensitivity range	QALY	Sensitivity analysis results
Developing UTI after prophylactic antibiotics	0.05 0.01–0.18 ^{6,19}		Prophylactic antibiotics dominant if <0.09, cost effective over range
Developing UTI without prophylactic antibiotics	0.30 0.09–0.75 ^{6,19,20}		Prophylactic antibiotics dominant if >0.25, cost effective if >0.12
Developing antibiotic-resistant UTI after prophylactic antibiotics	0.15 0.08–0.25 ^{21,22}		Prophylactic antibiotics dominant over range
Developing antibiotic-resistant UTI without prophylactic antibiotics	0.08 0–0.5 ²¹		Prophylactic antibiotics dominant if >0.025, cost effective over range
Costs			
Prophylactic antibiotics	\$10 \$4–28 ²³		Prophylactic antibiotics dominant if <\$12.64, cost effective over range
UTI treatment	\$40 \$19–105 ⁸		Prophylactic antibiotics dominant if >\$28.7, cost effective over range
Antibiotic-resistant UTI treatment	\$200 \$100–10,000 ^{8,23}		Prophylactic antibiotics dominant over range
Utilities			
Prophylactic antibiotics, no UTI	0.97 0.89–0.99 ¹⁰	0.018653	Prophylactic antibiotics dominant if >0.962
Prophylactic antibiotics, UTI treated	0.82 0.7006–0.979 ^{10,16}	0.015769	Prophylactic antibiotics dominant over range
Prophylactic antibiotics, antibiotic-resistant UTI	0.72 0.7006–0.738 ¹⁶	0.013846	Prophylactic antibiotics dominant over range
No prophylactic antibiotics, no UTI	1 0.9–1 ¹⁶	0.019231	Prophylactic antibiotics dominant over range
No prophylactic antibiotics, UTI treated	0.85 0.7106–0.98 ^{11–15}	0.016346	Prophylactic antibiotics dominant if <0.955
No prophylactic antibiotics, antibiotic-resistant UTI	0.75 0.7106–0.76 ¹⁶	0.014423	Prophylactic antibiotics dominant over range

UTI: urinary tract infection