A Bayesian Belief Network Model for Risk of Vascular Catheter-Associated Infection

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Abstract:
Central Venous catheters are one of the commonly inserted medical devices in hospitals, and the most common cause of hospital acquired bloodstream infections. In this study, we have developed a Bayesian Belief Network (BBN) model to assess the baseline risk of Vascular Catheter-Associated Infection (i.e. line infection). Bayesian Belief Networks or Bayesian Networks are a class of probabilistic graphical models for reasoning under uncertainty. The graphical aspect of BBNs can be used in a qualitative manner to represent relationships between a set of variables while the *strength* of the causal relationship between variables on the other hand, can be quantified using probability calculus. BBNs can capture probabilistic relations between variables and contain historical information about their relationship, and are powerful tools for modeling causes and effect in many domains. They are also very effective in modeling situations where data are uncertain and vague or incomplete and only partially available. These properties of BBN make them an ideal candidate for modeling risk of line infection. The model has been built based on the risk factors introduced in literature, and the input provided by a panel of seventeen subject matter experts. After the qualitative validation of the structure of the model, we have quantified and validated the model using eight years of clinical data. This model can be used in decision making, sensitivity analysis and audit to assist the decision maker in understanding how hospital level policies may affect risk and what risk factors are most sensitive to potential policy changes. Further it can be used in risk-benefit analysis to highlight the improvements in risk factors (e.g. requirements for level of proficiency for health provider inserting the catheter that; novice vs. expert) would have the greatest impact on risk reduction.

Keywords: Bayesian Belief Network, Healthcare Risk Modeling, BBN, Catheter Infection, Risk.

1. INTRODUCTION

Central Venous Catheter (also called CVC, central line, or Vascular Access Device (VAD)), is a catheter that is placed into a large vein in the neck (internal jugular vein), chest (subclavian vein), or groin (femoral vein) to give medicines, fluids, nutrients or blood products to the patients. Intravascular catheters, as essential components of modern medical care, are one of the most commonly inserted medical devices in the United States, and the most common cause of hospital acquired bloodstream infection, alongside urinary catheters. Unfortunately, most hospital acquired infections, in an already venerable patient population, are caused by the very same devices that are designed and used to provide lifesaving care. A study on medical intensive care units in the US has shown that 87% of bloodstream infections are attributed to central line [1].

2. Developing a Bayesian Belief Network for Risk of Vascular Catheter-Associated Infection

A comprehensive literature review has been conducted to extract what researchers believe to be risk factors in line infection. Richet et.al (1990), consider underlying disease, method of insertion, type of cannula (tube), type of dressing used, duration and purpose of catheterization as important risk factor, indicating that the impact of factors such as site of insertion, receipt of antimicrobial agents before, during and after catheterization, and the frequency of intravenous therapy (IV) are unclear. Moro et al. (1994), conclude from their study, that duration of catheterization, jugular insertion, transparent dressing, TPN (total parenteral nutrition), second catheterization period and skin colonization and hub colonization show significant association with catheter infection. In another study, Mahieu et al. (2001), find that catheterization duration, exit site colonization, hub colonization, insertion at bedside, whether patient is on antibiotics at insertion and TPN duration among important factors that may affect the risk of line infection.

To assess the risk of developing line infection as a function of individual patient's risk factors and patient-provider (i.e. intervention related), a Bayesian Belief Network framework has been chosen. Use of BBNs in modeling the risk of experiencing line infection offers capabilities that could possibly provide more realistic, relevant and meaningful assessments. Bayesian Belief Networks are probabilistic in nature and the uncertainty of our assessment of line infection risk, given the state of all relevant risk factors can be expressed explicitly.

A Bayesian Belief Network, that includes or reflects the factors introduced in literature as factors influencing risk of line infection, has been developed. Additionally, a panel of 8 experts, contributed in the construction of this BBN, providing input on the factors thought to be of importance, causal relations between these factors and their subjective assessment on some of the nodes in the model were field data was not available or unreliable. The elicitation of model structure was performed in three phases. In the next section these phases are described.

2.1. Line Infection (LI) BBN

Based on risk factors introduced in literature and the panel of experts input elicited, a BBN is developed for risk of line infection. This BBN is depicted in Figure 1 and Table 1 provides a brief description of BBN variables.

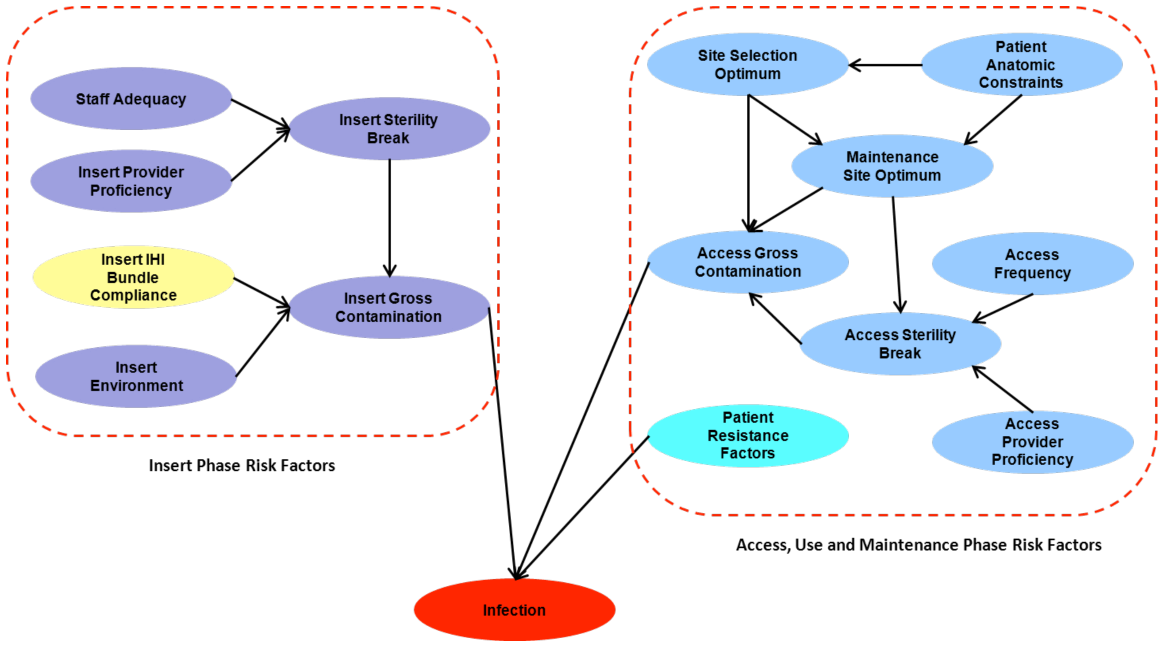

Figure 1. Line infection BBN

Line Infection BBN

Factor	Description
Insert Environment	Bedside versus controlled environment
Insert IHI Compliance	IHI bundle protocol (http://www.ihi.org/knowledge/Pages/Tools/CentralLineInsertionChecklist.aspx); hand hygiene, skin preparation,
Insert Provider Proficiency	Provider's experience, proficiency and judgment
Staff Adequacy	Assistance to provider performing the procedure
Anatomic Constraints	Influences site selection, de novo vs. change, dressing change
Site Selection	Chest, neck, groin
Access Frequency	Frequency of port access
Access Sterility break	Unrecognized break in sterility
Access Provider Proficiency	Provider's experience, proficiency and judgment
Patient Resistance Factors	Physiological and pharmacological

Table 1. Line infection BBN factors

3. MODEL QUANTIFICATION and VALIDATION

3.1. Data and Quantification

To carry out the quantification of the line infection BBN, certain modifications had to be made to the structure of the BBN without compromising the integrity and accuracy of the model [5]. we extracted line infection data from ICU patients, as the data were most reliable and the results could be extrapolated to the entire hospital. In any given institution, most of the lines are in the ICU and very few lines on the floors, and in fact some institutions have rules where you cannot have a line on the floors. We extracted and analysed 12897, ICU patient records from October 2001 to September 2009.

3.2. Qualitative and Quantitative Model Validation

3.2.1 Qualitative Validation

In developing the Bayesian belief networks for this study, we started with a basic draft of a model that contained the important factors and relations between the factors discussed in the literature and the input of one of the experts. We then consulted the domain experts extensively through multiple sessions of face-to-face interviews and reached to the consensus model that is presented here as the final version. This consensus was reached after many iterations to the point that all experts agreed that model is now presenting all the known major factors affecting the risk of pressure ulcer (and the risk of line infection in the case of vascular catheter associated infection). Naturally, peer review has been a crucial step in developing and qualitatively validating these models. In such a peer review of the BBN models, some steps and methods, suggested by Marcot, et al. (2006) [6] have been generally followed. Last, we asked our panel of experts to evaluate the last version of the model (the qualitative model) in following categories; model completeness, model accuracy, ease of understanding and perceived predictive validity, to ensure sufficient confidence in the structure of the model before proceeding to model quantification.

3.2.1 Quantitative Validation

Using the conditional probability tables constructed with available data (2001-2009) and expert elicited estimates, the BBN was compiled, and the results have been validated against actual data for relative frequencies of line infection. We also used a Bayesian model uncertainty treatment [7], which updates BBN model's output based on model's performance data (i.e. historical differences between model prediction and the actual value of the parameter of interest) to adjust model predictions. Table2 shows the average error 8 years, after the Bayesian adjustment.

	Actual Relative Frequency from Data	BBN Model Prediction	% Error
Pressure Ulcer	3.06E-02	3.12E-02	2%

Table 2- Average accuracy of the LI BBN model

4. CONCLUSION

Central Venous catheters are the most common cause of hospital acquired bloodstream infections. Hence it is important that we have a realistic assessment of the risk of individual patients in experiencing such adverse event while in hospital, before we could develop effective mitigating strategies to reduce this risk.

Bayesian Belief Networks present a framework in which we could probabilistically capture cause and effect relationship, and therefore are an ideal candidate for modeling how patient level and provider-patient level factors may influence the risk of an individual patient in experiencing line infection.

Using eight years of clinical data, and a panel of eight subject matter experts we have developed, quantified and validated a causal model for risk of line infection in the form of a BBN. The results of the quantification of this BBN using our available clinical data, indicates that the line infection BBN model, predicts the risk of line infection for an individual patient with an average of 3% error.

References

[1] Trautner, B., Darouiche, R., 2004, catheter-Associate Infections, Archives of Internal Medicine, Vol. 164, PP. 842-850

[2] Richet, H., Hubert, B., Nitemberg, G., Andremont, A., Buu-Hoi, A., Ourbak, P., ... & Bouvier, A. M. (1990). Prospective multicenter study of vascular-catheter-related complications and risk factors for positive central-catheter cultures in intensive care unit patients. *Journal of clinical microbiology*, *28*(11), 2520-2525.

[3] Moro, M., Vigano, E., Lepri, A., 1994, Risk Factors for Central Venous Catheter-Related Infections in Surgical and Intensive Care Units, Infection Control and Hospital Epidemiology, Vol. 15, No. 4, PP.253-265

[4] Mahieu, L., Muynck, A., Leven, M., Dooy, J., Goossens, H., Van Reempts, P., 2001, Risk Factors for Central Catheter-Associated Bloodstream Infections Among Patients in a Neonatal Intensive Care Unit, Journal of Hospital Infection, Vol. 48, PP.108-116

[5] Kazemi, R., A hybrid methodology for modeling adverse events in complex healthcare settings, 2011, PhD Dissertation, University of Maryland, College Park

[6] Marcot, B. G., Steventon, J. D., Sutherland, G. D., & McCann, R. K. (2006). Guidelines for developing and updating Bayesian belief networks applied to ecological modeling and conservation. Canadian Journal of Forest Research, 36(12), 3063-3074.

[7] Droguett, E. L. (1999). Methodology for the treatment of model uncertainty.