CONSTRUCTION OF A CLINICAL DECISION SUPPORT SYSTEM FOR DENTAL CARIES MANAGEMENT USING BAYESIAN NETWORKS

M. Bessani*, E.C.C.C. Lins**, A.C.B. Delbem*** e C.D. Maciel*

*Department of Electrical and Computer Engineering, University of São Paulo, São Carlos, Brazil
** Engineering Modelling and Applied Social Science Center, Federal University of ABC, Santo André, Brazil
*** Institute of Mathematical and Computer Sciences, University of São Paulo, São Carlos, Brazil
e-mail: michel.bessani@usp.br

Abstract: Caries are still a major problem and an active area of research; it is a multifactorial dynamic process, and therefore, management should be dichotomous, acting on both the symptoms and the causal factors. On this scenario, we propose a clinical decision support system for modern caries management using a Bayesian network as framework. The first version of the network was modelled using recent findings and conclusions from the scientific literature on cariology area. Two specialists were asked about the network on a personal meeting, and their opinions agree: this kind of system can be helpful on areas such as: public health, supporting the primary dental care; and dentistry education, as a problem based learning system. In addition, we used some well-defined cases on the network, the suggested outputs are in agreement with our expectations. The next steps are the validation of the Bayesian network using data from specialist's decisions.
Keywords: Clinical decision support system, Bayesian network, dental caries management.

Introduction

One actual systematic revision by [1] shows that oral conditions still are a major health problem around the world, and caries is the largest of them. It affects mostly disadvantaged individuals on developed countries, while affecting the major population part on developing countries [2].

For the caries management decision reasoning, a great deal of knowledge is necessary: risk factors, treatment outcomes, incidence and progression rates, amongst others [3,4]. All these are open to the professional judgment [5]. Moreover, the capacity of a healthy professional to always make the correct decision is limited by cognitive functions, like reasoning and memory capacities [6]. These factors results on divergence between decisions made by different clinicians, which is a serious issue because it often results in overtreatment or undertreatment [7].

Such context of uncertainty on the reasoning and the divergence between clinicians' decisions has motivated us to initiate the development of a clinical decision support system (CDSS) for caries management. CDSS can be defined as the use of computers to access knowledge in order to support the decision making process by using the specific characteristics of each patient [8].

We chose to use Bayesian networks (BN) as the inference engine in such system. It can efficiently represent knowledge from specific complex domains using a graphical representation [9], including clinical decisions [10].

BN's are used in areas such as social-behavioral models [11], oncology [12], and others health areas [10]. Many systems for caries diagnosis support already exist, while a few are under development [13]. However, we found only one work [14] focused on caries management. It also uses a BN, but the construction technique was not presented; furthermore, the system reasoning is based solely on symptoms suggesting medicines and invasive approaches.

The CDSS described here is based on the modern caries management [3,7]. It uses individual caries risk factors and scientific evidence to suggest the most suitable treatments for each patient situation.

Materials and methods

Here we describe the materials and methods used for the construction of the CDSS. First, a brief presentation of the caries dynamic process is shown, followed by the definition of a Bayesian network, and finally we describe the construction of the BN.

Caries Dynamic Process – Caries is a chronic, transmissible disease of multifactorial etiology [3,5]. It is the consequence of a physiological process that happens on the oral environment involving the mouth microorganisms [4].

Different factors influence the caries process [3,15], such as diet, oral hygiene, oral cavity biofilm, salivary flow, and sociodemographic conditions.

The management of individual risk factors, early lesion detection, and the use of minimal invasive dentistry [5] can lead to the best treatment outcomes for the lesions and a control of the caries dynamic process throughout life. This is the philosophy under our system reasoning for the caries management.

Bayesian Networks – Formally, a BN can be defined as [16]:

- A set of variables and a set of directed edges between variables;
- Each variable has a finite set of mutually exclusive states;
- The variables together with the directed edges form an acyclic directed graph (DAG).

BN's can represent causal relations through the dependences between variables [16]. The edges links parent nodes (Pr) to children nodes (C). Each children is directly dependent of its parents, and each children node has a conditional probability table P(C1|Pr1, …, Prn) quantifying the relationship between connected nodes [17]. The nodes values can be evidentiated, producing a new probability distribution over the entire network (i.e. one state is defined as "true" – 100% probability – while the others are set to 0%).

If we assume conditional independence between the parents nodes (Pr) and use the chain rule [16], P(C1|Pr1, …, Prn) can be rewritten as (1).

$$P(C_1|Pr_1, \dots, Pr_n) = \prod_{k=1}^{n} P(C_1|\, Pr_k) \qquad (1)$$

Bayesian Network Construction – The BN construction was based on the scientific literature. The network was created and modelled using the software package GeNIe 2.0 (Decision System Laboratory, 2013). We divided the construction in two parts: the structure (qualitative), and the probabilities (quantitative), as proposed by [9].

Network Structure – The network structure has two parts: the risk factors, and the treatment and return. The first part uses the causal and predictive factors to suggest the most likely caries risk classification: low, medium, or high. Its structure is shown on Figure 1.

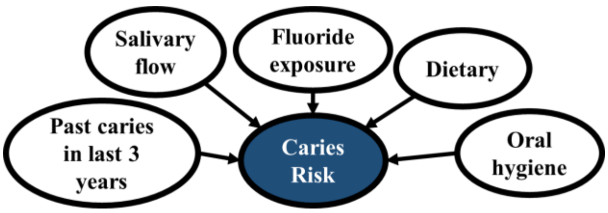

Figure 1- First part of the BN, the risk factor analyses.

We chose these factors because of the high agreement on the caries risk assessment research area about their causality and predictivity of the caries process [3,4,19–22]. All of them are measurable through interviews or visual inspection, thereby facilitating the input of evidences by the user.

Each parent node state and its strength of influence on caries risk are listed on Table 1. Strength I indicates the most important factor for the caries risk assessment, while strength III indicates less important factors.

The second part of the network uses clinical evidences and the caries risk classification as parent nodes to the treatments and return visit nodes. Its structure is shown on Figure 2 and clinical evidences states are described on Table 2.

Table 1 - Causal and predictive factors states and strength of influence on caries risk.

Factor	States	Strength
Past caries in last 3 years	Zero; Between 1 and 2; More them 3	I
Salivary flow	Normal; Low	II
Fluoride exposure	Yes; No	II
Dietary	Good; Regular; Poor	III
Oral hygiene	Good; Regular; Poor	III

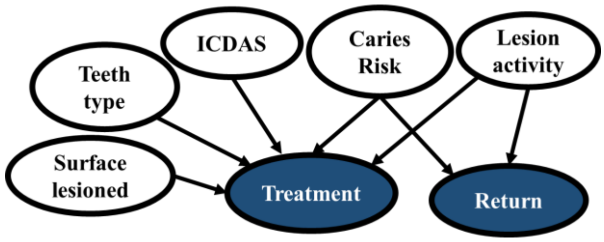

Figure 2 - Second part of the BN, treatment and return suggestions.

Table 2 - Chosen clinical evidences states and strength of influence; strength I factor is the most important, while strength III factors are less important.

Clinical Evidence	States	Strength
Surface lesioned	Occlusal; Smooth	III
Caries risk	Low; Medium; High	II
ICDAS	1&2; 3; 4; 5&6	I
Lesion activity	Yes; No	II
Teeth type	Molar; Premolar; Anterior	III

ICDAS is the International Caries Detection and Assessment System. It can be defined as a workflow for caries visual detection and measurement, and its output is the main threshold between the different treatments. A more in-depth discussion on the caries process and the ICDAS classification can be found in [7].

The other variables provide information on the progression or regression chances of the lesion [23–25], directly affecting the decision between invasive or therapeutic treatments [26]. The treatment and return states are described on the Table 3.

Table 3 - Description of the output's treatment and return nodes states.

Variable	States
Treatment	Fluoride &/OR Sealants; Restoration; Endodontic treatment
Return	1 year; 6 months; Before 6 months

Network Probabilities – Almost all the data about caries status has traditionally been described by the DMFT (Decayed, Missing and Filling Teeth) index [27], which represent epidemiological indices. Conversely, works analyzing causal factors and treatments normally use only one variable per time [2,26].

During the work, we couldn't find the data correlating all the necessary variables. Therefore, we used information from the findings and conclusions of scientific literature for the network construction; the same references used on the network structure were used to obtain the probabilities. For that, we used a methodology proposed by [9] for manual construction of probability tables from certainty expressions.

First, we transformed the conclusions from the literature into probabilities by using this relation. The cases between two consecutives conclusions were estimated using their strength of influence: we estimated the probabilities of the intermediary situation between two consecutives conclusions, and used this new probability for estimating the other missing probabilities, repeating this procedure until the table was complete. Situations that were not between consecutive conclusions received the same probability of the nearest conclusion.

The complete BN can be seen on Figure 3. The white nodes represent evidences, which are the user inputs, and colored boxes represent the decision nodes with the suggestions.

Results & Discussion

Due to the lack of data correlating all the variables and outputs of the system, the first evaluation was performed by presenting the system to two dentists on a personal meeting, one from clinical practice, and another from academia area. The following paragraphs are based on their observations.

This system can be helpful on areas such as public health and dentistry education. The causal relations exposed on the BN graphical interface should lead to an easy understanding of the system and its main function: support the user on the caries management reasoning, suggesting the most indicated treatment and return decisions for each patient scenario by considering individuals risk factors.

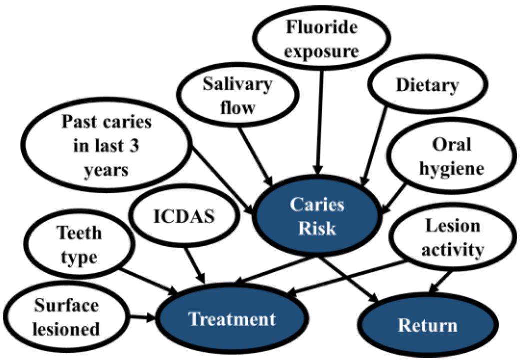

Figure 3 - Complete BN constructed to support caries management decision. The blue nodes are the outputs.

On the public health area, specifically on primary care, this system can help clinicians other than dentists, like hygienists and pediatricians, on the prevention and control of dental caries, and help with dental care screening of populations.

On dentistry education, this system can be useful as a platform for problem based learning (PBL) classes, helping students to analyze and understand the necessary reasoning for caries management.

In addition, we used some well-defined cases as input of the BN and the suggestions outputs can be seen on Tables 4, 5 and 6.

Table 4 - Caries risk suggestions using some well-defined cases. L, M and H represent Low, Medium and High states.

Past Caries	Salivary flow	Fluoride exposure	Dietary	Oral hygiene	Caries Risk
Zero	Normal	Yes	Good	Good	L 60% M 20% H 20%
1 or 2	Normal	Yes	Poor	Poor	L 0% M 40% H 60%
Zero	Low	No	Poor	Poor	L 0% M 0% H 100%
3 or more	Low	No	Good	Good	L 0% M 20% H 80%

Table 5 - Treatment suggestions using some well-defined cases. F/S, Rest and Endo respectively represent Fluoride &/OR Sealants, Restoration and Endodontic treatment.

Surface lesioned	Teeth type	ICDAS	Caries Risk	Lesion activity	Treatment
Occlusal	Molar	1&2	Low	Yes	F/S 100% Rest 0% Endo 0%
Smooth	Premolar	5&6	High	No	F/S 0% Rest 50% Endo 50%
Smooth	Premolar	5&6	High	No	F/S 0% Rest 50% Endo 50%

Table 6 - Return suggestions performed by the network using some well-defined cases.

Caries Risk	Lesion activity	Return
Low	Yes	1 Year 0% 6 Months 100% Before 6 Months 0%
Low	No	1 Year 100% 6 Months 0% Before 6 Months 0%
Medium	Yes	1 Year 0% 6 Months 0% Before 6 Months 100%
Medium	No	1 Year 0% 6 Months 100% Before 6 Months 0%

Conclusion

In this work, we describe the earlier stages of a CDSS for caries using BN, and focusing in preventive and conservative dentistry. The expert opinions was encouraging, and the output for the well-defined cases are consistent. However, we need real clinical data to validate the network and its usability; this is one of the next steps. We also aim to compare the system results with specialist's decisions using such real cases and randomly generated cases. When this clinical and synthetic data becomes available, we will perform the statistical validation of the network.

Acknowledgements

This study was supported by the financial assistance of the CNPq (Brazil).

References

[1] Marcenes W, Kassebaum NJ, Bernabé E, Flaxman A, Naghavi M, Lopez A, et al. Global burden of oral conditions in 1990-2010: a systematic analysis. J Dent Res 2013;92:592–7.
[2] Zero DT. Sugars - the arch criminal? Caries Res 2004;38:277–85.
[3] Limeback H. Comprehensive Preventive Dentistry. West Sussex, UK: John Wiley & Sons, Ltd.,; 2012.
[4] Selwitz RH, Ismail AI, Pitts NB. Dental caries. Lancet 2007;369:51–9.
[5] Pitts NB. Are we ready to move from operative to non-operative/preventive treatment of dental caries in clinical practice? Caries Res 2004;38:294–304.
[6] Wagholikar KB, Sundararajan V, Deshpande AW. Modeling paradigms for medical diagnostic decision support: a survey and future directions. J Med Syst 2012;36:3029–49.
[7] Zero DT, Zandona AF, Vail MM, Spolnik KJ. Dental caries and pulpal disease. Dent Clin North Am 2011;55:29–46.
[8] Sim I, Gorman P, Greenes R a, Haynes RB, Kaplan B, Lehmann H, et al. Clinical decision support systems for the practice of evidence-based medicine. J Am Med Inform Assoc 2001;8:527–34.
[9] Kjærulff UB, Madsen AL. Bayesian Networks and Influence Diagrams: A Guide to Construction and Analysis. New York: Springer Science+Business Media; 2008.
[10] Berner ES. Clinical Decision Support Systems: Theory and Practice. 2nd ed. New York: Springer; 2007.
[11] Walsh S, Dalton A, Whitney P, White A. Parameterizing Bayesian Network Representations of Social-Behavioral Models by Expert Elicitation A Novel Application of Conjoint Analysis. Artif. Intell. Med., 2010, p. 227–32.
[12] Julia Flores M, Nicholson AE, Brunskill A, Korb KB, Mascaro S. Incorporating expert knowledge when learning Bayesian network structure: a medical case study. Artif Intell Med 2011;53:181–204.
[13] Pretty I a. Caries detection and diagnosis: novel technologies. J Dent 2006;34:727–39.
[14] Bhatia A, Singh R. Using Bayesian Network as Decision making system tool for deciding Treatment plan for Dental caries. J Acad Insdustrial Res 2013;2:93–6.
[15] Kidd EAM. Essential of dental caries. 3rd ed. New York: Oxford University Press; 2005.
[16] Jensen F, Nielsen T. Bayesian networks and decision graphs. 2nd ed. New York: Springer Science+Business Media; 2007.
[17] Pearl J. Probabilistic reasoning in intelligent systems: networks of plausible inference. 1st ed. San Maeto: Morgan Kaufmann; 1988.
[18] Decision Systems Laboratory, 2013. GeNIe and SMILE - Decision Systems Laboratory. Available from: http://genie.sis.pitt.edu. [Accessed: 10 February 2014].
[19] Featherstone JDB, Domejean-Orliaguet S, Jenson L, Wolff M, Young D a. Caries risk assessment in practice for age 6 through adult. J Calif Dent Assoc 2007;35:703–7, 710–3.
[20] Fontana M, Zero DT. Assessing patients' caries risk. J Am Dent Assoc 2006;137:1231–9.
[21] Baelum V. Caries management: technical solutions to biological problems or evidence-based care? J Oral Rehabil 2008;35:135–51.
[22] Baelum V, Heidmann J, Nyvad B. Dental caries paradigms in diagnosis and diagnostic research. Eur J Oral Sci 2006;114:263–77.
[23] Carounanidy U, Sathyanarayanan R. Dental caries: A complete changeover (PART III): Changeover in the treatment decisions and treatments. J Conserv Dent 2010;13:209–17.
[24] Braga MM, Mendes FM, Ekstrand KR. Detection activity assessment and diagnosis of dental caries lesions. Dent Clin North Am 2010;54:479–93.
[25] Ferreira Zandoná A, Santiago E, Eckert GJ, Katz BP, Pereira de Oliveira S, Capin OR, et al. The natural history of dental caries lesions: a 4-year observational study. J Dent Res 2012;91:841–6.
[26] Feigal R, Gooch B, Ismail A, Kohn W, Siegal M, Simonsen R. Evidence-based clinical recommendations for the use of pit-and-fissure sealants. JAMA J Am Dent Assoc 2008;139:257–68.
[27] Monse B, Heinrich-Weltzien R, Benzian H, Holmgren C, van Palenstein Helderman W. PUFA--an index of clinical consequences of untreated dental caries. Community Dent Oral Epidemiol 2010;38:77–82.