AN EXPERT SYSTEM FOR PLANNING DENTAL CARIES PREVENTIVE PROGRAMS

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Support
Fellowship provided by the Brazilian National Research Council (CNPq) under supervision of Dr. Steve Eklund and Dr Brian Burt.

Previous presentation:
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ABSTRACT

One problem dental public health administrators or policy makers often face is choosing among alternate dental caries preventive programs, including the option of using no preventive program at all. Questions on what can be prevented and at what cost and by what means are always present. The aim of this project is to develop a Knowledge-Based Expert System (KBES) prototype to guide the planning of dental caries preventive programs. While a final choice must include judgment on the part of local decision makers, such a computer program may offer a valuable framework to guide the process of choice. The KBES prototype has been called Preventive Program Model (PPM) and was developed using the C Language Integrated Production System (Cips). It has three modules: 1) strategies recommended for fluoride-, diet- and sealant-based programs, 2) efficacy/effectiveness of dental caries preventive measures, and 3) an estimation model for the effectiveness of the sealant-based program. This paper describes the knowledge representation used in the development of the Preventive Program Model and discusses the importance of the development of decision support systems for dental public health programs.

Key Words:
Preventive Dentistry, Public Health Dentistry, Community Dentistry, Knowledge Representation, Dental Caries, Planning Technique, Expert System
A Knowledge-Based Expert System (KBES) is a computer program that relies on a body of knowledge to perform a somewhat difficult task usually performed only by a human expert. Just as a human expert reasons and arrives at conclusions based on personal knowledge, an expert system reasons and arrives at conclusions based on the knowledge it possesses (1). One widely-quoted definition of expert systems given by Gaschnig (2) says that expert systems are interactive computer programs incorporating judgment, rules of thumb, intuition, and other expertise to provide knowledgeable advice about a variety of tasks.

In studying knowledge and its use, many interesting features have been identified by Brachman (3). Human expertise tends to be narrow and highly specialized and what distinguishes the true expert is the ability to rapidly recognize patterns in and bring appropriate rules to bear on a problem. Although the rules are often heuristic, which means empirical knowledge that comes from having successfully solved a large number of similar problems, it is their application to narrow the search of a "solution space" or group of possible solutions that is important. One of the hallmarks of expertise is the ability of an expert to explain the reasoning that was used to solve a given problem. A human expert uses knowledge and reasoning to arrive at conclusions. The first part of human expertise is long-term memory of facts, structures, and rules that represent expert knowledge about the domain of expertise. The analogous structure in an expert system is called the knowledge-base. The second part of human expertise is a method of reasoning that can use the expert's knowledge to solve problems. The part of an expert system that carries out the reasoning function is called the inference engine (4).

A KBES derives its power from knowledge. The heart of any expert system is the knowledge it contains, and it is the effective use of this knowledge that makes its reasoning successful. Discussion of knowledge can be broad and encompass several fields. For the purpose of KBES development, knowledge is limited to the information about the world that allows an expert to make decisions. Knowledge in any specialty can be categorized as public and private.
Public knowledge includes the published definitions, facts, and theories of which textbooks and references in the domain of study are typically composed. Private knowledge consists largely of the rules of thumb that human experts generally possess but that has not found its way into published literature. Such rules of thumb, also called heuristics, enable the human expert to make educated guesses, to recognize promising approaches to problems, and to deal effectively with imperfect or incomplete data.

The literature on KBES applications in dentistry has been gradually growing since the mid-1980s. The review by Stheeman et al. (5) showed that dental KBES had been developed primarily for diagnostic support. Their review listed systems covering the areas of oral diagnosis (6), oral radiographic diagnosis (7), orthodontic diagnosis for general dental practitioners (8), endodontic diagnosis (9-12) and diagnosis of dental trauma (13). An expert system for diagnosis of dental emergencies (14,15) was also developed but not included in the 1990 review. The KBES developed by Sims-Williams (8) for orthodontic diagnosis has been expanded (16) and another orthodontic diagnostic KBES based on lateral cephalograms has been proposed (17).

Prosthodontics has received considerable attention since Stheeman's review with the development of expert systems for analysis of casting failures (18) and casting design (19-21). This is not a comprehensive list and some other expert systems developed for other clinical applications such as oral facial pain, orthodontics and restorative dentistry are included in a more recent literature review on decision-support systems in dentistry (22).

The purpose of computer-assisted decision making is to aid health care providers with decisions about diagnosis and treatment of patients. Shortliffe et al. (23) provides a rationale for computer-assisted decision making by stating that it can improve the accuracy of diagnosis, the reliability of clinical decisions, and the cost efficiency of tests and therapies by weighting time, inconvenience, or expense against benefits and risks. This rationale can be expanded in dental public health activities.

This review of literature found that no KBES has been reported for the specific task of guiding the planning of community-based dental caries preventive programs.
The aim of this project is to develop a Knowledge-Based Expert System (KBES) prototype for the planning of preventive dental programs. This prototype has been called Preventive Program Model (PPM) and was developed using the C Language Integrated Production System (CLIPS) (24). Its main purpose is to guide oral health planners in choosing among alternative dental caries preventive programs based on locally derived data and resources.
Knowledge Representation. The representation of a knowledge domain is the organization of the parameters into a symbolic program that can be processed by the inference engine. This project proposes a logically structured knowledge representation of those elements deemed necessary to plan a caries preventive program. The overall program was conceived as a system with the following modules:

1. Strategies recommended for fluoride-, diet-, and sealant-based programs;
2. Efficacy/effectiveness of dental caries preventive measures;
3. An estimation model for the effectiveness of the sealant-based program;
4. Change of program default options including the procedures for caries-risk assessment;
5. Data collection information;
6. Data input needed to run the program;
7. Effectiveness of dental caries preventive programs developed using the PPM model;
8. DEMO program (Demonstration program).

The Preventive Program Model (PPM) develops three core parts of the system which comprise the three first modules listed above and information is provided for one specific age group (7-year-old children). The PPM is a pilot prototype that aims to demonstrate the feasibility of using a knowledge-based expert systems for the planning of preventive dental programs.

Module 1. Module 1 guides the user to provide input data and make recommendations on a general preventive strategy. The strategies are based on the use of fluoride-based products, diet-based regimens, and use of pit-and-fissure sealants. The knowledge representation for this Module (Figure 1) is based on the combination of four parameters: epidemiological profile of the population, mean DMFT (Decayed, Missing and Filled Teeth) trend of the population, level of fluoride in the water supplies and level of refined carbohydrate consumption. These parameters are grouped in order to provide a specific strategy recommendation for each community. The strategy
type and the program to be recommended for fluoride-, diet- and sealant-based programs are based on the percentage of children grouped as low-, moderate- or high-risk.

**Fluoride and diet Strategy.** The fluoride and diet strategy is defined by combining different characteristics of the parameter "epidemiological profile of the population". The specific characteristics used for grouping are: mean DMFT for age 7, percent of children at age 7 with DMFT equal to 1.0 (moderate caries level) and the percent of children at age 7 with DMFT greater than or equal to 2.0 (high caries level). The PPM determines the risk groups based on the prior history of dental caries in the permanent dentition. For age seven, the low-risk children correspond to children with a mean DMFT equal to 0. The moderate-risk children are those with a mean DMFT equal to 1.0 and the high-risk children are those with mean DMFT greater than or equal to 2.0. The identification of each strategy is based on the epidemiological profile of the population which is given by different combinations of the above mentioned groupings. Each combination of the groups result in one of the following strategies: None, Targeting moderate- and high-risk children (DMFT >0), Population strategy and targeting high-risk children (DMFT >= 2), Population strategy only, Population strategy and targeting moderate- and high-risk children (DMFT >0).

**Fluoride and diet program recommendation.** Figure 2 illustrates graphically the different strategies for fluoride- and diet-based programs. If 25% of the population has DMFT=1 (moderate risk group - vertical axis) and 10% of the population has DMFT >= 2 (high risk group - vertical axis), the recommended strategy would be to target moderate and high-risk children. The fluoride and diet program recommendation is based on a combination of the parameters: mean DMFT trends of the population, level of fluoride in the water supply and level of refined carbohydrate consumption. Each parameter has three levels that provide different program recommendations for fluoride and diet programs. The possible recommendations are: program to be recommended, program to be considered, and program not recommended.

The recommendation of a fluoride-based preventive program is based not just on the level of fluoride in water supplies but also on the mean DMFT trends and the type of strategy.
recommended. The diet-based preventive program recommendations are based on the refined carbohydrate ingestion instead of water supplies levels.

**Sealant strategy type and program recommendation.** The strategies for sealant recommendation are listed as: None, Targeting moderate- and high-risk children (DMFT $\geq 1$), Population strategy and Targeting low- and moderate-risk children (DMFT $\leq 1$). These strategies are identified based on the percent of children at age 7 with DMFT greater than or equal to 2 (children classified as having high levels of dental caries). Figure 3 illustrates graphically the sealant strategies.

**Module 2.** Module 2 provides information on the effectiveness of different preventive measures. It is an on-line bibliographical facility with a literature review of preventive measures commercially available. It also presents a list of the references used, a graphic representation of results and the background history of pioneering work and clinical trials. The meta-analytical approach applied to each preventive method is recommended when possible and results should be presented in a concise and informative manner. The proposed format and summary of results was developed (25) for illustration. Further development for application in the field would request expert consensus on the proposed analysis for the different methods. The knowledge representation for this module (Figure 4) allows for information retrieval and prompt access to a literature review on the effectiveness of preventive measures. The dental caries preventive measures described in this module are: fluoridation of water supplies, school fluoridation of water supplies, salt fluoridation, topically applied fluoride solutions and gels, fluoride drops and tablets as dietary supplements, fluoride mouthrinses, fluoride dentifrice, fluoride varnish, slow release fluoride devices, fluoride in sugar, fluoride in beverages, pit-and-fissure sealants, and diet programs.
Module 3. Module 3 develops a predictive model to estimate the likely impact of using pit-and-fissure sealants on first and second permanent molars. Following the results from the sealant strategy suggested in Module 1 of the PPM, the user is guided to estimate the possible range of effectiveness of sealants applied in first permanent molars. The PPM asks the user to choose a time frame between 1 and 10 years for the sealant effectiveness estimation. Based on the mean DMFT estimation for the population after the number of years chosen, the PPM calculates the likely percent of effectiveness of the pit-and-fissure sealants. The internal operations and input information used in this module are shown in Figure 5. In a 5-year effectiveness estimation, the current mean DMFT for 7-year-olds would be projected for the same population at age 12 (figure 6). The number of saved surfaces that would be decayed or lost due to proximal decay is calculated using a series of transformations (DMFT-DMFS-Mean DF Occlusal surfaces-Mean DF Occlusal surfaces with sound proximals). The formulae for these transformations were based on published literature (26-28) and applied to the levels of dental caries at age 12. Once the number of occlusal surfaces at risk is calculated, the retention rate of the sealant for that time frame (5 years in this example) is used to calculated how many of those surfaces could be saved given the level of sealant retention. The number of saved occlusal surfaces and its impact on DMFS and DMFT is calculated reversing the previously used transformations. Finally, the percent effectiveness of pit-and-fissure sealants is given by dividing the mean number of saved first molars by the number mean number of sealed teeth and multiplying it by 100. The lower and upper bound is given by using different percent sealant retention rates (± 5% of mean retention rates) for the 5-year period.
Discussion

The literature review on dental expert-systems showed several clinical programs for diagnosis and treatment planning. Such programs haven't been widely used despite the fact about 62% of all dentists in the US have a computer in their offices (29). Decision support systems developed specifically for dental public health programs are rare. One spreadsheet-based program for manpower planning was developed by the World Health Organization and the Federation Dentaire International (30). No expert systems for dental public health programs have been reported (25).

When decision-support systems were reviewed by White (22), it was suggested that the use of decision-support systems in the clinic may challenge professional control. Institutions and organizations planning community health programs may face some different institutional and social impacts. The institutional hierarchy and decision over what new technology should be incorporated may create new work patterns that may not be readily accepted. The perception that automation technology can "de-skill" tasks and limit dental health departments to data entry operators could prevail. Dentistry has not traditionally been a priority area in public health programs. The use of decision-support systems may suggest that dental staff could be further reduced consequently weakening the advocacy role of such units. On the other hand, it can be argued that the trends in dental personnel reduction are well established and only new technology will make it possible to increase current levels of activity. The argument may be carried further to say that the only chance of preserving community-based dental programs is by providing sound and scientific basis for the evaluation of old programs and implementation of new ones.

New computer technology may be a source of systematic error as there is always the possibility of "bugs" in the system. Systems development is a dynamic process and all components of the system, including the knowledge representation should be up-dated as frequently as possible. Unlike algorithmic-based systems, expert systems can be updated without requiring substantial rewriting of the program. Expert systems developers will always be challenged to represent the
complexity of the real world with absolute rules. Systems should also clearly state their purposes and limitations.

The development of computer dental applications has been relatively slow compared to other health related areas. The current focus on management information and clinical systems may be due to the perception of a potential market for dental clinicians who likely will want to focus on financial returns. A growing movement to educate dentists on the use of computers in all levels of clinical activity has been verified and the American Association of Dental Schools (AADS) recognized dental informatics as an emerging academic discipline (31). Systems developed for public health programs such as the PPM may face a more restricted market and be less attractive to independent system developers.

A collection of research goals for dental public health was developed defining four major topic areas of research. These areas were: Epidemiological investigation, Prevention Research, Health Promotion and Health Education and Health Services Research (32). A knowledge-based expert system such as the PPM has elements from each one of these areas. If research support agencies such as the National Institute of Dental Research identifies the development of science transfer tools as a potential research area, the use of such tools for the planning, implementation and evaluation of public health programs may significantly contribute to the promotion of oral health and bridge the fields of research in dental public health and service.

Some legal issues related to ownership and responsibility over the knowledge in the KBES can also be raised. Preferably a system developed for community-based programs should be a "public domain" system. The responsibility for the knowledge content would be shared among KBES developers, experts who provided input to the program and the financing agency. To avoid litigation cases, computer applications should provide clear descriptions of what it aims to accomplish and the role of the user. Technical support should also become available to clarify potential difficulties faced by users.
History shows many examples of resistance to technological advances and the use of decision-support systems may not be an exception to this rule. If used properly these programs have a great potential for assisting health managers to allocate resources and promote the most good to society.
Conclusion.

This paper demonstrates that it is feasible to represent the knowledge domain used by experts in the planning of dental caries preventive programs. The feasibility of development of such systems for use by public health agencies would depend on the financial support of government or non-profit agencies. Efforts for the development of such a tool should be centralized by a government agency or non-profit organization and the program should represent the consensus view of experts. A pilot internal validation addressing specific parts of the program was carried out (25) and is published in a following article. Further development of the PPM prototype and studies looking into how the program works in normal conditions (external validity) should follow.

The use of KBES in dental public health programs may facilitate the implementation of dental caries preventive programs with emphasis on targeting strategies. It will make it possible to systematically register the parameters used and assumptions made during the planning stage.

With the use of KBES such as the PPM, guidelines for necessary information gathering, revision on the effectiveness of dental caries with instant access to the state of the art information and consideration of different preventive dental programs strategies will become the modus operants.

Some potential outcomes with the widespread use of knowledge-based expert systems in dental public health programs are: 1) the transfer of technology to dental public health officers, 2) the identification of areas lacking scientific information, 3) the simplification of the program evaluation process and 4) the facilitation of communication between dental health officers as well as academia and dental planners.
References


ACKNOWLEDGMENTS

Supported by the fellowship provided by the Brazilian National Research Council (CNPq).

Acknowledgments to Dr. Brian Burt for his help and support.
Module 1:
Strategies Recommended for Fluoride, Diet, and Sealant-Based Strategies

**FIGURE 1**

**Level of Fluoride in Water Supply**
- Fluoride Levels (ppm)
  - Low = 0 ≤ X ≤ 0.8
  - Mod = 0.8 < X ≤ 1.2
  - High = X > 1.2

**Mean DMFT Trends**
- Increasing
- Stable
- Decreasing

**Level of Carbohydrate Consumption**
- Sugar Consumption Index (SI)
  - Low = 0 ≤ X ≤ 1
  - Mod = 1 < X ≤ 5
  - High = 5 < X ≤ 10

**Epidemiological Profile of Population**
- Mean DMFT
  - % High-Risk Children (DMFT ≥ 2)
  - % Moderate-Risk Children (DMFT = 1)
  - % Low-Risk Children (DMFT = 0)

**Fluoride Strategy**
- None
- Target Moderate and High-Risk Population
- Target Moderate and High-Risk Population & Target High-Risk Population
- Target Moderate and High-Risk Population & Target Mod & High-Risk Population

**Sealant Strategy**
- None
- Target Moderate and High-Risk Population
- Target Low and Moderate-Risk Population
- Target Moderate and High-Risk Population & Target Low and Moderate-Risk Population

**Diet Strategy**
- None
- Target Moderate and High-Risk Population
- Target Low and Moderate-Risk Population
- Target Moderate and High-Risk Population & Target Low and Moderate-Risk Population

**Fluoride-Based Program**
1. Recommended for population and target strategies.
2. Recommended for targeting strategies and could be considered for population strategy.
3. Could be considered for population and targeting strategy.
4. Recommended for population strategy but could also be considered for targeting strategy.

**Sealant-Based Program**
1. Recommended for targeting strategies or could be considered for population strategy.
2. Recommended for population strategy and could be considered for targeting strategy.
3. Could be considered for population and targeting strategy.
4. Recommended for population strategy but could also be considered for targeting strategy.

**Diet-Based Program**
1. Recommended for population and target strategies.
2. Recommended for targeting strategies and could be considered for population strategy.
3. Could be considered for population and targeting strategy.
4. Recommended for population strategy but could also be considered for targeting strategy.
FIGURE 2
Graphic Representation of Fluoride and Diet Strategies

Strategy:
- None
- Targeting Moderate and High Risk Children
- Population
- Population & Targeting High Risk Children

Mean DMFT < 1
FIGURE 3
Graphic Representation of Sealant Strategy

Strategy:
- None
- Targeting Moderate and High Risk Children
- Population
- Targeting Low and Moderate Risk Children

% Moderate Risk Children (DMFT = 1)

% High Risk Children (DMFT ≥ 2)
FIGURE 4
Module 2
Dental Caries Preventive Measures

- Water Fluoridation
  - Water Fluoridation in Schools
- Topic Fluoride solution and gel
  - Salt Fluoridation
  - Fluoride Mouthrinse
- Fluoride Drops or Tablets
  - Fluoride Toothpaste
- Fluoride Varnish
  - Pit and Fissure Sealants
- Fluoride in Beverages
  - Diet Programs
- Fluoride Slow Release devices

Long-text View  |  Short-text View  |  Bibliographic list  |  Graphic Representation  |  Background History
Module 3

An Estimation Model for the Effectiveness of Sealant-Based Programs
FIGURE 6
Estimation Model for Mean DMFT

Eklund, SA Unpublished Data
COST-EFFECTIVENESS STUDY OF A SCHOOL-BASED SEALANT PROGRAM

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