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Nurse-led Design and Development of an Expert System for Pressure Ulcer Management

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ABSTRACT

The use of Clinical Practice Guidelines (CPGs) is known to enable better care outcomes by promoting a consistent way of treating patients. This paper describes a user-centered design approach involving nurses, to develop a prototype expert system for modelling CPGs for Pressure Ulcer management. The system was developed using Visirule, a software tool that uses a graphical approach to modeling knowledge. The system was evaluated by 5 staff nurses and compared nurses' time and accuracy to assess a wound using CPGs accessed via the Intranet of an NHS Trust and the expert system. A post task qualitative evaluation revealed that nurses found the system useable with a systematic design, that it increased access to CPGs by reducing time and effort required by other usual methods of access, that it provided opportunities for learning due to its interactive nature, and that its recommendations were more actionable that those provided by usual static CPG documents.

KEYWORDS

User Centered Design; Clinical Decision Support; Expert System

Figure 1: The Contents page of a CPG (Adult Wound Care Formulary).

INTRODUCTION

CPGs provide evidence-based recommendations on how healthcare professionals should care for people with specific conditions. The major barrier to their use is clinical workload and lack of time to access these lengthy narrative documents [1]. The last two decades have seen considerable research into computer interpretable guidelines (CIGs) which consist of formalisms such as document models, decision trees and probabilistic models representing CPGs [2]. The main issues with creating CIGs lies in the difficulty of transforming guidelines into a formal representation as well as the need to address syntactic and semantic compatibility across multiple institutions [2]. Most research on CIGs has focused on encounters between patients and physicians. In contrast, there is little research on the use of CIGs in nursing even though nurses are frequent users of CPGs in practice [3]. Research on CIGs often highlights the importance of integrating CPGs with a patient's electronic health record, however in the UK, most NHS Hospitals do not have in place electonic health records with built-in decision support based on CPGs. In practice, to access CPGs in hospitals, nurses must either look through various folders to find the appropriate document or log into a Trusts' Intranet either on a desktop or laptop computer or via their mobile phone and perform searches which often return a vast number of results that nurses must scan to find the appropriate documentation. This process is therefore very time-consuming and often ineffective. This work aims to improve access to CPGs by providing a better solution than accesing documents or information on the Intranet. This presents important challenges around how to encapsulate and encode domain knowledge in an electronic system, how to design a solution that can visualise the clinial process effectively, and be used quickly and with ease in a clinical setting [4]. The lead author is a staff nurse and we outline a user-centered approach to the design, development and evaluation of a prototype expert system for woundcare management. The web-based prototype was developed using a graphical tool for modelling knowledge and is an important demonstration of how domain experts are enabled to develop software systems using such tools. Wound care management was chosen as this area constitutes a major area of nursing, being delivered in all care settings. Consequentially, there are numerous guidelines for different types of wounds and appropriate treatment with best evidence is continiuosly evolving. In practice, there are a limited number of expert Tissue Viability Nurses (TVN) which limits access to expert opinion in clinical settings. Pressure Ulcers are chosen as they constitute a type of wound that can be seen in all areas of nursing practice. The contribution of our work is the nurse-led creation of a CIG encapsulating domain knowledge delivered via a user friendly expert system with the aim of making CPGs more accessible and actionable in practice.

METHODS

Knowledge Elicitation with an Expert

Knowledge was elicited by the lead author via a series of interviews with a TVN with over 10 year's clinical experience in a number of NHS Trusts. Interviewing more TVNs would have been preferable, however the TVN is a specialist role and there are a limited number of TVNs in practice. The interviews

Table 1: Requirements elicited via the TVN

ID	Requirement
REQ1	The system should provide inbuilt calculators to compute MUST [6] and Waterlow [7] scores where the MUST scoring system identifies adults who are malnourished, at risk of malnutrition, or obese and Waterlow gives an estimated risk for the development of a pressure ulcer in a given patient.
REQ2	Dressing recommendations should include both primary (dressings that comes directly in contact with the wound bed) and secondary (dressings used to cover a primary dressing when the primary dressing does not protect the wound from contamination) if required.
REQ3	Recommended dressings should only include those stocked at the Trust and should include images of the dressings (the dressing box and the actual dressing).
REQ4	Wound and dressing history should be available to prevent recommending a dressing that is not effective and/or to stop wound treatment that has been started in the community.
REQ5	Methods to capture factors that affect healing, e.g. co-morbidities, nutrition and smoking status.
REQ 6	The provision of information about other relevant interventions defined as: control of co-morbidities; referral to smoking cessation sessions; and referral to dietitians.
REQ 7	The provision of a link to the CPGs that were the basis of the assessment recommendation.
REQ 8	The ability to print a summary of the assessment and recommendation, where a patient label could be affixed and this information stored with the patient record.

focused on methods of access to CPGs for wound care, the task of wound assessment and features of the proposed expert system. The CPG used at the TVN's Trust is known as the Adult Wound Care Formulary. The contents page of a wound care CPG is shown in Figure 1. Including appendices, the document is 76 pages. It is reviewed every two years so it can accommodate up-to-date evidence. The TVN articulated that nurses may access CPGs in three different ways: 1) paper documents, 2) general search on the Intranet and 3) contacting the TVN. Access via the Intranet is by typing the term 'wound' into a search engine, however, this returns many results, not all relevant, such as other CPGs, for example, surgical wounds guidelines. If a nurse is unable to find the information, they can email the TVNs and wait for a reply that may take some hours. The TVN also remarked that an important part of the process is transforming document information into knowledge that can be used afterwards to dress wounds which is not addressed by any CPG method at the Trust.

Regarding the task of wound assessment, the TVN stated that any assessment by the expert system must focus on: the type of wound; type of tissue being dealt with; presence of infection; level of exudate (liquid produced by the body in response to tissue damage); condition of the surrounding skin; wound location; and its size and depth. She also suggests that a known Wound Assessment Processes guide the assessment. An example would be the TIME (Tissue, Infection, Moisture and wound Edge) process [5]. After the assessment nurses must define a treatment objective. She illustrated this by saying that even if a wound is infected, if the amount of exudate is heavy, then that should be addressed before moving to dressings. Furthermore, the TVN emphasized that if the wound is bleeding then this must be stopped before addressing any other possible treatment objectives. Only when treatment objectives are defined can a dressing be chosen. The TVN defined possible treatment objectives as: (i) reduce exudate; (ii) treat infection; (iii) clean wound bed; (iv) treat cellulitis of surrounding skin; and (v) haemostasis (stop bleeding). Lastly, the TVN highlighted the importance of recognizing the need for specialized help from TVNs or surgeons. While a dressing can be recommended by the system and applied on a wound 'in the meantime', specialized help should also be sought if it is noticeable that there is no improvement or if the wound is quite complex (e.g. pressure Ulcer Grade III/IV). She also highlighted the need to assess if the chosen dressing is effective, for example if there is no improvement within 5 to 7 days the wound must be re-assessed and a different dressing be chosen.

Regarding functionality of the system, the TVN suggested the wound assessment process should mirror the assessment task as she described it above. She emphasized the importance of a simple system where only necessary questions are asked and highlighted the importance of confirming answers given by nurses using the system. These suggestions were translated into eight requirements shown in Table 1.

Use Case Scenarios

Two storyboards were created to demonstrate potential use case scenarios. This was to confirm the expert knowledge elicited from the TVN was understood and could be applied to real world situations. The first

storyboard (Figure 2) illustrates the system being used by a nurse in a hospital accessing the system on a computer on wheels. The computer on wheels medium is used as it is typical to access other hospital equipment on trolleys so it can be easily moved around a ward. This nurse is unsure about which dressing to use and is using the system to find an answer. After dressing the wound, the nurse prints the recommendation. The storyboard highlights decision-support and the promotion of continuity of care by storing the recommendation within the patient folder.

The second storyboard (Figure 3) illustrates a nurse using the system on their mobile phone while visiting a patient at home. From the assessment this wound appears to have gotten worse. Thus, they use the system to find a new dressing. The system recommends a dressing, however it also highlights the need to involve a TVN. This storyboard highlights the use of the system on a mobile phone and demonstrates elements that are expected in a final interface such as images, links to guidelines and recommendations for further input from specialized healthcare professionals. Both storyboards were shared with the TVN, who thought the type of interactions and interface design were appropriate for real world nursing contexts and reflected the expert knowledge communicated during the interviews.
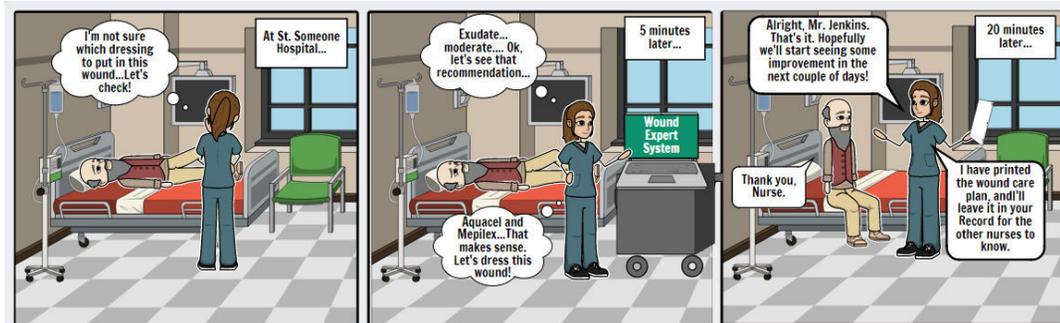

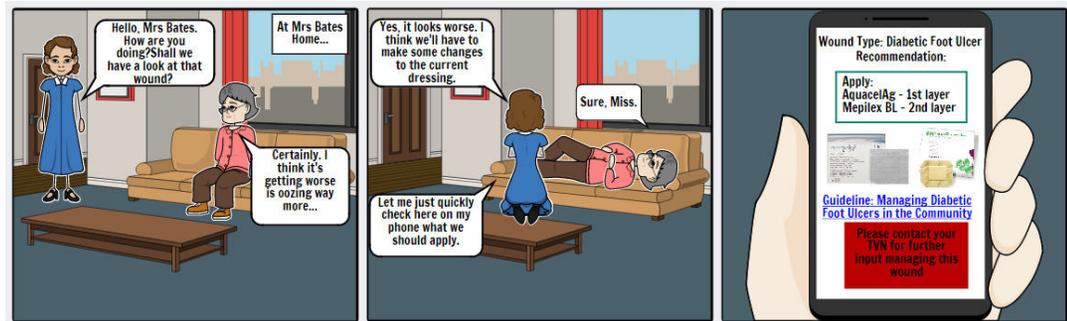**Figure 2: Nurse using expert system in hospital setting.**

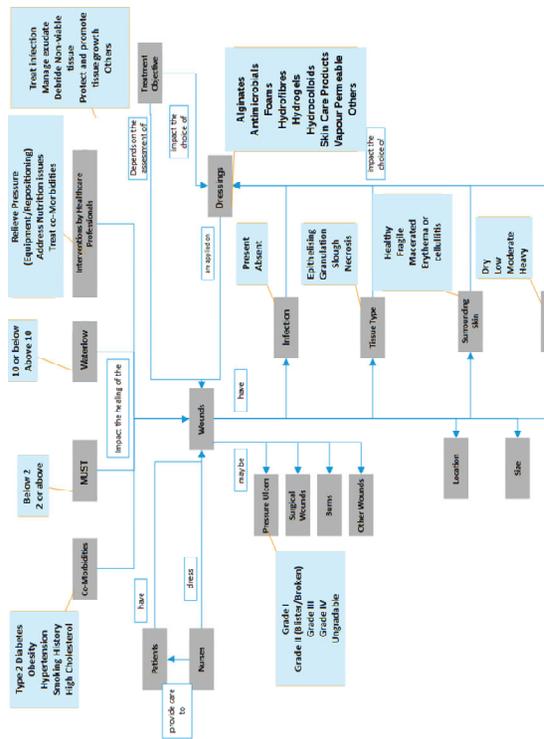**Figure 3: Nurse using expert system in home (community) setting.**

Figure 4: Knowledge Map

> *Wound Assessment: [Grade II (non blister) + No Infection + Low Exudate + Healthy Surrounding Skin]* →
> *Treatment Objective: Protect and promote tissue growth* →
> *Dressing recommendation: Primary Dressing Foams (E.g. Mepilex Border) or Cavilon Film/Spray Dressing.*

Figure 5: Sample Rule

KnowledgeBase Development

Explicit domain knowledge was extracted from three CPGs: Pressure Ulcer Prevention and Management Guidelines, Wound Management Guidelines for Secondary Healing and the Adult Wound Management Formulary and was combined with tacit knowledge elicited from the TVN during the interviews. The knowledge map in Figure 4 was produced which reflected information gathered during the design process, for example, assessment is guided by the TIME process commonly followed by nurses in clinical practice and systematic tools such as MUST and Waterlow are automated to capture patient data. Actionable treatment objectives must be defined before a dressing be chosen, and the importance of capturing other factors that affect healing is highlighted. All possible combinations of inputs for patient and wound assessment from the figure were used to create rules about treatment objectives and types of dressings. These rules are then implemented in the prototype expert system. A sample rule is shown in Figure 5.

Prototye Implementation

The prototype was implemented using Visirule [8], an AI-powered software that provides grahical tools to define and evaluate expert systems and allows non techical users to create diagrams representing knowledge which are then converted into code. It allows to publish expert systems as a web application. The prototype was implemented by the lead author. The web application publishing feature was extremely useful during the implementation phase as it allowed the evolving prootoype to be shared with the TVN throughout the process to elicit feedback. The finalized prototype can be accessed at https://visiruleexamples.com/vrapp/lpaexamples/woundcareexpertsystem. Interfaces from the expert system are shown in Figures 6 and 7. Each screen is composed of 2-3 short questions (or statements) and following the question, an answer(s), an explanation of the answer and an optional graphic showing where the question fits in the overall assessment path (excluded here for display purposes). Figure 6 shows the Patient Assessment screen and Figure 7 shows the questions related to Exudate and Surrounding Skin.

RESULTS AND DISCUSSION

The prototype was evaluated in a number of ways. The knowledge base was tested with the TVN to ensure all recommendations were valid and correct. The system was evaluated by 5 staff nurses (4 female, 1 male) who ranged in age from 28-30 all of whom had been practicing nursing for at least 6 years. The nurses used both the expert system and Intranet CPGs on a desktop computer to evaluate representative woundcare vignettes created by the TVN. This was a lab-based study where users were logged into the Trust's Intranet and had access to the correct CPG from the beginning of the task so the time taken to log in and find the correct document was not accounted for in the study. Evaluations were recorded using Free Screen Recorder 6.3.0 and the time and accuracy of each assessment was noted. This was followed by a post-task semistructured interview where questions were selected and adapted from W3C's Web Accessibility Initiative (WAI) Usability Testing Questions.

Figure 6: Patient Assessment Screen

Figure 7: Exudate and Surrounding Skin Questions

Regarding accuracy, the expert system and Intranet CPGs were equally successfull in finding a correct solution in all but one case where both failed. However use of the expert system resulted in shorter time to make assessments (on average 273.8 vs 231.2 seconds per assessment or just over 15% less time). However this did not include the time and effort to log into the Intranet and search for the relevant document. These factors were reflected in responses from the post-task interview, one participant stated: "*The system is very easy to use, I think nurses will find it easier and faster to use than looking for the guidelines on the Intranet, sometimes it can take a while to find the right 'keyword' on the search page and the answer we are looking for*". Another participant commented about how interacting with a tool rather than a document aided learning, "*With this system you learn how to describe as well as assess a wound - the type of wound, surrounding tissue and grades of pressure ulcer - as you need to supply information. Also it gives a straightforward answer about the best type of dressings to apply and images showing how to apply a dressing are extremely useful*". A third participant commented about the usable format "*It is systematic and mirrors the workflow but also provides sources of information or referral to TVN if required for more information*".

CONCLUSIONS

This paper presents a nurse-led user-centered approach to creating CIGs delivered via an expert system. The work demonstrates that nurses can and should be active participants in developing clinical systems, in order to develop solutions that accurately encapsulate domain knowledge and reflect how systems are used in clinical practice. An evaluation of the prototype highlighted how the system makes CPGs more accessible by providing access to a dedicated resource rather than searching many documents on the Intranet. The system is useable and required less time and effort on the part of nurses and can supply actionable recommendations that provide more information that standard CPGs. In future work we intend to extend the system beyond pressure ulcers to other types of wounds. We would like to involve more stakeholders, including more nurses and also a UX designer to improve the front end of the application. We plan to evaluate the system in a live clinical environment, initially in a community setting and then in a hospital and to evaluate the usability of the system more formally using standardized instruments such as the System Usability Scale.

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