Building an Ontology for Pressure Ulcer Risk Assessment to Allow Data Sharing and Comparisons Across Hospitals

Hyeoneui Kim, RN, PhD[1]; Jeeyae Choi, RN, DNSc[2]; Lelanie Secalag, RN[2]; Laura Dibsie, RN, MSN[3]; Aziz Boxwala, MD, PhD[1]; Lucila Ohno-Machado, MD, PhD[1]

[1]Division of Biomedical Informatics, University of California, San Diego, San Diego, CA; [2]Spaulding Rehabilitation Hospital, Boston, MA; [3]University of California San Diego Medical Center, San Diego, CA

Abstract

As a way to promote consistency and completeness of pressure ulcer risk assessment, as well as to establish a framework for data and knowledge sharing in this domain, we constructed an ontology that represents how the characteristics of the high risk patients defined by the Braden scale are operationalized at two different settings. We observed great similarity between the two study hospitals. Forty scenarios that portrayed patients at each site were added to the ontology and algorithmically assessed for pressure ulcer risk using the ontology reasoner FACT++. When validated by manual assessment by the nurses from each site, high consistency in the assessed risk level was observed with the average consistency score of 0.82 (SD= 0.06) out of 1.0. The results suggest that explicitly defining the site specific methods for assessing pressure ulcer risk that comply with the standard methods defined in the Braden scale can improve assessment consistency.

Introduction

Pressure ulcer is a serious patient safety concern that causes significant discomfort to patients and high treatment cost to payers [1]. Identifying the patients at risk of developing a pressure ulcer is a crucial first step of prevention. However, assessing the risk for developing a pressure ulcer is a complex task that requires interpretation of various aspects of patient status. The Braden scale[1], a widely adopted pressure ulcer risk assessment scale [2-3], determines the risk based on 6 risk factors. This scale provides detailed explanations on how to identify patients who have these risk factors, at various severity levels. Nonetheless, applying the described methods directly to assessment practice is not always straightforward and often requires additional steps of translation across specific practice settings.

The purpose of this study was to explore a consistent and systematic way to apply the standard methods of risk assessment defined in the Braden scale to different practice settings to promote consistency and accuracy of the risk assessment, which will facilitate data sharing across different healthcare settings. Specifically, we aimed to (1) identify site-specific methods of pressure ulcer risk assessment in terms of discrete patient data and data synthesis used for the assessment, (2) compare the methods from 2 different settings for similarities and differences, (3) construct a pressure ulcer risk assessment ontology that integrates site-specific methods into a common standard method, and finally to (4) demonstrate the consistent and systematic application of the assessment methods using patient scenarios.

Background and Significance

Challenges in assessing pressure ulcer risk with the Braden scale

Validity and inter-rater reliability are the key requirements of risk assessment scales. Validity of the Braden scale has been proved in many studies, but its reliability has been less often evaluated. A few studies raised concerns about the inter-rater reliability of this scale, especially at the individual parameter level [4-7]. The Braden scale's six parameters represent six risk factors related to pressure ulcer formation (*Sensory Perception*, *Activity Status*, *Mobility Status*, *Moisture Exposure*, *Nutritional Status*, and *Friction & Shear)*. Not all parameters are defined in a way that can be readily applicable to assessment practice due to the complex and sometimes chronic nature of the related risk factors [8].

Studies showed that understanding various aspects of patient status and correctly applying the patient characteristics defined in each parameter to assessment practice are the keys to accurate and reliable risk assessment with the Braden scale [4-5, 9-10]. The findings from these studies indicate that explicitly defining the patient data and the synthesis methods required to identify risk factors improves accuracy and inter-rater reliability of the assessment.

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[1] www.bradenscale.com/images/bradenscale.pdf

In a previous study we have developed a prototype decision support tool that would assemble patient data relevant to pressure ulcer risk assessment from an Electronic Medical Record (EMR) system. In that pilot study, we identified the ways in which the parameter definitions of the Braden scale were operationalized at a single study site. We converted the operational definitions directly into decision rules. The generalizability of this tool was limited, as it failed to explicitly represent the translation between the site-specific risk assessment methods and the standard methods defined in the Braden scale.

Using an ontology to represent and integrate various methods of pressure ulcer risk assessment

Studies have utilized ontologies to systematically map patient- or site-specific data into a common knowledge framework. Systematic abstraction of patient-specific data to high level standardized disease phenotypes was demonstrated in autism cases using an ontology and an added rule-based inference function [11]. Similarly, site-specific neurologic data were integrated into a standard cerebrovascular disease ontology using the description logic based inference engine embedded in that ontology [12]. Problem Solving Methods (PSM), a plug-in module of earlier version of Protégé, is another example of employing an ontology modeling approach to the representation of sharable knowledge on inference methods [13].

The underlying idea in these studies is to model the common domain knowledge or concepts as high level entities and specific applications of the knowledge or concepts as specializations of the high level entities. This is a viable approach to representing site-specific methods for pressure ulcer risk assessment in relation to the standard assessment methods defined by the Braden scale.

Methods

This study was done in collaboration with 2 tertiary academic medical centers. One is a rehabilitation hospital where a commercial EMR system has been used for several years and the other is an acute care hospital that mostly uses paper-based records, except in intensive care units, where an in-house built EMR system is used. Both sites assess pressure ulcer risk using the Braden scale.

Identifying site-specific data and data synthesis methods for pressure ulcer risk assessment

We had extracted 38 detailed patient characteristics (e.g., *"patient has no problem with communication*", "*patient sometimes has a communication problem"*) that are grouped into 15 patient characteristics categories (e.g., *"ability to communicate*") from the Braden scale parameter definitions. The 38 patient characteristic descriptions were presented to a nurse from each study site, who was experienced in assessing pressure ulcer risk using the Braden scale. These nurses identified the specific data items that they use to evaluate patients against the 38 characteristics. When multiple data items were related to a single patient characteristic in the Braden scale, the nurses also explained how those discrete data items were synthesized for the evaluation.

We presented the data items collected at one site to a nurse at the other site to identify those that were potentially misleading due to the unfamiliar local expressions. These items were clarified either by being replaced with a standardized term matched in the Systematized Nomenclature of Medicine, Clinical Terms (SNOMED-CT) or by providing definitions.

Discovering the commonalities in assessing the risk

We converted the parameter definitions of the Braden scale to IF-THEN statements, i.e., high level data abstraction rules. We produced their site-specific versions by replacing the general patient characteristic descriptions with the corresponding site-specific data items. We then examined the site-specific data abstraction rules of the two sites to find the commonalities that could be promoted to a high level common rule. For example, the ability to effectively communicate pressure-related discomfort or pain is described as one of the patient characteristics that are important on evaluating the risk factor related to the *Sensory Perception* function. Both sites assessed communication capability by synthesizing *orientation status*, *emotional status* and *limitations in verbalization.* These three items can potential be promoted to a common rule in the category of "*ability to communicate*".

Building a pressure ulcer risk assessment ontology

We constructed a 2-layer ontology using Protégé-OWL [2] to map the pressure ulcer risk assessment methods defined at the two study sites to the standard assessment methods defined in the Braden scale. In Figure 1, Layer 2 represents the former and Layer 1 represents the latter.

Relating the site specific data to the general patient characteristics defined by the Braden scale was straightforward in many cases: one site-specific data item represented one general description (Condition B and Condition C of Figure 1). When a general

[2] http://protege.stanford.edu/overview/protege-owl.html

description was mapped to a synthesis of multiple site specific data items that could not be promoted to the common rule, we created a subclass of the related general description and annotated the class with the site-specific data synthesis rule as in Condition A of Figure 1. We then created a synthesized version of the site-specific data as an instance of this subclass.

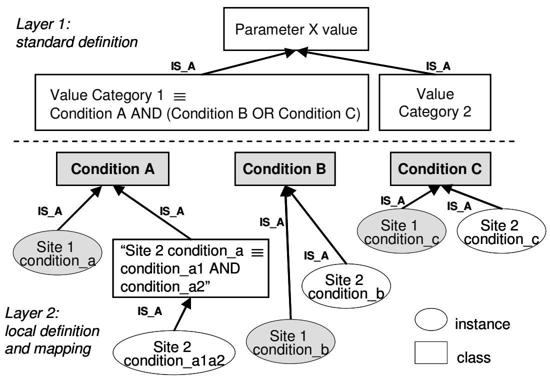

Figure 1. A schematic view of the 2-layer ontology

Table 1 depicts the way that the Braden scale is modeled in the ontology. One of the *Sensory Perception* parameter values *no impairment* was presented as an example.

Sensory Perception: No Impairment *– the patient responds to voice AND has no sensory loss AND has no communication problem*
$\text{SensoryPerception\_NoImpairment} \equiv \exists \text{hasResponseLevel.RespondToVoice} \wedge \exists \text{hasSensoryLoss.NoSensoryLoss} \wedge \exists \text{hasCommunicationStatus.CommunicationIntact}$
"Communication Intact" *is further specified as below*
$\text{CommunicationIntact} \equiv \exists \text{Orientation.Intact} \wedge \exists \text{Emotion.Calm} \wedge \exists \text{Verbalization.Intact}$
Specific patient status values *indicating the conditions specified above are as below*
$\text{RespondToVoice.x} \in \{\text{alert, respondToVoice, obeyCommands, openEyesToPain}\}$ $\text{NoSensoryLoss.x} \in \{\text{noSensoryLossFinding, sensoryIntactOnDermatomeAssess}\}$ $\text{Calm.x} \in \{\text{behaviorCalm, RASS\_alertCalm}\}$ $\text{OrientationIntact.x} \in \{\text{orientedx3, orientedVerbalResponse}\}$ $\text{VerbalizationIntact.x} \in \{\text{noAphasia, verbalResponsePresent}\}$

Table 1. Defining the *Sensory Perception* parameter and the value *no impairment*

Testing the effects of the explicitly defined assessment methods on assessment consistency

We created two sets of 20 patient scenarios reflecting various levels of pressure ulcer risk. The set of scenarios was created using data identified from one site. These 40 scenarios were added to the ontology as 40 classes defined with the site-specific data instantiated in the second layer. We then classified the 40 scenarios under the parameter value classes in layer 1 using FACT++, a description logic reasoner provided with Protégé-OWL [14].

The two nurses who identified the site-specific assessment methods reviewed the 20 scenarios in paper forms and scored the Braden scale. We offered an option of "*need more data*," so that nurses could select it when they felt the presented data were not enough to make the risk assessment with the Braden scale. This was done to test the completeness and the relevancy of the site specific assessment methods identified at the 38 patient characteristics levels by placing them back into the entirety of pressure ulcer risk assessment context. Another nurse from each site also assessed the 20 scenarios following the assessment methods defined by the expert nurses from the same site.

We compared the parameter values determined by the ontology and by the nurses, and assigned consistency scores. We didn't calculate Kappa statistics because there were unused value categories in certain parameters. When the same values are assigned to a presented scenario by two different assigners at a given site, we gave a score of 2. When the values differed by 1 point (e.g., very limited vs. completely limited), a score of 1 was given. When the values differed by more than 1 point, a score of 0 was given. We then generated summary consistency scores for each parameter separately by sites, for easy interpretation. We divided the total scores that each parameter had earned with the 20 scenarios by the maximum possible score of 40. That is, if two different assigners assigned the same value on the parameter for every scenario, the summary score becomes 1. If they assigned values differed by 1 point to all, the summary score becomes 0.5, if differed by more than 1 point, the summary score becomes 0.

Results

Data items used at the two sites

We identified 19 data items from site 1, which are assembled into 62 patient status descriptions corresponding to the 15 patient characteristic categories of the Braden scale. From site 2, 14 data items that are assembled into 58 patient descriptions were identified. Eighteen of the 19 data items identified from site 1 were the regularly documented structure data items. On the other hand, half of the data items identified from site 2 were documented in nursing narrative notes.

The cross review of data items showed that the site-specific expressions of patient data are not a huge obstacle to sharing assessment methods, but the ordinal descriptors of the data, defined for the site specific usage are. Seven items from site 1 and 1 item from site 2 were deemed unclear to the other site's nurse. Two of them required definitions (e.g., *close guard*) and five of them required better quantifiable descriptors (e.g., *maximum assistance* vs. *total* *assistance*). These items were clarified by adding textual definitions or numeric qualifiers. "*Bowels: continent/incontinent*" was the only item that required an alternative name. Although its meaning was conveyed, it required a more suitable expression. This item was replaced with "*Bowel: occasional accident*", a term mapped from SNOMED-CT.

Patient characteristics	Data items used
Communication status	Orientation, emotion, Verbalization ability
Walking amount	Activity observation
Ability of change body position independently	Limb strength, position change schedule
Maintaining body position	Position change schedule
Skin moisture pattern	Skin observation, urinary or bowel pattern
Nutritional intake mode	Diet order
Oral intake amount	Intake & output assess
NPO duration	Diet order

Table 2. Data items commonly used by the sites

We observed that the two sites used almost identical data items in evaluating 8 of the 15 patient characteristic categories (Table 2). We also observed many discrepancies in the data items used to evaluate the other patient characteristic categories, which include "*response level*", "*sensory loss*", "*activity level*", "*protein intake amount*", "*transfer mobility*", "*non-oral nutritional intake amount*", and "*fluid intake status*".

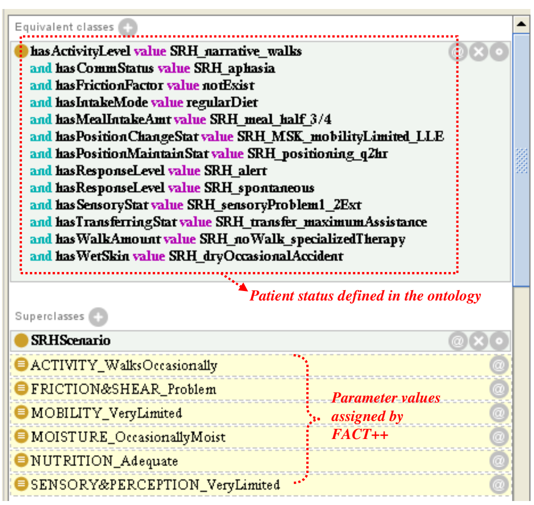

Figure 2. Parameter values assigned to a patient scenario by FACT++

Pressure ulcer risk levels assessed for the scenarios

The 40 patient scenarios were classified into the value categories of the 6 Braden scale parameters using FACT++. Figure 2 is a part of the interface for the Protégé-OWL ontology that shows how a scenario case is defined in the ontology and how it is classified under the Braden scale parameter values based on the data abstraction rules embedded in this ontology.

Consistency in parameter value assignment

We hypothesized that the consistency scores between the ontology and the nurses would be higher than those between the nurses because variability in interpreting the data can still exist among nurses at a given site, even with the implementation of detailed guidelines. Overall, we observed high consistency scores in most of the parameters. In general, we observed higher levels of consistency between the ontology and the expert nurses than between other pairs (see Table 3). This was expected because the ontology represents the assessment methods identified by the expert nurses. The opposite results like in the *Moisture Exposure* parameter at site 1, where the consistency between the nurses was higher than the consistency between the ontology and nurses, suggest that the assessment methods identified by the expert nurse was either incorrectly or incompletely represented in the ontology.

	Site 1			Site 2		
Parameter	O-E	E-A	O-A	O-E	E-A	O-A
SensPerc	0.80	0.65	0.70	0.83	0.83	0.85
Moisture	0.53	0.80	0.53	0.90	0.83	0.93
Activity	0.80	0.75	0.85	1.00	0.95	0.95
Mobility	0.83	0.85	0.78	0.83	0.85	0.88
Nutrition	0.99	0.75	0.83	1.00	0.95	1.00
FricShear	0.73	0.83	0.80	0.73	0.73	0.80

O: Ontology, E: Expert nurse, A: Another nurse
Table 3. Consistency scores of parameter assessment

Discussion

In this study, we demonstrated that site-specific methods for pressure ulcer risk assessment can be explicitly defined and integrated into the standard assessment methods that the Braden scale provides. In addition, the scenario testing seems to show that a high level of consistency can be achieved in assigning parameter values when nurses use the same data items based on the explicitly-stated decision guidelines.

However, lack of directly comparable counter examples and use of the patient scenarios, which might be simpler than real patient cases, constitute limitations of this study. Among others, the high level of consistency shown in *Nutritional Status* assessment in both sites is noticeable. *Nutritional Status* has been identified as the least consistently assessed parameter because it requires long-term nutritional intake information for a patient [4]. The high level of consistency could be explained as a true positive effect of following the explicitly defined assessment methods, but could also indicate that the testing scenarios and/or the site-specific assessment methods were over-simplified. Further studies are necessary to elucidate this question.

The scenario testing results also showed that certain site-specific data items and data synthesis methods were not completely captured in the ontology. We are following up with the expert nurses on this result to better understand the causes of this discrepancy. However, this may imply that the pressure ulcer risk assessment as a whole is bigger than the sum of its parts – the collection of discrete patient data. When the discrete data are assembled together in the risk assessment context, additional features about the patient status may arise, as explained by the studies on humanistic- or context-dependent views on the nature of nursing inference [16].

Further investigation on the noted limitations needs to follow this study. First, the site-specific assessment methods obtained from one nurse need to be validated in a larger group of nurses at that site. Second, the risk assessment methods compiled in this study need to be tested with real patient data to identify any practical issues in applying this approach to real world practice. Missing data and difficulties with temporal abstraction of long-term observations are a few examples of such issues. In addition, we need to include more diverse settings in future studies, to better capture practical pressure ulcer risk assessment methods that can be shared across various practice settings.

Conclusion

Consistent and accurate assessment of risk for developing pressure ulcers is a critical first step for effective prevention. This study demonstrated modeling the site-specific methods for pressure ulcer risk assessment within a framework of standard methods of the Braden scale. The model built for this study has limitations that need to be addressed in a future studies. If these limitations are successfully addressed, the resulting model may serve as the basis to build a generalizable decision support tool for pressure ulcer risk assessment that can assist nurses with consistent and accurate pressure ulcer risk assessment, and allow comparison of adjusted outcomes across different healthcare settings.

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