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Building an Expert System

A Systematic Approach to Developing an Instrument for Data Extraction From the Literature

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When building an expert system that will be acceptable to clinicians in their practice, it is imperative that the knowledge engineer identifies, defines, and describes a clinical problem precisely. This can be accomplished by eliciting private knowledge from expert clinicians or by analyzing public knowledge available in the scientific literature. This study describes a systematic method for examining public knowledge found in health care textbooks and practice guidelines surrounding the concept of oral feeding in premature infants in a neonatal intensive care unit. It includes the development of an instrument for extracting data from these sources to standardize definitions of terminologies. Preliminary results and plans for further analysis are reported. This method can be applied to other clinical problems deemed appropriate for decision support system development.
Key words: *decision making; decision making, computer-assisted; decision support systems, clinical; decision support techniques; expert systems; nursing informatics*

EXPERT systems are automated knowledge-based systems that represent a specific expression of medical and nursing informatics to help caregivers interpret data and make better decisions. They can improve clinical practice and foster positive health outcomes. In order to build an expert system it is imperative that the knowledge engineer identifies, defines, and describes a clinical problem precisely. This precision facilitates acceptance of the system by clinicians and enhances communication when decisions are modeled.[1-3] Clinical problems can be defined with precision by eliciting 2 types of knowledge, private and public. Private knowledge consists of heuristic and experientially based information that has not been made available in the literature. This type of knowledge usually comes from expert clinicians. Public knowledge consists of knowledge that has been made available in the literature and usually comes from textbooks, reports, and journals.[4] The purpose of this article is to report a systematic analysis of public knowledge found in health care textbooks and practice guidelines surrounding the concept of oral feeding in premature infants. Walker and Avant's concept analysis and Weber's content analysis were adapted for the development of an instrument that extracts data from textbooks and practice guidelines about the definition of oral feeding.[5,6] Ultimately, the results of this analysis will be used to build an expert system, modeling decisions made by neonatal nurse practitioners (NNPs) when initiating oral feeding in premature infants cared for in the neonatal intensive care unit (NICU).[1-3]

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SIGNIFICANCE

Despite extensive work on the standardization of nursing terminologies to describe diagnoses, interventions, outcomes, and

patient problems, a concept-oriented approach to their development is lacking.[7-19] Additional issues related to the development of nursing terminologies include (1) the existence of multiple data sets in some practice areas and the lack of even 1 classification system in other practice areas, and (2) the fact that existing terminologies are usually developed for human interpretation, with computer interpretation as a secondary goal.[8] This is significant because knowledge that is understandable to humans is often ambiguous when applied to an automated system.

The Nursing Minimum Data Set (NMDS) was designed to organize nursing terminologies, creating a common nursing framework to describe nursing practice and evaluate its effectiveness across practice settings. It includes the data elements of nursing diagnoses, interventions, and outcomes as well as a nursing care intensity measure and a health record number.[9,10] In 1973 the North American Nursing Diagnosis Association (NANDA) was formed to develop a classification of nursing diagnoses. A list of over 100 diagnoses was compiled representing clinical problems in nursing.[11] In 1992 the Nursing Interventions Classification (NIC) team, headed by McCloskey and Bulechek, was interested in standardizing nomenclature to link nursing diagnoses and interventions for the purpose of building information systems.[12] They constructed and validated a taxonomy of nursing interventions called the NIC. The Nursing Outcomes Classification (NOC) team followed development of the NIC system with a comprehensive taxonomy of standardized patient outcomes, applicable across the care continuum, to link to these nursing interventions.[13,20]

In 1995 the American Nurses Association established the Nursing Information and Data Set Evaluation Center (NIDSEC) to develop and disseminate standards pertaining to clinical information systems that support the documentation of nursing practice. NIDSEC developed standards to evaluate the following 4 dimensions of nursing data sets and the systems that contain them: nomenclature, clinical content, clinical data repository, and general system characteristics.[21] NANDA, NMDS, NIC, and NOC are 4 of the American Nurses Association recognized nomenclatures. Additional data sets recognized by the American Nurses Association include the Home Health Care Classification (HHCC), the Omaha Problem Classification System, the Patient Care Data Set (PCDS), the Perioperative Nursing Data Set, and the Systematized Nomenclature of Human and Veterinary Medicine (SNOMED).

Saba's HHCC derived terms from patient records in a national sample of home health care agencies, producing 147 nursing diagnoses and interventions.[14] This classification scheme is part of a nursing information system designed to predict resource requirements.[14,22] The Omaha System was developed in a community health setting. It is a problem-oriented scheme and includes a problem rating scale.[10,17] Ozbolt's PCDS is focused on the acute care setting. Standard terms were derived from patient care planning and documentation materials from 9 hospitals in the United States. This standardization led to the development of a computer program designed to assist nurses in making decisions in each step of the nursing process.[10,15,19,22-23] More recently, the Perioperative Nursing Data Set, an automated language, was developed. This data set is composed of 4 domains. The domains are safety, physiologic response to surgery, patient and family behavioral response to surgery, and health system. Each domain includes nursing diagnoses, interventions, and outcomes related to perioperative nursing care.[10,16]

Methodological challenges related to creating these nomenclatures have been reported in the literature.[12,24-26] The NIC team reported difficulty in completing their initial list of nursing interventions because of the large number of available nursing textbooks and differences among texts regarding the nursing interventions for a particular condition.

For example, when comparing several nursing texts, nursing interventions for the nursing diagnosis, *Activity Intolerance*, varied greatly. A systematic method for the selection of sources was developed. After this selection process was completed, nursing interventions related to the diagnosis were collected, despite variability among sources.[12] In developing their initial list of nursing-sensitive patient outcomes, the NOC team identified a large variety of sources. For this reason they designed a sampling plan and selection criteria to determine which sources would be used.[26] Ozbolt discussed issues in determining how to assign order to the standard terms derived from in-patient records. She adapted Saba's 20 components of nursing diagnoses and interventions in home care as a system of organization.[24]

Nursing concepts must be defined precisely when building automated systems designed to communicate information about patient care, health outcomes, resources, cost, policy, research, and clinical and administrative decision-making across multiple health care disciplines and settings. Since most nursing classification systems were designed for human interpretation, they do not provide the level of precision necessary for computers. For this reason a concept-oriented strategy for standardizing nursing terminologies with the precision necessary for automation is important. Evaluation criteria related to concept-oriented approaches in computer-based systems have been developed.[8] These include the ability to separate concepts into constituent components, combine simple concepts into composite concepts, retain concepts once these have been defined, support multiple linguistic expressions and hierarchies, avoid redundancy, support synonymy, and provide precise, explicit definitions for each term. These criteria are particularly important when developing expert systems because these systems require more precise, finely granular data than typically exists in the classification systems discussed previously. SNOMED is an example of a concept-oriented expert system.[8,18] It is a comprehensive set of over 150,000 health care terms. Concepts include anatomy, morphology, normal and abnormal functions, symptoms and signs of disease, chemicals, drugs, enzymes and other body proteins, living organisms, physical agents, occupations, social contexts, diseases/diagnoses, and procedures. Computer-based tools are used to describe, manipulate, and reason about these concepts.

THE METHOD PHASE I

Determining how to systematically approach the literature

Because of the vastness and variability of the literature, a systematic approach to determine how and where to locate textbooks and practice guidelines was necessary. Textbooks and practice guidelines were used because these included a more comprehensive definition of the concept of oral feeding as compared to journals. In consultation with a health sciences librarian, 3 published lists of books and journals, 2 unpublished lists of books, and 4 electronic databases were selected. The published lists included Brandon/Hill's Selected List of Print Nursing Books and Journals, Brandon/Hill's Selected List of Books and Journals for the Small Medical Library, and the Interagency Council's List of Information Resources for Nursing.[27-29] The unpublished lists were provided by The National Certification Board of Pediatric Nurse Practitioners and Nurses, Inc. and The National Certification Corporation for the Obstetric, Gynecologic and Neonatal Nursing Specialties (NCC).[30,31] Contact with the American Board of Pediatrics/Subboard of Neonatal-Perinatal Medicine resulted in a course outline, but no list. The National Association for Neonatal Nurses (NANN), the Association of Women's Health Obstetrics and Neonatal Nurses (AWHONN), a National Guidelines Clearinghouse, and the Agency for Healthcare Research and Quality were also contacted; however, no additional lists were identified.

The 4 electronic databases included MEDLINE (1966 to December Week 4 2000), CINAHL (1982 to January 2001), HealthSTAR (1975 to December 2000), and EMBASE (all years).

Creating the source list from the 5 book lists and 4 databases ($N = 166$)

A source list of textbooks and practice guidelines deemed relevant to the concept of oral feeding in premature infants was developed from the book lists and databases. Since the 3 published lists were organized by subject headings, textbooks from the following subject headings were selected: dictionaries, maternal-child nursing, obstetric and gynecologic nursing, pediatric nursing, gynecology and obstetrics, nutrition, and pediatrics ($N = 105$). Inclusion criteria were titles related to the keywords *premature infant, infant nutrition*, and *feeding methods*. These keywords were chosen in an attempt to include all textbooks with some discussion of oral feeding in premature infants. Examples were *Mosby's Medical, Nursing, and Allied Health Dictionary*, *Comprehensive Neonatal Nursing: A Physiologic Perspective, Whaley and Wong's Essentials of Pediatric Nursing, Taber's Cyclopedic Medical Dictionary, Clinical Nutrition: Enteral and Tube Feeding*, and *Rudolph's Pediatrics*. Exclusion criteria were titles unrelated to these keywords. Examples were *Dictionary of Medical Acronyms and Abbreviations, Maternity and Women's Health Care, Management of the Infertile Woman*, *Pediatric Rehabilitation Nursing, Chronic Pelvic Pain: An Integrated Approach*, and *Comprehensive Adolescent Health Care*.[27–29]

The 2 unpublished lists had no subject headings. For this reason textbooks were selected from these lists by selecting titles related to the keywords *premature infant, infant nutrition, and feeding methods* ($N = 58$). Inclusion criteria were titles related to these keywords. Examples were *Breastfeeding the Newborn: Clinical Strategies for Nurses, Pediatric Nutrition Handbook, Manual of Neonatal Care*, and *Core Curriculum for Neonatal Intensive Care*. Exclusion criteria were titles unrelated to these keywords. Examples were *Sports Medicine: Health Care for Young Athletes, Pediatric Primary Care, Pediatric and Adolescent Gynecology*, and *Physical Assessment of the Newborn*.[27,28] Practice guidelines were selected from the 4 electronic databases by the following search strategy: keywords *infant nutrition, feeding methods* were combined via the Boolean operator "OR." This result was combined with the keyword, *infant, premature* via the Boolean operator "AND"; then limited to *human* and *English language* and *practice guidelines*. An independent search by the health sciences librarian was completed to assess reliability. Three identical sets of practice guidelines were obtained from each search ($N = 3$).[32–34] The outcome of the procedure for the selection of textbooks and practice guidelines was an initial source list of 47 (Initial yield = 47 selections). After redundancy among lists was corrected, a source list of 40 selections was compiled (Corrected yield = 40 selections).

Assessing validity of the source list

The corrected source list was assessed for content validity by a multidisciplinary panel of clinical experts. This panel consisted of 1 neonatologist and 2 NNPs. One NNP was a full-time clinician in a neonatal intensive care unit. The other NNP and the neonatologist held clinical faculty positions at academic institutions, with dual clinical and teaching responsibilities, respectively. The procedure for assessing content validity included a letter, explaining the purpose of the reference list, and a response rating form. Each expert was asked to respond to the following 3 questions:

1. Are there other sources you would include? If yes, please list these sources.
2. Are there more recent editions of the references listed that you are aware of? If so, please list them.
3. Are there sources listed that could be deleted from the list? If so, please list them and indicate why.

One expert suggested the addition of 2 neonatal physiology textbooks and a

Table 1. The source list categorized by strata ($N = 43$)

Strata	Number of sources
Medicine	17
Nursing	14
Nutrition	05
Reference	04
Practice guideline	03

neonatal-perinatal medical text of infant diseases. These suggestions were added to the source list and a final list consisting of 43 selections was compiled (Final yield = 43). Finally, by using the Library of Congress classification system, the source list of textbooks and practice guidelines ($N = 43$) was categorized by strata. First, the Library of Congress subject headings for each source were recorded. The following 4 categories were identified: medicine, nursing, nutrition, and reference. Next, each source was assigned to an appropriate category, creating 4 strata. The 3 sets of clinical guidelines comprised the fifth strata (see Table 1).

THE METHOD PHASE II

Scoring each textbook and practice guideline from the source list

In order to determine whether the content of each textbook and practice guideline was relevant to the concept of oral feeding in premature infants, a source rating form was developed. This form was similar to that used by the NIC team when compiling their list of nursing interventions. The specific feeding terms of interest were the result of an ethnographic study conducted by Panniers.[3] These included the following 4 oral feeding terms: nipple feeding, breast feeding, gavage feeding (bolus and continuous), and transpyloric feeding. The content of each textbook and practice guideline was reviewed for information about each specific feeding term as it related to premature infants. The source rating form (See Table 2) was organized as follows:

1. Is there a reference to at least 1 of the feeding terms in this source?
2. Do at least 1 of the feeding terms in this source refer to *infants* or *premature infants* or *both*?

Table 2. The source rating form for textbooks and practice guidelines

Title of source:
Author: Edition: Publication data: Chapters/pages:
Location of source:
1. Refers to at least 1 of the following feeding terms:

Nipple feeding	Y ____	N ____	
Breast feeding	Y ____	N ____	
Gavage feeding	Y ____	N ____	
Bolus	Y ____	N ____	
Continuous	Y ____	N ____	
Transpyloric feeding	Y ____	N ____	

2. At least 1 of the feeding terms refers to *infants* or *premature infants* or *both*:

Nipple feeding	I ____	P ____	# ____
Breast feeding	I ____	P ____	# ____
Gavage feeding	I ____	P ____	# ____
Bolus	I ____	P ____	# ____
Continuous	I ____	P ____	# ____
Transpyloric feeding	I ____	P ____	# ____

3. Overall score:
4. Comments:

Note: Y = yes, N = no, I = infants, P = premature infant, # = page #.

Table 3. Scoring criteria for each textbook and practice guideline

Score	Accept/reject	Criteria for accept/reject
1	Reject	No reference to any of the above feeding terms OR no discussion of feeding term as it relates to *infants* or *premature infants* or *both*
2	Accept	One reference to one of the above feeding terms with a discussion of how the term relates to *infants* or *premature infants* or *both*
3	Accept	Greater than 1 reference to any of the above feeding terms, but not all references accompanied by a discussion of how each term relates to *infants* or *premature infants* or *both*
4	Accept	Greater than 1 reference to any of the above feeding terms with a discussion of how each term relates to *infants* or *premature infants* or *both*

After a source rating form was completed for each textbook or practice guideline, an overall score was assigned based on the scoring criteria outlined in Table 3. For example, if the source had no reference to any of the feeding terms or there was no discussion of how this feeding term related to *infants* or *premature infants* or *both*, it received a score of 1 and was rejected. Therefore, even if the source listed all 4 terms, it was rejected if there was no specific reference to *infants* or *premature infants* or *both*. If, however, the source included 1 reference to 1 of the feeding terms with a discussion of how the term related to *infants* or *premature infants* or *both*, it received a score of 2 and was accepted. A source that included greater than 1 reference to any of the feeding terms, but not all references were accompanied by a discussion of how each term related to *infants* or *premature infants* or *both*, was accepted with a score of 3. Finally, sources that referred to greater than 1 reference to any of the feeding terms with a discussion of how each term related to *infants* or *premature infants* or *both*, received a score of 4 and were also accepted.

Developing the coding system

A coding system was developed that extracted data from each textbook and practice guideline about each of 4 specific feeding terms. Walker and Avant's concept analysis and Weber's content analysis were adapted.[5,6] Modifying Walker and Avant's procedure of concept analysis, 4 steps were undertaken: a concept was selected, the purpose of the analysis was determined, the defining attributes were identified, and a model case was constructed. The concept to be analyzed was oral feeding in premature infants. The purpose of the analysis was to determine a precise definition for use in building an expert system, modeling decisions made by NNPs when initiating oral feeding in premature infants cared for in the NICU.[1–3] The defining attributes were provided by the participant observation phase of Panniers' recent ethnographic study.[3] These included the 4 oral feeding terms: nipple feeding, breast feeding, gavage feeding (bolus and continuous), and transpyloric feeding. The model case was constructed by trial and error in an attempt to encompass all aspects of the attributes of oral feeding in premature infants. Weber's discussion of creating and testing a coding scheme was helpful in refining this last step. Four broad categories, designed to ensure precision and comprehensiveness in data collection, were defined. These consisted of a basic definition, assessment, nursing activities/behaviors, and caregiver/premature infant dyad activities/behaviors. Entire paragraphs were coded and the coding scheme

Table 4. The coding system for each premature infant feeding term found in each textbook or practice guideline (score ≥ 2)

Premature infant feeding term:
1. Basic definition:
2. Signs/indications for nursing intervention:
3. Nursing activities/behaviors related to the implementation of the intervention:
4. Caregiver/premature infant dyad activities/behaviors related to the implementation of the intervention:

Comments:

(see Table 4) for each oral feeding term was as follows:

1. Basic definition
2. Signs/indications for nursing intervention
3. Nursing activities/behaviors related to the implementation of the intervention
4. Caregiver/premature infant dyad activities/behaviors related to the implementation of the intervention

THE PILOT STUDY

Results

A pilot study was undertaken to test the source rating form and coding system. A source title was randomly selected from each of the 5 strata (see Table 1). The following sources were piloted: *Whaley and Wong's Essentials of Pediatric Nursing, Breastfeeding the Newborn: Clinical Strategies for Nurses, Williams Obstetrics, Taber's Cyclopedic Medical Dictionary*, and *Nutrient Needs and Feeding of Premature Infants*. A source rating form was used for each of the 5 sources and the scoring criteria previously described were applied to each source. Scoring results (see Table 5) indicated that the strata of *nursing* and *nutrition* were rated the highest (both sources received a score of 4), followed by *medicine* (score of 3), *reference* (score of 3), and *practice guideline* (score of 2). During the initial stage of the pilot study, an additional step was identified as necessary before a source rating form could be completed for each source. This additional step involved a method for ensuring that all information about oral feeding in each source was identified and copied. Initially, the table of contents of each source was used; however, by trial and error it was determined that each source index served as a more comprehensive guide. Using each source's index as a guide, the terms *infant, premature infant, preterm infant, nutrition*, and *feeding* were scanned. Appropriate pages were recorded and copied. In addition, the specific feeding term and alternative labels were scanned. For example, when attempting to locate all the information in *Whaley and Wong's Essentials of Pediatric Nursing* about the term *nipple feeding*, it was necessary to refer to the following additional terms in the index: *infant, premature infant, preterm infant, nutrition, feeding, bottle feeding, formula feeding; feeding, nipple; feeding, formula; feeding, bottle*. If these additional terms were found, appropriate page numbers were recorded and copied. This additional step provided rigor by further

Table 5. Pilot study: Using the source rating form to rate 1 source from each stratum

Category	Source title	Overall score
Nursing	*Whaley and Wong's Essentials of Pediatric Nursing*	4
Nutrition	*Breastfeeding the Newborn: Clinical Strategies for Nurses*	4
Medicine	*Williams Obstetrics*	3
Reference	*Taber's Cyclopedic Medical Dictionary*	3
Practice guideline	*Nutrient Needs and Feeding of Premature Infants*	2

Table 6. Pilot study: Using the coding system for the term nipple feeding

Strata	Source	Basic definition	Signs/ indications	Activities	Dyad behaviors
Nursing	*Whaley and Wong's Essentials of Pediatric Nursing*[35]	Bottle feeding refers to the use of bottles for feeding mild formula or human milk	Normal vital signs; strong suck; coordination of suck and swallow; a gag reflex	Use an angled bottle; feed 6 times a day; provide time and patience	Hold infant close to body with back curved slightly; support cheeks/chin to enhance nipple compression
Nutrition	*Breastfeeding the Newborn: Clinical Strategies for Nurses*[36]	Bottles give supplementary nourishment to newborns and consist of 3 basic styles: standard, preterm, & Nuk	No discussion	No discussion	No discussion
Medicine	*Williams Obstetrics*[37]	No discussion of term	...	...	...
Reference	*Taber's Cyclopedic Medical Dictionary*[38]	An artificial substitute for a female nipple, used for bottle-feeding infants	No discussion	No discussion	No discussion
Practice guide-line	*Nutrient Needs and Feeding of Premature Infants*[32]	No discussion of term	...	...	...

ensuring that all potentially relevant information was in fact, collected.

In the next stage of the pilot study, the portion of each source that had been identified and copied for data extraction was reviewed. The paragraph, the unit of print to be coded, was scanned for information about nipple feeding in premature infants. Relevant information was underlined and recorded according to the 4 categories of basic definition, signs/indications, nursing activities, and dyad behaviors (see Table 6). The nursing source provided the most comprehensive result by including the indications for readiness to nipple-feed, nursing interventions specific to the activity of nipple feeding, and behaviors between caregiver and infant. For example, readiness to nipple-feed included the following signs: vital signs within normal limits, presence of a gag reflex and strong suck, and the ability to coordinate sucking and swallowing. Nursing activities included the use of an angled bottle and feeding schedule. Dyad behaviors addressed proper positioning of the infant while feeding. It is also interesting to note that the nursing, nutrition, and reference sources used the term *bottle feeding* in their discussion of a basic definition.

DISCUSSION

A method of information analysis about the concept of oral feeding in premature

infants has been described. While this is a work in progress, the pilot study has demonstrated that information extraction needed to build expert systems is complex, but that the method can be made explicit and can be shared with other researchers and clinicians. After completing the data extraction from textbooks and practice guidelines, peer-reviewed journals will be analyzed.

Concept analysis is a strategy to determine the characteristics and meaning of a concept. The method presented in this article was designed as a particular type of concept analysis for the purpose of standardizing nursing terminologies for use in computerized systems. We believe this method is amenable to explaining other clinical problems and, as such, can add to the body of knowledge related to the construction of expert systems.

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