CLINICAL ENCOUNTER INFORMATION FLOW: APPLICATIONS IN EVALUATING MEDICAL DOCUMENTATION TOOLS

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LIST OF ABBREVIATIONS

SOAP .... subjective-objective-assessment-plan

SBAR .... situation-background-assessment-recommendation

CBD .... computer-based documentation

LINC .... Laboratory Instrument Computer

CMS .... Centers for Medicare and Medicaid Services

ENT .... ears-nose-throat

SP .... standardized patient

SNOMED-CT .... Systematized Nomenclature of Medicine Clinical Terms

LCS .... least common subsumer

cTAKES .... clinical Text Analysis and Knowledge Extraction System

NLP .... natural language processing

yTEX .... Yale cTAKES

UMLS .... Unified Medical Language System

MeSH .... Medical Subject Headings

VUMC .... Vanderbilt University Medical Center

CELA .... Center for Experiential Learning Assessment

PSD .... patient scenario description

RN .... resultant note

CHAPTER I

INTRODUCTION

This study investigated whether the flow of biomedical information from a patient through to a final clinical note during a clinical encounter is measurable, and if the use of specific documentation tools influenced the note's content. The current project defines the transfer of clinical concepts from patient to note "clinical information flow." The measure of "clinical concept permeability" is used by this study to describe how information travels from the patient, through the healthcare provider, and then to the resultant note. The alteration of information from patient to resultant note is also examined. To trace information flow, investigators collected data from a series of clinical encounters conducted in a simulated environment. There is limited research evaluating factors affecting the degree to which information conveyed by a patient to a healthcare provider is absent from a resulting clinical note (1–6). Existing research is inadequate with respect to scope of understanding flow of information from the patient visit to the end clinical note

Different types of clinical documentation tools are available to healthcare providers (7–12). These documentation tools are used to record clinical encounters, such as patient clinic visits, laboratory results, and details for performed procedures. Commonly used clinical documentation tools are paper-based, computer-based, or are dictation-based (5,9,10,13–15).

The present study investigated how the type of documentation tool affects clinical note content. Documentation tool impact on note content was examined in the context of simulated clinical encounters. To trace information flow, patient scenario descriptions for the simulated clinical encounters, notes generated by the simulation study's subject, and audio transcripts of the standardized encounters were collected and analyzed by independent physician reviewers. These reviewers manually identified clinical concepts and subjective content differences present in each of these dataset items. Study investigators then adapted and utilized existing tools to identify clinical concepts from the simulation dataset and compute semantic relatedness measurements. Measurements of semantic relatedness, semantic similarity and semantic distance were computed. These measurements were used in assessing transfer of information from case description to clinical note.

Healthcare provider subjects in the simulated clinical encounters navigated a series of standardized clinical encounter simulations where they were randomized to different documentation tools to generate clinical notes. This study's investigators then analyzed the data collected from simulations featuring either dictation or a locally-developed computer-based documentation (CBD) tool. The CBD tool, StarNotes generates narrative text documents and enables users to access predefined documentation templates.

By analyzing data collected during simulation encounters for two disparate documentation systems, this project validated new information flow measures. These measures reflect the documentation system's ability to capture clinical content, and provide the means to compare the two documentation systems. Through clinical concept identification and semantic measurement computations, this study depicts information flow in a simulated clinical encounter. This analysis also identifies distinctions in clinical note content possibly originating from differences in documentation tools.

CHAPTER II

BACKGROUND

Communicating and Capturing Information in a Clinical Setting

In a typical clinical encounter, an exchange of information occurs between a patient and a healthcare provider. This exchange of information can include direct communication between the healthcare provider and the patient (2,16,17). Patients will indicate their problems or concerns and elicit advice from the healthcare provider on what can be done to remedy their situations (4,16–19). A healthcare provider can observe and examine a patient to obtain additional information. Other sources of information besides the patient may also be available during the clinical encounter. For example, the healthcare provider may refer to the patient's existing medical record. Previous clinical notes, information from laboratory results, or medication lists may provide useful information to the healthcare provider. There may also be situations where the patient is accompanied by a relative or caretaker, who may serve as another source of information (3,9,14,17,19).

As the clinical encounter proceeds, healthcare providers may then take verbally expressed information in tandem with non-verbal findings in order to catalyze additional questions for further clarification and refinement (3,16,17). Most clinical encounters will also incorporate a diagnostic physical exam (18,20). Any newly obtained information with may then be synthesized with the healthcare provider's existing clinical knowledge, and any relevant clinical history items in the patient's medical record to formulate a set of diagnoses, an assessment, and a follow-up plan for the patient (18–20).

An Overview of Clinical Documentation

"Clinical documentation" records healthcare providers' observations and impressions of patient care (15). Clinical documentation accompanying patient care comes in many forms. Healthcare providers create documentation that summarizes clinic visits, telephone calls to patients, and other clinical encounters. This clinical documentation may help assist both present and future healthcare colleagues with patient care management (13,21–23). A clinical note is a type of clinical documentation that captures information from a patient interaction. These clinical notes persist with the medical record and serve to guide other healthcare providers in their decision-making process for the patient (2,9). The healthcare provider formulates therapies and treatment regimens after consulting existing clinical notes in a patient record, and then summarizes rationale for new care plans (11,13,15,21–23).

Factors Affecting Clinical Documentation

Clinical documentation achieves several objectives. These objectives include ensuring delivery of patient care (7,11,12,16,21,23), meeting local and federal clinical documentation requirements (9,15,24), and to protect against legal action (23,25). The amount of time available to a healthcare provider for a given clinical encounter may also impact documentation practices (7,13,26).

In a given clinical note, a healthcare provider generally attempts to capture patient information that will be germane to both present and future care. The healthcare provider is also attempting to meet legal requirements (9,15,24) and provide sufficient information for billing purposes (4,5,11–13,15,21,22). To ensure that appropriate patient care is delivered, a healthcare provider may offer a plan for the patient within a clinical note, as well as the rationale surrounding the plan (7,11,12,16,21,23). Other healthcare providers responsible for the patient may review the clinical note and use it in shaping their own clinical decision-making. In this capacity, the clinical note can serve as a primary means of communication between different health professionals (12,16,21,23). Healthcare providers must also meet the requirements set forward by institutional, regional, and federal policies with respect to medical documentation (7,25,27–30). Healthcare providers are also tasked with specifying diagnoses in their clinic notes, and in clarifying any diagnostic procedures completed during their encounter with a patient. Providers may also feel compelled to provide additional documentation for the sake of protecting against potential legal action, as a form of "defensive medicine." In practicing defensive medicine, healthcare providers may include detailed information and descriptions in their clinical note in order to mitigate the potential for future legal actions by their patients (23,25).

Time constraints must also be considered when exploring the contents of a clinical note and the intentions of a healthcare provider in documenting an encounter. Lack of time in a patient encounter may cause a healthcare provider to be more selective with the content included in a clinical note (7,13,26). Alternatively, the healthcare provider may defer documenting certain elements until after the encounter has already ended. Deferring documentation until an encounter is complete may result in a healthcare provider incorrectly recalling and then documenting patient information (1–3,5,16). Clinical settings in the United States generally afford healthcare providers a limited amount of time for each patient encounter (31). The healthcare provider may be left with little time to document the encounter after completing the history-taking and the physical exam process (14,17,32,33). In turn, healthcare providers may document in parallel to their interaction with the patient. Alternatively, healthcare providers may complete their clinical documentation tasks at a time outside of their normal working period. Healthcare providers must then optimize the amount of time spent meeting documentation objectives (5,7,32,33).

Clinical Documentation Tools

Specific types of tools support the process of clinical documentation (6–8,12). The simple method of handwriting a clinical note has existed at least since the fifth century B.C.E., with Hippocrates and his colleagues pioneering the idea of portraying a patient's clinical course in the medical record (34). Clinical notes in modern times have become more primarily focused on specific patient problems (6,13,35). Modern clinical notes also frequently incorporate specific structuring schemes. Examples of these schemes include SOAP (subjective-objective-assessment-plan) and SBAR (situation-background-assessment-recommendation) (5,9,24). Structuring clinical notes may improve the standardization of clinical documentation practices (9). Form-based templates have also emerged to further the organization of clinical notes (36,37).

Another commonly used method for clinical documentation involves dictation with human or machine transcription. As with paper-based tools, dictation-based tools are also widely used in clinical settings for capturing patient encounter information. The process of dictation involves a healthcare provider vocally conveying clinical information into an audio recording device. The audio is then transcribed into a text document by a transcriptionist or by speech-recognition software, and is then relayed back for review by the originating clinic, institution, or healthcare provider in some manner (30,36,38). Speech-to-text software programs have also recently been introduced that can also help complete the dictation transcription task (39,40).

The introduction of computers to the field of medicine has driven development of computer-based documentation (CBD) tools (41–49). Ledley (41) and Slack et al. (44) were among the first to describe a role for computers in assisting medical documentation in 1966. Slack demonstrated the possibility of CBD through the "Laboratory Instrument Computer," (LINC) which was capable of recording histories and physical examinations (44,45). This was followed in 1977 by Maultsby Jr. and Slack's extension of LINC to enable capture of psychiatric histories (42), as well as a CBD system developed by Stead et al. for capturing obstetric visit information (46). Hammond et al. also developed a CBD system as part of a computerized medical record called TMR at Duke in 1980, and presented issues of system growth and evolution (48). In 1983, Pryor et al. reported on a new CBD tool, the HELP system, which featured documentation functionality as well as logic for assisting with medical decision making (43).

Early forms of CBD software largely mimicked their handwritten counterparts (12). Documentation software has since advanced to incorporate automation features. These automation features can include text macros or text auto-completers. Shortcut-based selectors and auto-completers can enable software users to rapidly substitute abbreviated text with longer phrases or terms where needed. Some clinical documentation software can also integrate with existing health information system backbones. For instance, certain CBD tools enable quick inclusion of laboratory data, vital signs information, or prior clinical encounter elements, directly into a clinical note without the need for retyping information or through a copying and pasting process (12,30). Specialized templates can also be designed for use within CBD tools. Similar to paper-based versions, these templates encourage standardized reporting of patient information (36). Most CBD tools generally feature a mix of structured entry and unstructured entry components. Unstructured entry allows users to document any information, generally without restriction. In contrast, users of structured entry tools select from a list of predefined elements.

Structured entry components allow capture of clinical information through the application of a clinical interface terminology (50–53). A clinical interface terminology is a "collection of health care–related phrases (terms) that supports clinicians' entry of patient-related information into computer programs," and is implemented by the host CBD application (51). The clinical interface terminology connects a healthcare provider's conceptualization of a clinical term within a CBD application to one defined in a controlled vocabulary (50–52,54–58). Unstructured data captured by a CBD tool usually includes any clinical information entered as narrative text within the tool (26,35,66,67).

Documentation tools vary in their usability. Healthcare providers should be able to navigate and complete a paper based form easily (6,12,14,70). However, CBD and dictation-based tools may require additional training and hands-on experience before the healthcare provider is fully comfortable with them. Healthcare providers that are exposed to certain documentation tool types during their clinical training periods, or while working in a professional capacity, will more easily adapt to using similar documentation tool types (7,32,71). The amount of time needed to document an encounter can then considerably vary as based on a healthcare provider's experience with a given documentation tool.

Clinical Documentation System Evaluation

There is significant interest from healthcare enterprise stakeholders in defining objective measures for comparing and contrasting clinical documentation systems (6,27–29). Expectedly, these stakeholders desire documentation systems that improve patient outcomes, increase patient safety, and reduce medical costs (8,74). Stakeholders desire tools and methodology for efficiently evaluating clinical documentation systems available for deployment. Effective evaluation of a clinical documentation system in turn requires a deep understanding of the information it is being used to capture. Specifically, an understanding of the information flow that occurs from a patient encounter to the clinic note is critical in developing effective evaluation techniques.

A pivotal issue surrounding the evaluation of documentation systems is in understanding the process of clinical note generation and its resulting content (3,6,8,74,75). Establishing clear relationships between a clinical documentation tool and its impact on resulting clinical note content remains an active field of research (3,6,8,11,13,75). Previous studies have examined specific functionalities of documentation tools and have not assessed these tools in a cohesive manner (54,76–79). Measuring the effectiveness of a clinical documentation tool requires an evaluation methodology that assesses the documentation tool as a whole.

The healthcare provider's specialization and expertise with certain documentation tools will likely determine the content of clinical notes (5,7,14,26), yet the documentation tool also impacts note content (6,10,75). For instance, a documentation tool could impact note content by offering a healthcare provider a pre-defined template. The healthcare provider could then be inclined to select clinical terms available in the template (8,36,37). Medical terms that may be irrelevant to clinical management can then be captured in this way and lead to over-documentation of the clinical encounter (31,80). Similarly, clinical terms that are relevant to a clinical encounter but are not included in a pre-defined template may remain absent from the final clinical note. This scenario results in under-documentation of the clinical encounter (31,80,81). Other features of a documentation tool may lead to over-documentation and under-documentation as well. Nevertheless, no recent efforts attempt to comprehensively evaluate documentation tools. By understanding the interplay of documentation tool functionality, factors leading to under-documentation and over-documentation can be better exposed and remedied.

CHAPTER III

PROJECT SPECIFIC TOOLS

Overview

The study presented in this thesis examined the flow of information from a patient, through a healthcare provider, and then to a resulting clinical note within the context of a simulated clinical environment. Investigators used a simulated clinical environment to help clearly assess the impact of a clinical documentation tool on resultant note content, and to mitigate covariate impact on documentation quality. The actors in the simulated environment, called standardized patients, followed a standardized patient scenario description (PSD) (Chapter IV). Independent physician reviewers then identified and traced clinical concepts from PSDs to notes generated by the physician subjects. The study then mapped clinical concepts the SNOMED-CT controlled vocabulary to facilitate tracing of information flow. Computation semantic similarity metrics provided a measure of how clinical concepts changed as they progressed from PSD to resultant note.

Clinical Simulation

In a simulation study, an actor portrays the role of a real-world patient, as a standardized patient (SP). These actors follow a standardized script of dialogue and interact in a prescribed manner with the simulation environment's subjects. Researchers create the standardized script, and include all necessary details for the actor to play the role of the patient. This includes specific responses to questions that would occur during a clinical encounter, details of the patient's clinical history, as well as a description of mannerisms and mood that the actor must convey. Very few elements of the actor's role remain unscripted. Researchers also discourage actors from offering impromptu elaboration of any clinical topics not specified by the script. Standardization of the actors' behaviors and their responses to clinical inquiries is achieved through rigorous training (82–84).

Medical education curriculums routinely incorporate simulation environment-based learning. These simulations have been utilized to help novice healthcare professionals refine their communication abilities and clinical examination skills (82,83). For example, actor patients are used in Objective Structured Clinical Examinations (OSCE) and in the United States Medical Licensing Exam (USMLE) (85–87). Multiple prior investigations demonstrate the reliability of these types of environments in simulating real-world clinical environments (82–84). Recently, Williams found that SPs bear strong realism in their portrayals of real world patients and can accurately portray a variety of clinical cases in a reliable manner (88).

The advantage provided by a simulated environment is the degree of control available for testing, training, and investigative purposes. Standardized exam administrators can tweak the conditions of a simulation environment in order to minimize or eliminate all distracting factors such as ringing telephones or overhead intercom paging. Investigators can then hone in on specific dependent variables of interest. Moreover, the use of actors in place of real world patients mitigates patient harm and clinical risk (82,83,89).

The simulated environment also lends itself to clinical research purposes by enabling numerous opportunities for safe observation and review (84,90–94). For example, Howard et al. assessed the abilities of sleep-deprived anesthesiologists in a simulated clinical environment (90). Investigators were free to examine anesthesiologist performance without subjecting a real patient to any danger. Research can record video and audio from simulated clinical encounters for deep analysis. Robust auditing of each simulation encounter then becomes feasible (82,83).

SNOMED-CT

This project relies on the "Systematic Nomenclature of Medicine - Clinical Terms," SNOMED-CT (95–98), as it best approximated the clinical concepts identified by reviewers during the dataset analysis phase of this project (Chapter V). The medical terms included in SNOMED-CT facilitate standardized coding, reporting, retrieval, and analysis of various forms of clinical data (95,98). SNOMED-CT is composed of a set of clinical concepts, terms, and relationships between these elements, organized into a hierarchical format. Table 1, adapted from (98), lists the highest level concepts present in SNOMED-CT.

Table 1. Highest level concepts present in SNOMED-CT.

▪ Clinical Finding ▪ Observable Entity ▪ Procedure ▪ Qualifier Value ▪ Body Structure ▪ Pharmaceutical or biologic product ▪ Substance ▪ Organism ▪ Specimen	▪ Event ▪ Social Context ▪ Situation with Explicit Context ▪ Physical Force ▪ Physical Object ▪ Environment or Geographical Location ▪ Staging and Scales ▪ Record Artifact ▪ Special Concept ▪ Linkage Concept

Different levels in the SNOMED-CT hierarchy reflect different degrees of concept granularity. Concepts in the hierarchy are chained together through "is-a" acyclic relationships. Unique numeric identifiers accompany all concepts and can link multiple synonymous terms. Each concept has a unique "fully specified name," which is the preferred form of a clinical term and includes a semantic type tag. The UMLS defines and maintains semantic types, which serve as broad subject categories for concepts (99). Some examples of semantic categories include "clinical finding," "procedure," and "disorder." Multiple clinical terms can act as synonyms for one unique fully specified name, as well (98).

The basic relational unit in the SNOMED-CT hierarchy takes the form of a triplet, expressed as [concept "A" - relationship type - concept "B"]. Domain experts manually assign relationships between concepts for only known valid assertions. The representational structure of

SNOMED-CT allows for post-coordination of concepts. Concepts that do not presently exist within SNOMED-CT can be constructed as needed by chaining existing concepts and relationship types together (95,98). For example, there is no unique concept for the clinical term "backache aggravated by forward bending." Instead, the "backache (finding)" concept can be post-coordinated with the concepts "aggravated by (attribute)" and "forward bending (observable entity)".

Semantic Similarity and Relatedness Metrics

"Semantic relatedness" is defined as the degree of relatedness shared by two concepts (100). For example, thiazolidinedione treats diabetes, making the clinical terms "thiazolidinedione" and "diabetes" semantically related. Semantic relatedness metrics compute the degree of the relatedness between pairs of concepts (100–102). The term "semantic similarity" can be confused with semantic relatedness, but is in fact a distinct measure. Pedersen and colleagues (100) define semantic similarity as a "special case of relatedness that is tied to the likeness (in the shape or form)" of two clinical concepts. Semantic similarity assesses the overall "likeness" of two concepts and reflects their taxonomical proximity to one another. The terms "acute respiratory infection" and "bronchitis" are both pulmonological disorders and demonstrate semantic similarity.

Semantic similarity measures are highly adaptable to the biomedical domain. Their biomedical adaptations can be grouped into several categories: based on taxonomical structure, based on information content measures, derived from context vector relatedness measures (100–103). Many of these measures utilize the principle of a least common subsumer (LCS). The LCS is the closest "parent" concept of the two concepts in a similarity computation.

Similarity measures rely on a given taxonomy's hierarchical organization and incorporate computations of path-length between two given concepts. One of the earliest metrics was put forward by Rada and colleagues (104), which validated a path-based measure for MeSH-based semantic networks. Wu and Palmer (105) later developed a path-based measure that normalized the measure by hierarchy depth of each of the pair of concepts. Leacock and Chodorow (106) offer a slight variation to Wu and Palmer by including the concepts themselves within the path measure. Work by Li and colleagues (107) further adapts path-based measures by incorporating a non-linear method for accounting for hierarchy depth. The main benefit of taxonomical similarity measures is that they are simple to implement and understand. They also do not require any domain data or corpus based information to conduct computations as everything is dependent on ontological relationships. This is simultaneously the primary drawback for these measures, as they rely primarily on is-a relationships. These measures are also highly dependent on the coverage of the terminology and will suffer in instances of poorly defined sub-sections of ontology hierarchies (100,101,103).

The second category of similarity measures relies on a biomedical term's information content. Batet and colleagues define information content as measuring "the amount of information provided by a given term based on its probability of appearance in a corpus" (101). The information content measure is the inverse relationship between the frequency of a word and its informativeness. Words that occur infrequently in a given corpus are more informative. Several of these metrics are derived from Resnik's formula (108), which computes the similarity of two concepts as the amount of taxonomical information shared by the pair. Lin (109) demonstrates one such extension of Resnik's work, in a similarity computation that relates Resnik's computation to the sum of the concept pair's information content. Jiang and Conrath (110) also adapted Resnik's formula, and provide a method for computing the dissimilarity between two concepts. The advantage of an information content similarity measure is that it relies on a real-world corpus in its calculation. However, these measures, like taxonomical methods, are also reliant on is-a style relationships in determining final similarity scores.

Context vector relatedness metrics assert that two terms have a high degree of similarity if the terms frequently exist in similar contexts. Constructing these vector measures requires having some form of corpus where terms are present (100,101,103). The Mayo Clinic Corpus of Clinical Notes has typically served as the default corpus for these types of measures when working in the biomedical domain. These types of vector measures excel in providing a high degree of face validity to domain experts. Nevertheless, their output quality is tightly intertwined to the amount of manual fine-tuning and post-processing done to the corpus as well as to the overall amount of information available in the corpus (101).

Sánchez and Batet (103) offered an alternative, more cohesive approach to semantic similarity measure computation. They developed metrics that redefine existing taxonomical path-based metrics in terms of information content. Their measures compute an intrinsic information content value. This value captures ontological relationship information, such as the presence of common subsumers, which would not be ordinarily included in a path-based metric equivalent. Sánchez and Batet accomplished this by creating an approximation for path length between two concepts, and computed it as the cumulative difference in information between the concepts. Subtracting the information content of the LCS of the two concepts from the information content of the concept alone yields this measure. Sánchez and Batet then proceeded to apply this method in order to redefine existing path-based ontological measures. Some examples of these redefined measures include intrinsic content versions of Leacock and Chodorow, Lin, and Rada. Sánchez and Batet also created intrinsic content versions of a simple minimum path measure, of a Jaccard distance measure, and of Sokal's measure (111).

The cTAKES Pipeline and yTEX

Existing open-source software can facilitate computations of semantic similarity metrics. The clinical Text Analysis and Knowledge Extraction System (cTAKES), a natural language processing (NLP) software pipeline (112), combined with the Yale cTAKES(yTEX) extensions, enable a flexible approach to semantic similarity computation (113,114). Specifically, yTEX offers a robust framework for computing a variety of semantic similarity measures relevant to the biomedical domain.

The semantic similarity measures provided by yTEX are compatible with the majority of biomedical ontologies available. The developers of yTEX evaluated their measures with concepts originating from the UMLS Metathesaurus, MeSH, and SNOMED-CT. The yTEX pipeline allows implementation of its semantic similarity functionality in several manners. Users can instantiate and run the yTEX pipeline on a local computer via a command-line interface, or incorporate it into a Java programming language based custom software. The yTEX semantic similarity metrics are also accessible via a RESTful web interface. As with other common RESTful web interfaces, the yTEX web service utilizes HTTP, URI, and XML web standards. On submitting a set of concepts for comparison to the yTEX web interface, the yTEX web service will return a XML payload to the accessing client. The payload will contain results from the initial client request (114).

The present study computed the semantic similarity measures listed in Table 2 via yTEX. The current study's investigators selected all available path-finding measures from yTEX as they all provide fast and reliable approximations of similarity between clinical terms. The investigators also selected information-content based computations to account for real-world utilization of clinical terms.

Table 2. Semantic similarity measures available via yTEX and selected for the present study.

Path-finding	▪ Wu & Palmer ▪ Leacock & Chodorow ▪ Path ▪ Rada
Information Content Based	▪ Modified Lin ▪ Modified Leacock & Chodorow ▪ Modified Path (Jiang & Conrath) ▪ Modified Rada ▪ Modified Jaccard ▪ Modified Sokal & Sneath

CHAPTER IV

CLINICAL SIMULATION STUDY DESIGN

Study Design Overview

This study used data generated through a series of simulated clinical encounters. Investigators selected a group of 32 healthcare providers as the subjects for the encounters. Each subject sequentially interacted with four different standardized actor patients. The subject then used one of four documentation tools to record the simulated clinical encounter. Figure 1 provides a diagram of the simulation study's design. Independent physician reviewers analyzed the patient scenario descriptions as well as the clinical notes resulting from the simulated encounters. These reviewers traced the flow of clinical concepts from patient scenario description, through the healthcare provider subject, to the resultant clinical note.

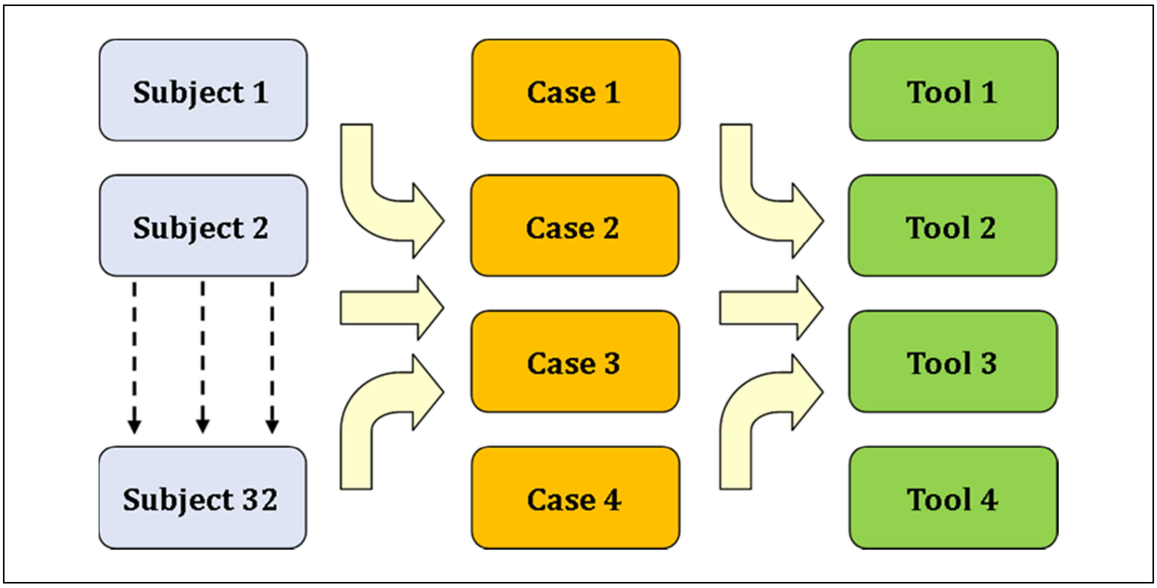

Figure 1. Clinical simulation study design overview.

Study Design Specifications

The present investigation utilizes data generated through a series of simulation environment studies. Vanderbilt University Medical Center (VUMC), a large primary and tertiary academic medical center hosts the simulation environment. The VUMC Program in Human Simulation features the Center for Educational Learning Assessment (CELA), which offers an interactive simulation environment with standardized patient actors for the purposes of teaching and assessing interviewing skills, physical exam techniques, communication skills, and the interpersonal skills of healthcare providers.

The simulation studies featured four distinct clinical scenarios, where cases were designed to emulate new patient visits to a general internist and will cover both acute and chronic medical conditions requiring documentation. The case scenarios were developed through a collaborative effort of content and education experts using an established case template. All four cases were designed to evaluate the same elements, while including different clinical situations that could in turn potentially affect the various methods for clinical documentation. A total of 32 physician subjects participated in this portion of the study. Each physician utilized one of four different documentation tools for each of the four encounters. Specifically, physicians created clinical notes through handwritten means, dictation, a computer-based documentation system called StarNotes, and a separate CBD system called Quill.

The StarNotes system offered users an semi-structured, narrative-text style computerized documentation environment, while Quill offered users a more structured, template-driven documentation environment. The StarNotes tool featured a template for the physical exam section (Figure 2). Simulation study subjects using the template were able to fully modify the pre-existing terms in the template. Investigators also videotaped these studies and captured all audio from the simulated encounters. The present study focused on data from the StarNotes system and dictation encounters.

PHYSICAL EXAMINATION:
CONSTITUTIONAL: awake and alert; well developed; well nourished;

HEAD/NECK: normocephalic, atraumatic; AF S&F; neck supple without tenderness or masses
EYES: PERRLA, conjunctiva clear, sclerae anicteric
ENMT: ear canals patent; tympanic membranes pearly gray with good light reflex bilaterally. Nares patent without discharge and turbinates without bogginess or injection. Gums without erythema, edema, exudate. Oropharynx pink without lesions, or erythema. Soft Palate without lesions. Mucous membranes moist. Tonsils normal and symmetric, without exudate.
RESPIRATORY: CTA bilaterally, moving air well, breath sounds symmetric
CARDIOVASCULAR: RRR, normal S1 & S2, no MRG
GI: soft, nontender, nondistended, normal bowel sounds, no hepatomegaly, no splenomegaly
LYMPHATIC: no lymphadenopathy in the cervical chains
SKIN: no visible rash
PSYCHIATRIC: alert and oriented, follows simple commands, affect appropriate

Figure 2. Physical exam template available via the StarNotes system.

To trace information flow in the simulated clinical encounters, this project defined and calculated a measure of clinical concept permeability. The permeability of a clinical concept is its ability to travel from a patient to a resultant clinical note, without being interrupted or altered in any manner. In a simulated clinical encounter, concept permeability is represented as the transfer of clinical terms from a pre-defined case scenario to the end resultant clinical note. Information flow is then assessed in terms of the permeability of clinical concepts.

Standardized Case Scenarios Overview

From a set of extensive behavioral task analysis studies and focus group sessions, the clinical simulation studies' investigators determined several criteria essential to healthcare providers utilizing a clinical documentation tool. These behavioral task analyses provided a detailed account of how healthcare providers use clinical documentation tools. Specifically, prior studies demonstrated that documentation tools must be readily efficient, accurate, and content expressive (11,71).

Healthcare providers seek clinical documentation tools that are highly efficient (71). The tools should require no more than a minimal amount of time and effort for completing a clinical documentation task. Additionally, tools should be accurate and enable a healthcare provider to correctly capture a clinical case. Researchers have also found that healthcare providers seek clinical documentation tools that allow capture of expressive content (11,71). Content expressivity can be achieved through narrative text capture functionality (11).

Reliably assessing these core elements for a given documentation tool dictated a robust evaluative framework. To this end, the preliminary studies' investigators formulated four diverse standardized patient scenarios for use in a simulation environment. These scenarios were designed to be reflective of real-world clinical encounters, where various environmental factors regularly interact with individual healthcare provider attributes to affect the resulting clinical documentation. Collectively, the scenarios offered a well-developed, reproducible modality for comparative assessment of documentation tools.

Standardized Patient Scenario Description #1

The first scenario derived focuses on a patient with the chief complaint of back pain. Most specialties of physicians encounter back pain patients. As it is associated with numerous acute and chronic etiologies, arriving at a correct diagnosis may be difficult if the healthcare provider did not obtain a potentially time-consuming, comprehensive patient medical history. Coupled with a physical exam that requires notable patient manipulation and techniques to determine a diagnosis, a back pain patient could absorb a considerable portion of a healthcare provider's allotted time for an encounter. Here, it was expected that a documentation tool's efficiency would be especially important to the healthcare provider.

Documentation expressivity was also relevant to this case, as certain back pain etiologies are often associated with specific phrases conveyed by the patient. For example, a description of "knife-like" acute-onset pain may more rapidly help distinguish nephrolithiasis from a musculoskeletal disorder. Healthcare providers could also relate their level of concern for the back pain experienced by the patient. This case scenario featured a patient with a lumbar disc herniation, which could potentially evolve into a debilitating condition if not quickly addressed. Narrative linguistic nuance from a healthcare provider can help relay the urgency of the patient's condition to other clinical team members.

This scenario also stressed documentation accuracy for reasons similar to those aforementioned. Accurately capturing physical exam signs was critical to diagnosing this case. For instance, without accurate documentation of a straight leg raise sign or absence of costovertebral tenderness, appropriate case management can be difficult to determine.

Standardized Patient Scenario Description #2

The second scenario featured a patient arriving to the clinic possessing a history and physical exam consistent with pneumococcal pneumonia. Her chief complaint on arrival is of a persistent cough. Documentation efficiency is a critical element for the encounter, as eliciting a full history is time consuming yet pivotal in focusing on a specific set of differential diagnoses for cough. Moreover, certain aspects of her history relevant to her true diagnosis may remain unaddressed, unless the healthcare provider is thorough in history-taking and documentation. Specifically, a practitioner may overlook her volunteer work at a rescue mission in a hurried encounter, potentially missing recognition of the clinically important differential diagnosis of tuberculosis.

The documentation's expressivity expected for this scenario to portray the healthcare provider's urgency in seeking treatment for the patient. Availability of this expressivity in the documentation can again assist the medical team members in understanding the need for an expedited pace for laboratory and radiographic orders, as well as medication administration. This case may even warrant an inpatient hospital stay, a situation where initial clinical documentation is vital in shaping the patient's treatment plan.

Several components of the patient's history are necessary for adequate clinical management, highlighting the need for documentation accuracy. For example, the time, duration, and onset of symptoms, as well as conveyance of mucous coloring, past similar episodes, and smoking status are all relevant to clinical decision-making.

Standardized Patient Scenario Description #3

The third scenario involved a patient with a complaint of worsening severe headaches and an ultimate diagnosis of migraines. This case warranted eliciting an extensive family and social history in addition to the history of present illness, likely at the cost of encounter time. For this case, healthcare providers could neglect critical alternative diagnoses to migraines in their documentation if the tool's efficiency is questionable. For instance, by not addressing conditions such as multiple sclerosis or other neurological disorders within their documentation, healthcare providers do this type of patients a disservice.

The element of documentation expressivity helps capture the quality and intensity of the migraine symptoms experienced by the patient. Similar to the discussed back pain patient from above, the patient's choice phrasing can assist practitioners in diagnosis and healthcare decisions. A patient remarking that she visualized "flashing lights" concomitant to her headaches is different from a patient describing the presence of "floaters."

This scenario also enabled evaluation of documentation accuracy through several case elements. For instance, the detailed timing and duration of the headache and its related symptoms assist in diagnosis refinement. Accurately capturing associated environmental factors is also important for documentation, due to their known ability to trigger classical migraines.

Standardized Patient Scenario Description #4

The fourth scenario centered on a new patient visit by an individual seeking diabetes care. The patient presented with an extensive medical and social history, highlighting the case's ability to evaluate documentation tool efficiency. It was expected that eliciting the numerous details of the patient's history would occupy a significant portion of the encounter time.

Nevertheless, obtaining these history elements was necessary in revealing the coinciding depression and multiple social issues the standardized scenario's patient was experiencing.

The detailed nature of this diabetic patient's case also offered an opportunity for evaluating a documentation tool's ability to capture expressivity. It was expected that tools enabling capture of expressive content would more vividly relay the harried and agitated yet depressive mood of the patient to other healthcare providers. Less expressive tools would stumble in realistically capturing the patient's emotional state, potentially altering clinical management downstream from this initial encounter.

As with the preceding cases, documentation accuracy was essential to this case's clinical management. Specific details surrounding the patient's recorded blood glucose levels, such as values and times measured, are necessary in tailoring clinical management. Moreover, accurately conveying the patient counseling conducted during the encounter was also important, such that future healthcare providers could ensure the patient remained compliant with medical recommendations.

Study Design Conclusions

The clinical simulation study's investigators derived a set of standardized patient scenarios that would expose a documentation tool's impact on clinical note content. The cases also enabled assessment of a documentation tool's efficiency, accuracy, and ability to capture expressive clinical terms. The study's design and the dataset resulting from the simulations facilitated the process of tracing information flow and in assessing clinical concept permeability for the given standardized patient encounters.

CHAPTER V

METHODS FOR TRACING INFORMATION FLOW

Overview

Clinical simulation experiments provided the dataset analyzed for achieving the goals of this study. Healthcare providers, designated as the studies' subjects, generated notes during the study using the either a computer-based documentation tool or a dictation-based documentation tool. The dataset also included patient scenario descriptions and the simulations' audio transcripts. The scenario patient descriptions were standardized medical cases developed by a set of physicians and clinical simulation experts, as part of a previous study. Independent physician reviewers identified clinical concepts present in the patient scenario descriptions and in the resultant clinic notes. The physician reviewers then mapped these concepts to SNOMED-CT codes. This study defined concept permeability as the total number of concepts present in both the SPD and in the resultant note. By aggregating several SNOMED-CT-based semantic similarity metrics, this study quantified partial concept transfer.

Materials

The patient scenario descriptions, simulated encounter audio transcripts, and resultant clinical notes from the collected dataset were loaded and processed into Atlas.ti 6.2.27, a qualitative software package. The software package was installed on a PC with a 2.83 GHz Intel Core2 Quad CPU and 8 GB DDR3 RAM, running Microsoft Windows 7 64-bit Enterprise Edition. Scripts created for data processing needs were written in Python 2.7. A MySQL (version 5.5.28) database was also established for maintaining processed data elements in an accessible repository.

Methods

Methods Overview

To trace information flow in the simulated clinical encounters, independent physician reviewers manually identified clinical concepts in the standardized PSDs and in the resultant clinical notes. A qualitative analysis software tool, Atlas.ti, helped manage the dataset of PSDs and resultant notes. A series of Python scripts then processed the Atlas.ti output to identify clinical concepts present in both the PSDs and the resultant notes. Investigators then examined dangling concepts that remained unmatched in the PSDs and resultant notes. Python scripts facilitated reconciliation of these dangling concepts through an application of semantic similarity measures. To utilize semantic similarity measures, investigators mapped clinical concepts to their SNOMED-CT equivalents. Investigators then created visual representations of the overlap in concepts found in PSDs and resultant notes.

Manual Concept Identification

Manual concept identification involved independent physician reviewers identifying clinical concepts from the patient scenario descriptions, the audio transcripts of each simulated patient encounter, and the clinical note generated by each CELA study subject. Any phrase, term, or quote contained within the text of the resulting documents deemed clinically relevant by the reviewer was marked as a clinical concept. Specific rules were utilized to assure consistent concept identification between reviewers and across different document types.

First, several note section categories were determined. Categories were partially based on commonly found sections within the SOAP note structure. The core note sections included: 1) history of present illness, 2) past medical history, 3) other history, 4) physical exam, and 5) assessment and plan. The past medical history encompassed several sub-sections, including medication history, procedure history, and vaccination history. The other history category included social history and family history.

Concept names were structured in the following manner: [root finding - qualifying elements]. Note section categories determined additional concept naming features. For concepts in the history of present illness section, concepts followed the general structure. Complex concepts were broken down into multiple simpler concepts wherever practical. The goal was to minimize post-coordination in the concepts being identified. The multiple simpler concepts were then mapped to the same quote. For example, the text "There is shooting pain down the right leg, down to the ankle, in the middle of the leg," would be mapped to two concepts: "back pain radiation quality shooting" and "back pain radiation right leg."

For concepts identified in the physical exam section, reviewers began each concept name with the anatomical location or system of the clinical finding, followed by any applicable qualifying elements. As with concepts identified for the history of present illness section, complex concepts were broken down into simpler concepts when sensible. Some examples of anatomical locations included abdomen, back, cardiac, extremities, eyes, lymphatic, musculoskeletal, and neurological.

For concepts identified in other sections of the note text, the concept name was prepended by the note section name, or the note sub-section's name, where applicable. For example, if the standardized actor patient was noted to have had knee surgery in the resultant note, a concept of "procedure history knee surgery" would be identified by the reviewer. By prepending concepts with note section and sub-section in this manner, currently active clinical problems will not be inadvertently mapped to previously occurring problems.

Each independent physician reviewer utilized the Atlas.ti software for identifying clinical concepts. Atlas.ti is a qualitative software package, generally used for analyzing multiple documents and document types at once by a group of researchers. The Atlas.ti software enabled each reviewer to annotate the collected clinical notes, case descriptions, and audio transcripts inline, independent of the other reviewer. Reviewer identifications, additions or modifications to the data could then be tracked and analyzed, while also persisting all attribution information. The software was largely selected for its ability to maintain multiple document information in this collective manner. Moreover, the software enables output of the reviewed dataset as structure XML, facilitating downstream analysis.

The "hermeneutic unit" describes a project file used by Atlas.ti and is the primary file containing all other documents and items, labeled as "primary documents." For this study, reviewers organized all simulation study dataset elements as primary documents into a shared hermeneutic unit. Quotes within the text of the primary documents were then mapped to clinical concepts, which were represented as "codes" within the hermeneutic unit. To maintain note section origin information, these clinical concept codes were collected into "families." Each primary note section was represented by a family name within the hermeneutic unit.

XML Parsing and Concept Information Extraction

On manual review completion of the simulation experiment's dataset, the reviewed data in the Atlas.ti hermeneutic unit was exported as a structured XML file. A Python script was written to parse the structured XML into elements of interest. Specifically, lxml (115), the BSD-licensed Python library, was utilized to parse the hermeneutic XML file into a tree data-type object. Once in tree format, the script extracted all reviewer identified concepts, details for each of these concepts, and their accompanying quote information. Details of interest included the concept's creation timestamp, the reviewer identifying the concept, its originating note section, and the quote associated with the concept. Quotes from the XML file were extracted along with information pertaining to their originating document. Originating document information included the scenario patient description being evaluated, the documentation tool in use, and the simulation study subject creating the document.

Once information from structured XML was parsed via Python scripts, it was uploaded into a local, restricted-access MySQL database. Separate tables were created to store information on note section ("families"), clinical concepts ("concepts"), document quotes ("quotes"), and the primary documents ("docs"). Foreign keys were created for each of the tables to enable relational mapping of data elements across all tables. A standard SQL query would then enable retrieval of any information needed for analysis and tracing information flow. Upload of data into the local MySQL database was achieved also through Python scripts.

Determining Concept Permeability

The investigators calculated concept permeability from the patient scenario description to the resultant note. This process is summarized in Table 3. If a concept was present in both the patient scenario description and in the resultant note, the concept was determined to be fully permeable, with a score of 1.0 for permeability. When a concept was present in the patient scenario description but not in the resultant note, it was designated as a dangling concept. Similarly, a concept found in the resultant note, but not found in the patient scenario description, was also determined to be a dangling concept (Appendix A). Dangling concepts required additional analysis to determine their permeability scores. This project adapted semantic similarity metrics for reconciling dangling concepts with known concepts.

Table 3. Concept permeability determination process.

Patient Scenario Description	**Resultant Note**	**Classification & Action**
Concept is present	Concept is present	▪ Concept is fully permeable ▪ Record score of 1.0
Concept is present	Concept is absent	▪ Dangling concept ▪ Apply semantic similarity measures
Concept is absent	Concept is present	▪ Dangling concept ▪ Apply semantic similarity measures

SNOMED-CT Mapping

To use existing semantic similarity metrics, the identified concepts from the simulation dataset were mapped to SNOMED-CT codes. SNOMED-CT was selected because it best approximated the concepts identified by reviewers in the hermeneutic unit, and allowed calculation of semantic similarity between clinical concepts (101,103). Investigators mapped clinical concepts to SNOMED-CT codes in a semi-automated fashion. A Python script was created to process each existing concept against an online SNOMED-CT database of concepts. The online SNOMED-CT database selected was one maintained by Dataline. Dataline provides access to a current SNOMED-CT database through a standard web service, SNAPI (116).

The Python script queried SNAPI for the best result to each concept requiring conversion to SNOMED-CT. The SNAPI results were weighted in terms of closeness of match of originating string, and by concept type. Concepts present in SNOMED-CT are all designated with a specific concept type. The concept types of interest for this mapping process included finding, observable entity, situation, and qualifier. The script enforced similarity of concept types in selecting an optimal SNAPI result. For example, the finding concept type was permitted to match with the situation concept type. However, the finding and situation concept types were not permitted to match with the qualifier concept type, as these were deemed distinct. The script also gave priority to the fewest number of SNOMED-CT codes needed to represent a given clinical concept.

Following the automated pass-through of concepts by the Python script, all coding results were manually reviewed by an independent physician reviewer. The reviewer reasserted that each concept was represented by the fewest number of SNOMED-CT codes. Manual querying was done through the SNAPI front end, SNOFLAKE (117), to ensure consistency of results.

Dangling Concept Reconciliation

Following mapping of concepts from the hermeneutic unit to SNOMED-CT codes, investigators reconciled all dangling concepts. A Python script aggregated and computed several semantic similarity metrics for the dangling concepts to assist in reconciliation. The script compared all dangling concepts to all of the concepts identified on the other side of the information flow spectrum. For example, the script compared a concept classified as a dangling concept in a resultant note to all identified and dangling concepts present in the relevant patient scenario description. The Python script only performed comparisons between concepts originating from the same note sections. When comparing concepts, the script ensured that concepts were similar semantic types.

Each concept-pair comparison was processed through a series of semantic similarity measures. A Python script accessed a remote web service, yTEX (113), which provided functionality for computing the semantic similarity measures of interest. For this project, taxonomical, corpus information content based, and intrinsic information content based types of metrics were accessed through the yTEX service. Wu and Palmer, Leacock and Chodorow, and Rada path-finding metrics were selected from the taxonomical group. Lin's similarity metric was chosen from the available corpus information content based measures. From the intrinsic information content based group, modified versions of Lin, Leacock and Chodorow, Rada, Jaccard, and Sokal and Sneath metrics were chosen.

The resulting scores computed by yTEX `for the concept pair, for all metrics (Table 2), were aggregated into a composite score. Scores resulting from the intrinsic information content based group were weighted the most. In instances when a concept is represented by a set of SNOMED-CT codes, each element of the set is computed against all elements of the set being compared. When the number of elements between two sets of codes differs, the root concept, "SNOMED CT Concept (SNOMED RT+CTV3)" and its code are used to perform the paired comparison. A sub-aggregate score was computed for these instances, with the root concept code being weighted the most. Each sub-aggregate score for a given metric was then aggregated with all the other metrics' sub-aggregate scores in similar fashion to single-coded concepts. When the final aggregated score reached a minimum value of 0.6, the dangling concept was designated a partial match. The partial permeability of the concept was set equal to the final aggregated score. The process of reconciling dangling concepts is summarized in Figure 3.

Dangling Concept Reconciliation Process

1. For each dangling concept, calculate similarity score between it and all concepts on opposite side
2. If a dangling concept is found in a resultant note, check it with all concepts in the matching patient scenario description
3. Choose the concept pair with the highest score at the end of the algorithm
4. For concepts represented by multiple codes, weight the root concept most
5. Scores from each metric class were aggregated into a composite score
6. Best composite score for a [dangling concept -- present concept] pair is kept after evaluating all concept-pairs
7. Count a concept-pair a partial match if best composite score hits a given threshold

Figure 3. Overview of dangling concept reconciliation algorithm.

Data Visualization

The information flow of clinical concepts from the patient scenario descriptions to resultant notes was visualized in terms of unique concept permeability. Investigators also created visualizations of concept overlap between patient scenario descriptions and resultant notes. A Python script utilizing the open-source matplotlib library (118) enabled dynamic creation of Venn diagrams and stacked bar graphs. Venn diagrams were created to illustrate the presence of unique concepts in patient scenario descriptions, versus resultant notes created via the dictation-based tool and the computer-based tool. Stacked bar graphs were created using matplotlib to contrast concept identification counts for clinical notes created by the dictation tool against notes created by the computer-based tool.

CHAPTER VI

RESULTS

Analysis Overview

To visualize information flow from the patient scenario descriptions to the resultant clinical notes, the study's investigators created a Venn diagram demonstrating the overlap of clinical concepts between the two sources (Figure 4). Unique clinical concept counts for each documentation tool and patient scenario description were also tabulated (Table 4). The study's investigators then applied the selected semantic similarity metrics (Table 2) in tandem with the dangling concept reconciliation algorithm (Figure 3) to derive a set of partial matching concepts between the PSDs and resultant notes. A sample of these partial match results are shown in Table 5. Investigators then plotted the frequency of each unique clinical concept with respect to documentation tool and presence in either the PSDs or resultant notes.

Distinct Clinical Concept Overlap

Venn diagrams were created to demonstrate the overlap of unique clinical concepts between the scenario patient descriptions and notes created via either documentation tool (Figure 4). A total of 122 unique concepts found in the scenario patient descriptions were also identified in notes created via dictation and notes resulting from StarNotes use. The notes created through dictation based tools had the largest number of unique clinical concepts not shared with either the set of patient scenario descriptions or with notes created via StarNotes. Overlap of distinct concepts between dictation notes and notes resulting from StarNotes use was also identified, with a total of 103 unique concepts fitting this category.

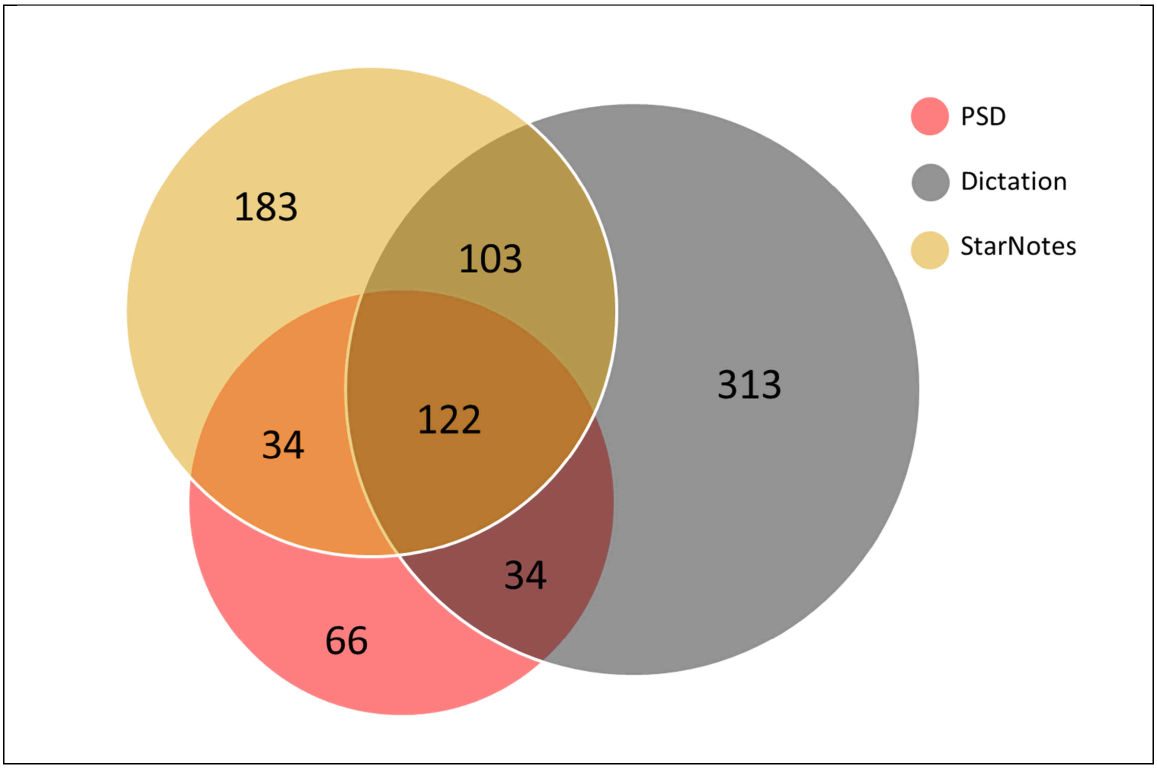

Figure 4. Venn diagram that demonstrates the occurrence of unique concepts in patient scenario descriptions (PSD), notes resulting from the dictation-based tool (Dictation), and notes resulting from StarNotes. The numbers in each circle and at the intersections of the circles represent the total count of unique concepts for the given classification.

On counting distinct clinical concept frequencies for the patient scenario descriptions and the resultant notes, this analysis found overall clinical concept loss occurring. The clinical concept loss was evidenced by the poor overlap in concepts present in the patient scenario descriptions and in the resultant notes, irrespective of documentation tool used. Concurrently, it was found that the permeability of clinical concepts was higher in the "Physical Exam" section of notes created via StarNotes than via dictation. This difference in concept permeability was demonstrated by the greater number of distinct concept overlap between the "Physical Exam" sections of notes created via StarNotes and the patient scenario descriptions, than "Physical Exam" sections of dictation-based notes. Dictation-based notes in general featured more clinical concepts not found in either the patient scenario descriptions or in case-equivalent notes created via StarNotes.

Distinct & Partial Match Clinical Concept Counts

The manual review process identified 256 distinct concepts for all patient scenario descriptions, 572 distinct concepts for notes created via the dictation-based tool, and a total of 442 distinct concepts for the notes created via StarNotes. All of the patient scenario descriptions had similar distinct identification counts (Table 4). The "DKA" case was found to contain the greatest number of distinct concepts (N = 135), while the cough case contained the fewest (N = 103). More unique concepts were identified in notes created via a dictation-based tool than notes created via StarNotes for all cases. Similar counts of concept match pairs were found in notes created via either StarNotes or dictation.

Table 4. Distinct concept counts for each documentation tool, stratified by patient scenario description (Case).

Case	Patient Scenario Description	Dictation	StarNotes
Back Pain	108	239	218
Diabetic Ketoacidosis	135	145	121
Headaches	115	171	154
Cough	103	227	172

The study's investigators applied the concept reconciliation algorithm (Figure 3) to derive a set of partial matching concepts for the PSDs and resultant notes. A sample selection of the resulting partial matches is shown in Table 5. A single concept partial matching pair included one clinical concept from a patient scenario description (PSD) and a clinical concept from a resultant note (RN). These concept pairs demonstrate partial permeability of information flow from the patient scenario description to the resultant note. As seen in Table 6 a total of 47 partial matching concepts were identified for StarNotes based resultant notes, and 35 partial matching concepts were found in dictation-based noted.

Table 5. Sample selection of partial match results from application of semantic similarity metrics algorithm. PSD = patient scenario description; RN = resultant note.

Subject ID	PSD (Case)	Tool	Note Section	PSD Concept	RN Concept	Permeability Score
57008	back pain	Dictation	HPI	back pain aggravated by leg movement neg	back pain radiation to left leg neg	0.8447
57042	pneumonia	StarNotes	HPI	chest pain location right lower	chest pain location right	0.8350
57018	pneumonia	StarNotes	HPI	chest pain location right lower	chest pain location right	0.8350
57008	back pain	Dictation	HPI	back pain onset acute	back pain location right thoracic	0.8311
57006	back pain	Dictation	HPI	back pain onset acute	back pain location right thoracic	0.8311
57015	back pain	Dictation	HPI	back pain aggravated by leg movement neg	back pain aggravated by bowel movements neg	0.8234
57007	pneumonia	Dictation	HPI	chills episode duration several minutes	rigors episode onset four days ago	0.8165
57007	back pain	StarNotes	HPI	back pain location low back	back pain aggravated by posture	0.7524
57022	back pain	StarNotes	Physical Exam	back tenderness	straight leg raise right quality pain	0.7485
57015	pneumonia	StarNotes	HPI	chest pain location right lower	rib pain location lower right	0.7473
57036	back pain	StarNotes	HPI	back pain aggravated by bending	back pain location right thoracic	0.7417
57023	back pain	StarNotes	HPI	back pain aggravated by bending	back pain location right thoracic	0.7417
57034	back pain	Dictation	HPI	back pain aggravated by cough	back pain location right thoracic	0.7417
57042	back pain	Dictation	HPI	back pain alleviated by lying down	back pain location right thoracic	0.7417
57017	back pain	StarNotes	HPI	back pain intensity low	back pain location right thoracic	0.7417

Table 6. All partial concept-match results for both dictation-based and StarNotes documentation tools, stratified by patient scenario description (Case).

Case	Dictation	StarNotes
Back Pain	23	37
Diabetic Ketoacidosis	1	1
Headaches	3	1
Cough	8	8
Totals	35	47

Distinct Clinical Concept Frequency Plots Overview

The study's investigators created composite plots demonstrating the frequencies of distinct clinical concepts in relation to documentation tool (Figures 5-15). The plots are organized into three zones along the x-axis and represented with different colored shading: 1) concepts present in both the patient scenario descriptions (PSDs) and the resultant notes (RNs) shown in light yellow, 2) concepts present only in the PSDs show in light red, and 3) concepts present only in the RNs shown in light blue. The y-axis represents the total number of occurrences for the given unique concept specified on the x-axis. The positive direction on the y-axis represents concepts identified in notes generated via the StarNotes tool and is colored blue. The negative direction on the y-axis represents concepts identified in notes generated via the dictation tool and is colored red.

Distinct Clinical Concept Frequency Analysis

Figure 5 demonstrates clinical concepts identified for the "Back Pain" case. Notes created via StarNotes (star) contained more concepts overlapping with the patient scenario description than was observed for notes created via the dictation-based tool (dictation). More concepts were found only in the dictation notes (N = 115) than were found in notes created using StarNotes (N = 72). Analysis of this difference revealed that dictated concepts exhibited greater expressivity and specification in their descriptions of frequency and intensity than their StarNotes counterparts. Some examples demonstrating this include the concepts "back pain radiation quality electric," "general behavior quality pleasant," and "lower right extremity sensation quality decreased."

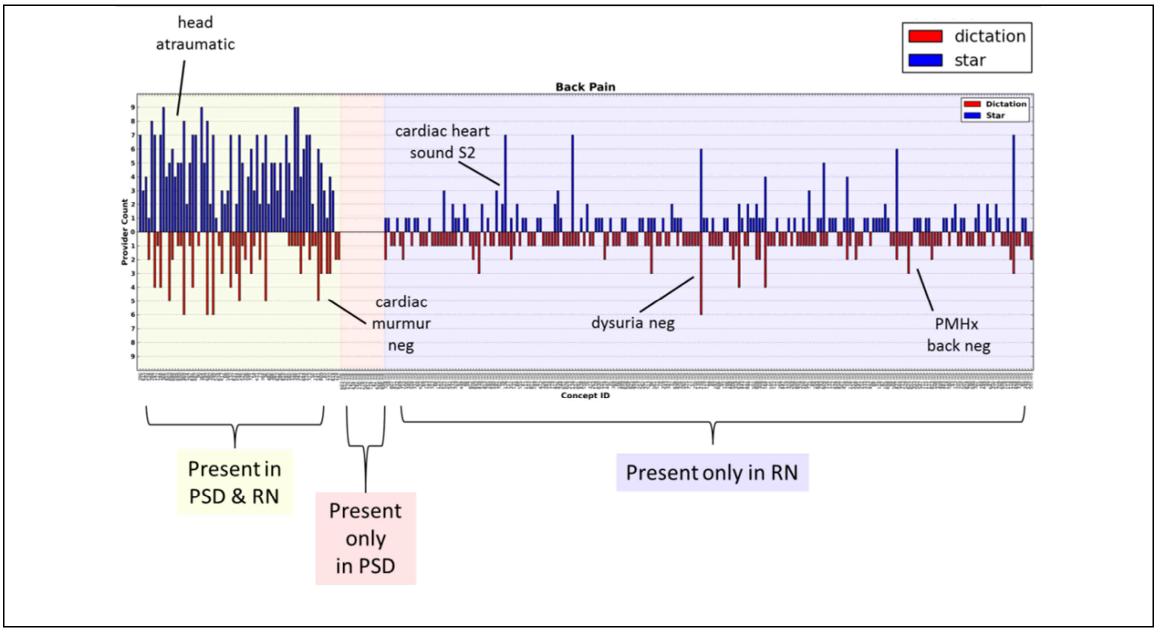

Figure 5. Unique concept frequency counts for the "Back Pain" patient scenario description. "PSD" represents "Patient Scenario Description," "RN" represents "Resultant Note," and "star" represents "StarNotes tool." Select identified concepts are displayed on the plot.

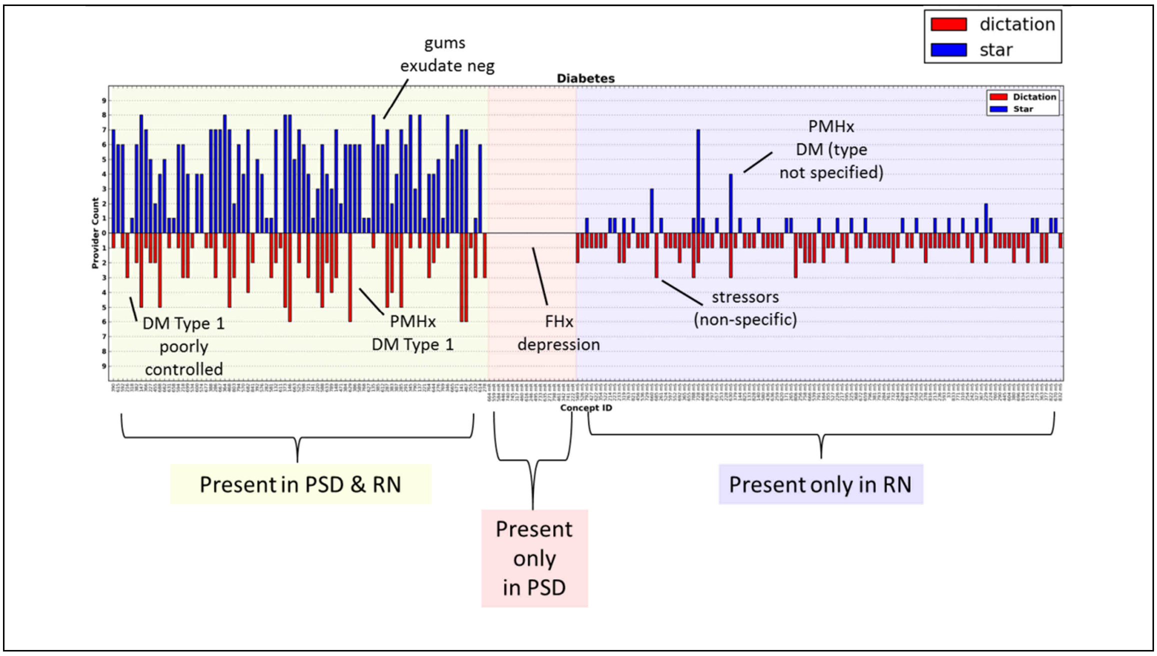

Figure 6. Unique concept frequency counts for the "DKA" patient scenario description. "PSD" represents "Patient Scenario Description," "RN" represents "Resultant Note," and "star" represents "StarNotes tool." Select identified concepts are displayed on the plot.

The distribution of concepts observed in both the resultant note and in the patient scenario description for the "DKA" case was similar to that of the "Back Pain" case (Figure 6). Specifically, more concepts notes that were created via StarNotes overlapped with concepts observed in the patient scenario description than observed for dictation-based notes. Similarly, a greater variety of concepts were observed only in resultant notes for the dictation-based tool than for notes created via StarNotes. Both the "Headaches" case (Figure 7) and the "Cough" case followed (Figure 8) the same pattern of overlap.

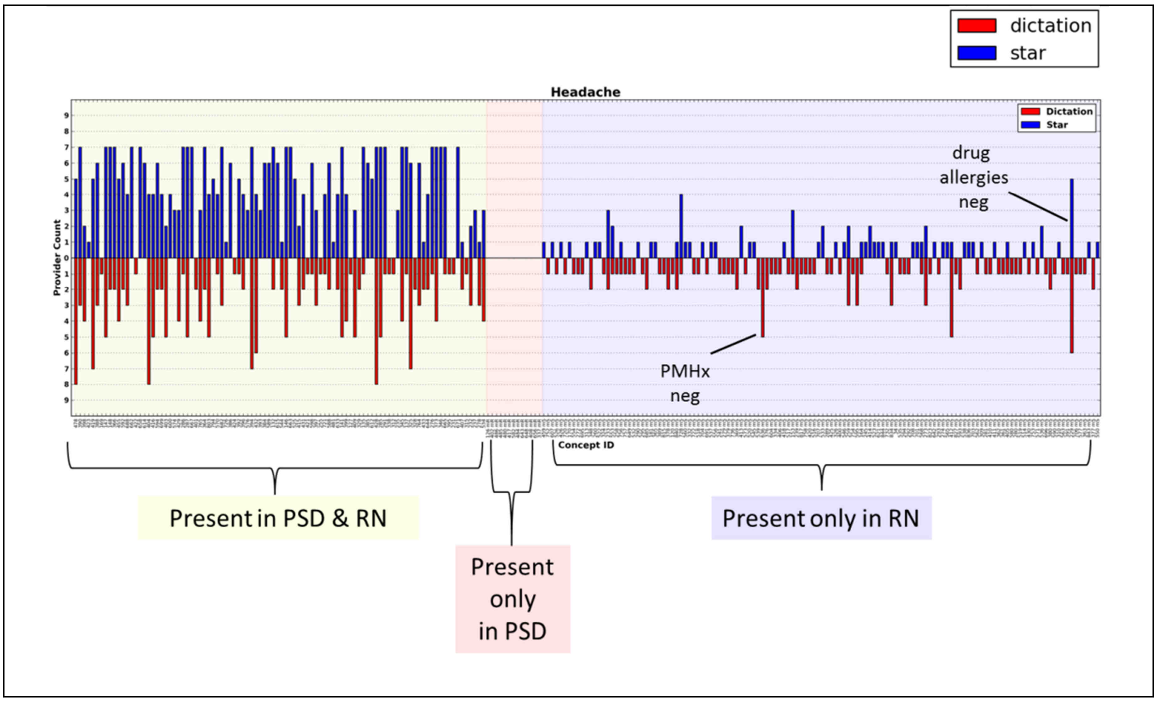

Figure 7. Unique concept frequency counts for the "Headache" patient scenario description. "PSD" represents "Patient Scenario Description," "RN" represents "Resultant Note," and "star" represents "StarNotes tool." Select identified concepts are displayed on the plot.

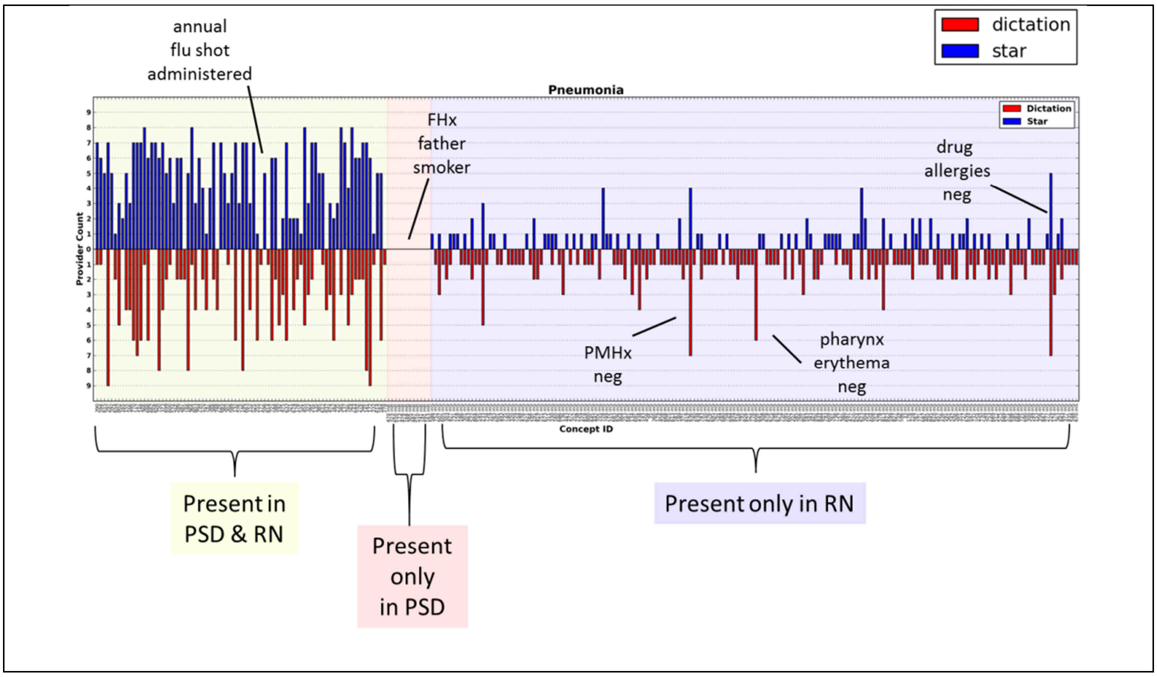

Figure 8. Unique concept frequency counts for the "Cough" patient scenario description. "PSD" represents "Patient Scenario Description," "RN" represents "Resultant Note," and "star" represents "StarNotes tool." Select identified concepts are displayed on the plot.

In analyzing clinical concept frequencies for the "History of Present Illness" note section for all patient scenario descriptions compared with resultant notes (Figure 9), no clear distinctions were observed between the two documentation tools. No clear distinction was observed for concepts overlapping in notes captured via either tool or concepts identified in the patient scenario descriptions. The "Physical Exam" note section starkly contrasted from the "History of Present Illness" note section (Figure 10). For the "Physical Exam" note section, there were 60 clinical concepts that overlapped between notes created via StarNotes and the patient scenario descriptions. Less overlap was observed between the patient scenario descriptions and notes created via the dictation-based tool (N = 48). Concurrently, a large number of concepts were identified as occurring only in the resultant notes created via StarNotes (N = 69) and via dictation (N = 190), but were not found in the patient scenario descriptions.

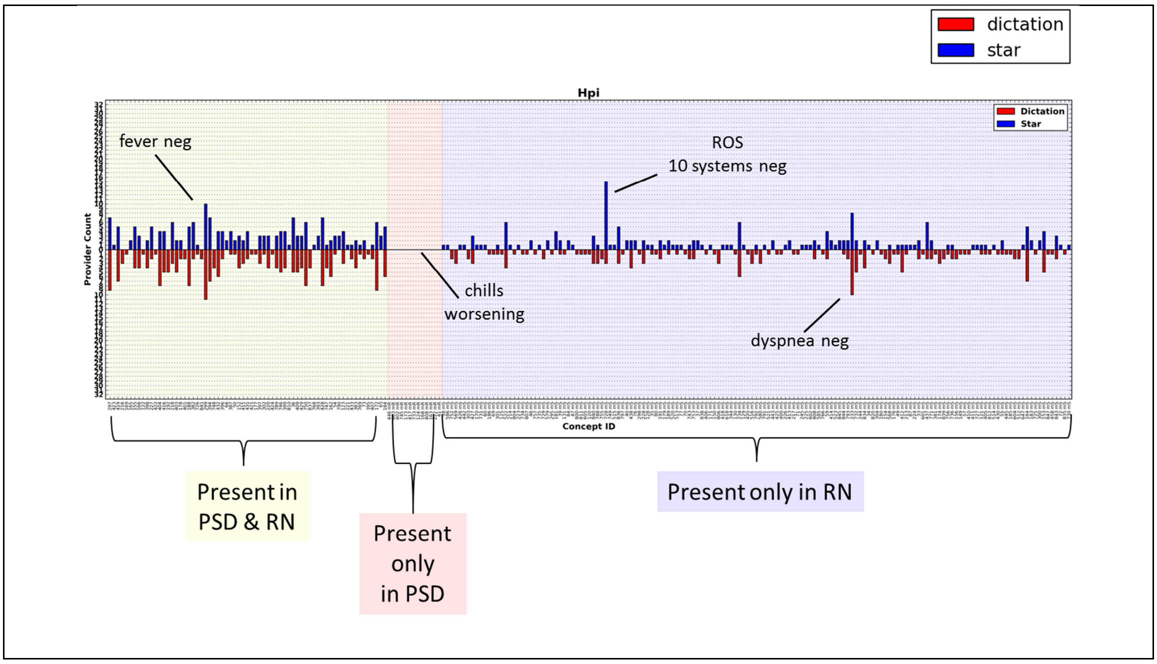

Figure 9. Unique concept frequency counts for the "History of Present Illness" note section, for all patient scenario descriptions. "PSD" represents "Patient Scenario Description," "RN" represents "Resultant Note," and "star" represents "StarNotes tool." Select identified concepts are displayed on the plot.

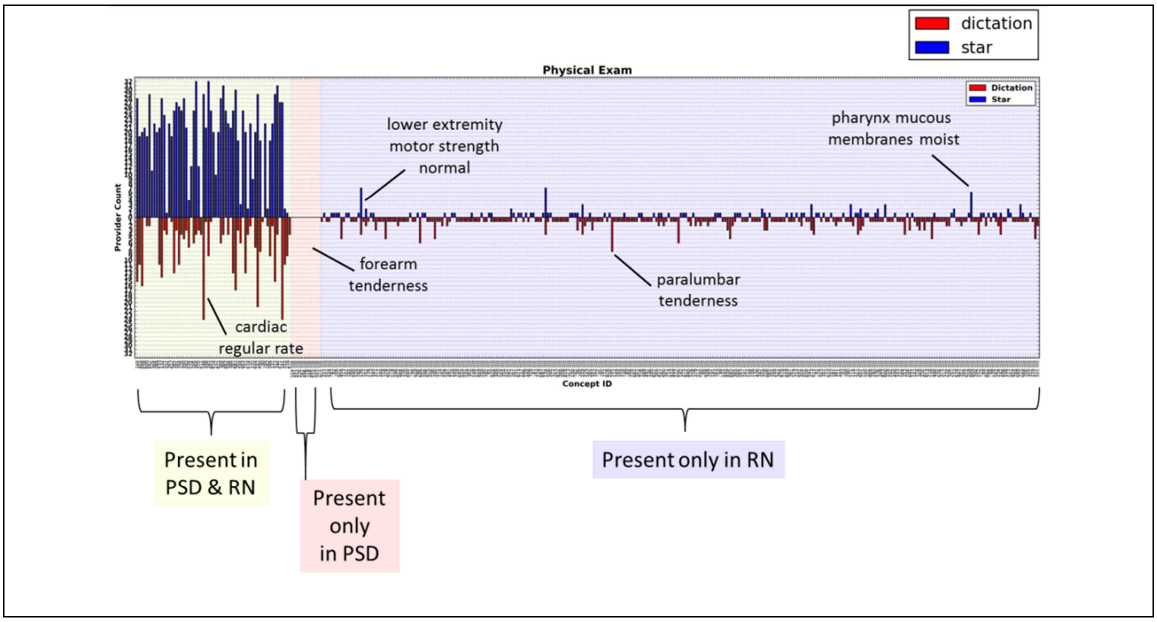

Figure 10. Unique concept frequency counts for the "Physical Exam" note section, for all patient scenario descriptions. "PSD" represents "Patient Scenario Description," "RN" represents "Resultant Note," and "star" represents "StarNotes tool." Select identified concepts are displayed on the plot.

Fewer clear distinctions were observed between notes created via the dictation-based tool and notes created via StarNotes in analysis of the "Past Medical History" note section (Figure 11) and the "Other History" note section (Figure 12). Notes created via both tools were missing more concepts present in the patient scenario descriptions than for the other note sections.

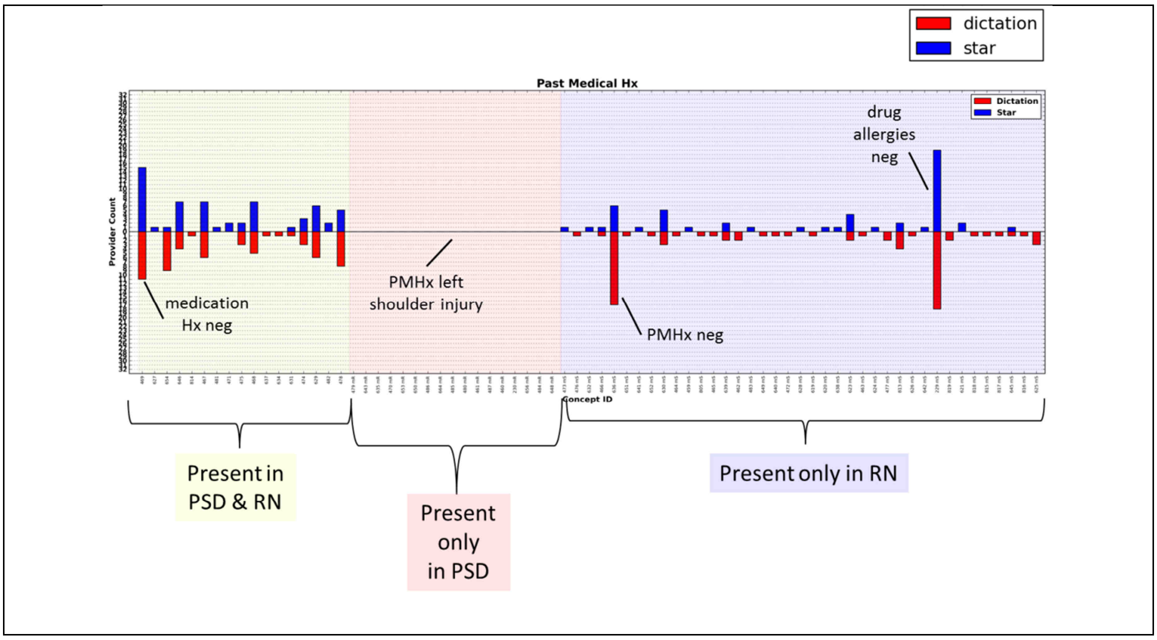

Figure 11. Unique concept frequency counts for the "Past Medical History" note section, for all patient scenario descriptions. "PSD" represents "Patient Scenario Description," "RN" represents "Resultant Note," and "star" represents "StarNotes tool." Select identified concepts are displayed on the plot.

"Headaches" Patient Scenario Description Detailed Analysis

The "Headaches" patient scenario description and its accompanying resultant notes were analyzed in greater detail to more clearly expose underlying differences in documentation tool performance. Similar to the History of Present Illness note section aggregate analysis (Figure 9), no clear distinction was noted between tools for the "Headaches'" History of Present Illness note sections (Figure 13). All StarNotes and dictation-based tool users captured the key clinical concept for the case (i.e. "headaches"), but no subjects captured the "headaches with possible mental status change" concept.

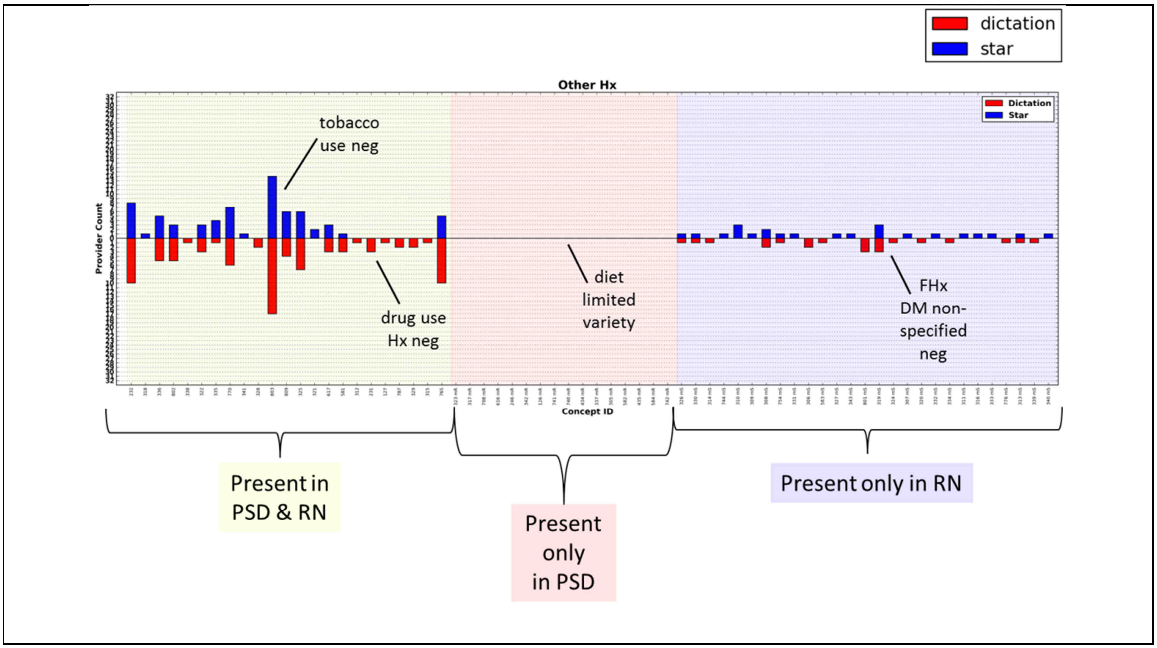

Figure 12. Unique concept frequency counts for the "Other History" note section, for all patient scenario descriptions. "PSD" represents "Patient Scenario Description," "RN" represents "Resultant Note," and "star" represents "StarNotes tool." Select identified concepts are displayed on the plot.

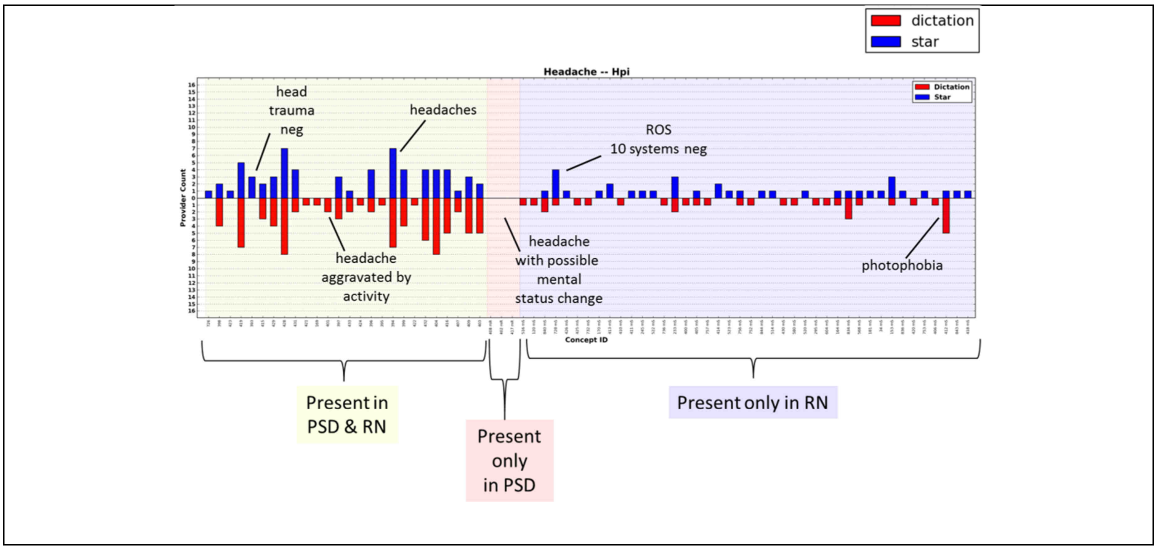

Figure 13. Unique concept frequency counts for the "History of Present Illness" note section, for the "Headaches" patient scenario descriptions. "PSD" represents "Patient Scenario Description," "RN" represents "Resultant Note," and "star" represents "StarNotes tool." Select identified concepts are displayed on the plot.

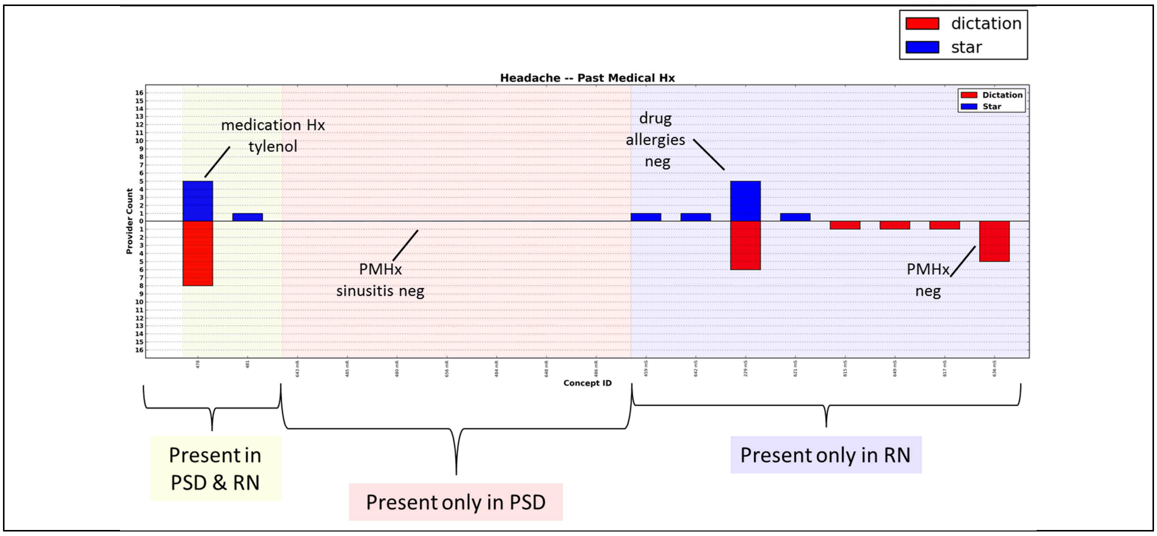

Figure 14. Unique concept frequency counts for the "Past Medical History" note section, for the "Headaches" patient scenario descriptions. "PSD" represents "Patient Scenario Description," "RN" represents "Resultant Note," and "star" represents "StarNotes tool." Select identified concepts are displayed on the plot.

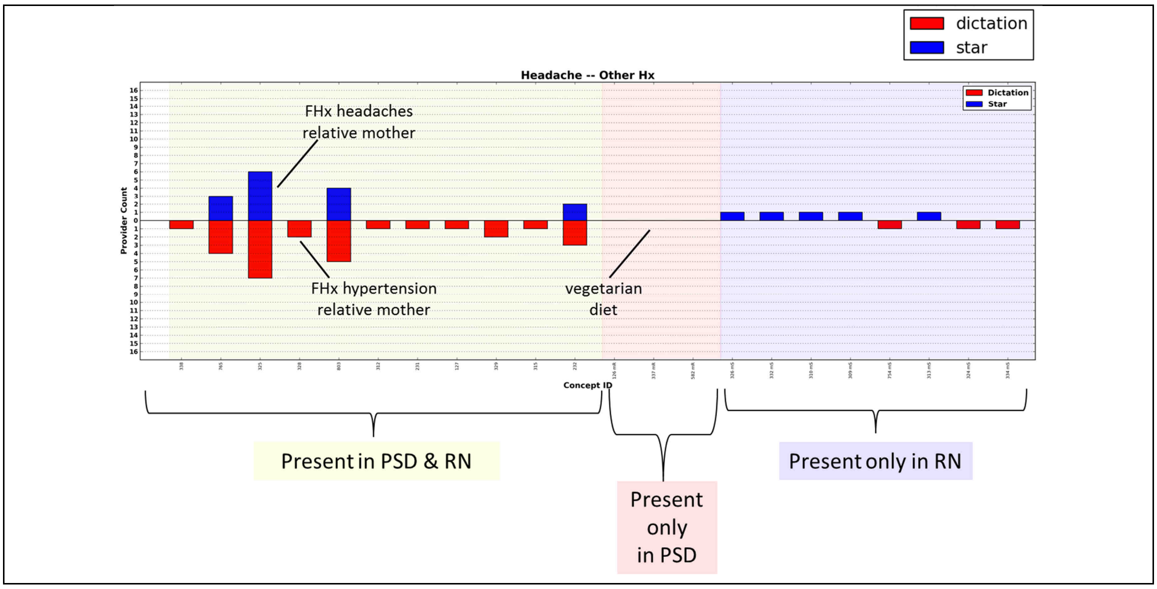

Figure 15. Unique concept frequency counts for the "Other History" note section, for the "Headaches" patient scenario descriptions. "PSD" represents "Patient Scenario Description," "RN" represents "Resultant Note," and "star" represents "StarNotes tool." Select identified concepts are displayed on the plot.

Analysis of the "Past Medical History" note section (Figure 14) revealed little overlap of concepts between the patient scenario descriptions and the resultant notes. Several concepts were identified only in the patient scenario description (e.g. "PMHx sinusitis neg"). No clear distinctions were observed for the documentation tools for "Other History" note section for the "Headaches" patient scenario description (Figure 15).

CHAPTER VII

DISCUSSION

This study demonstrated differences in the permeability of clinical content from a standardized patient encounter through to a clinical note between the two documentation tools evaluated. Dictated notes featured more unique clinical concepts absent from the patient scenario descriptions (N = 313) than notes created via StarNotes (N = 183), as demonstrated in Figure 4. Moreover, 66 of the 256 total unique concepts in the patient scenario descriptions were not captured at all by users of either tool. This set of missed concepts included items that physician subjects may have deemed as irrelevant in determining an ultimate diagnosis, assessment, and plan. For example, the concept "past medical history of left shoulder injury" was missed by all subjects for the "DKA" case. In the context of a poorly compliant diabetic patient presenting with new depression symptoms, discussing an old shoulder injury may not be an optimal use of patient encounter time.

Reasons for the observed differences in concept overlap were more clearly revealed by the Headaches patient scenario description sub-analysis. In this sub-analysis, it became apparent that the greatest distinction in unique clinical concept overlap occurred within the Physical Exam note section. The Physical Exam note section for subjects using the StarNotes tool had access to a note template (Figure 2). This presumably lowered the barrier for capturing clinical concepts for certain Physical Exam findings. The available list of predefined Physical Exam concepts may have prompted to subjects to elicit additional information from the simulation patients. In parallel, lack of a predefined template for the dictation tool may have encouraged users to document more expressive or descriptive concepts.

The resulting partial clinical concept matches from application of the semantic similarity algorithm achieved high face validity. Examples of concept pairs such as ["chest pain location right lower", "chest pain location right"] with a permeability score of 0.8350 and ["cough quality productive of yellow sputum", "cough quality productive of rusty yellow-colored sputum"] with a permeability of 0.7406 were reflective of high face validity among physician reviewers. Nevertheless, there exists an opportunity to further tune the algorithm to improve the matches delivered. For example the concept pair ["extremities lower right extremity sensation intensity decreased", "extremities right ankle motor strength quality decreased"] registered a relatively high permeability score of 0.7227. From a clinical perspective, the concepts of extremity sensation and extremity motor strength are markedly different. The taxonomical metrics' results included in the composite scoring scheme may have inflated this permeability score. This is since both of the concepts in this pair are located at a low level of the SNOMED-CT hierarchy, implicating greater specificity, and as a consequence a tendency towards semantic similarity.

The findings of this study suggested that information flow was traceable within a clinical simulation environment. The presented methodology for tracing information flow is not dependent on a specific documentation tool or system. It can be readily applied to other simulation settings utilizing tools not analyzed in the current study. The information flow tracing methodology is also capable of being generalized to non-simulated situations. For example, it could be utilized to study copying and pasting behavior by healthcare providers using CBD tools in real world environments. There are also potential applications for using the methodology in validating existing clinical note templates. Tracing the information flow that occurs from a given clinical note template to the actual resultant notes for a group of healthcare providers could help in the refinement of these templates. It could further be coupled to clinical documentation quality improvement efforts to help ensure certain evidence-based practices.

Analysis of information flow within the simulated clinical environment also revealed possible differences in documentation tool abilities. The methods of information flow analysis performed in this study may be applicable to the evaluation of documentation tools in real-world clinical environments. Overall, it appears that clinical simulation holds potential for evaluating medical documentation tools.

Project Limitations

The study did not evaluate the importance of concepts that did not flow from patient scenario descriptions to resultant clinical notes relative to those that did. The study findings would be bolstered with measures of significance for the observed clinical concept loss. The current study also only focuses on a limited set of documentation tools. Incorporating additional reviewer confirmation for clinical concept identifications as well for the SNOMED-CT mapping phase would further validate the results presented by this study. The partial concept matching algorithm will also require more formal evaluation and refinement. More assessment of this study's findings with respect to medical documentation tool performance is needed before they can be extrapolated to a real-world clinical environment. For example, the simulated clinical environments were devoid of workflow interruptions that are common during real patient encounters. The present study also only analyzes the ends of the information flow spectrum (i.e. the patient scenario description and the resultant notes). A follow-up analysis would need to explore the intermediary steps of the information flow process further.

CHAPTER VIII

CONCLUSION

Summary

This study demonstrated that information flow can be traced in a simulated clinical environment. By applying the presented methodology of tracing clinical concept flow from a standardized patient scenario description to a resultant note, this study's investigators were able to evaluate the performance of two medical documentation tools. The resulting findings suggest that both CBD and dictation-based documentation tools are subject to clinical concept loss. The presence of clinical note templates in the CBD tool may have eased documentation for subjects. This would explain the greater clinical concept count observed for computer-based notes when compared to dictation-based notes. There may be applications for this methodology in assessing documentation quality improvement efforts, as well as in evaluating other forms of documentation tools.

Future Work

Future research investigations can further examine the information transfer that occurs specifically at the interface of patient and healthcare provider communication. Other future research can focus on refinement of the semantic similarity scoring algorithms. With iterative development, there may be potential for these algorithms to be incorporated into natural language processing pipelines. The development for targeted relevance metrics for clinical concepts identified in resultant clinical notes would be another opportunity for research.

APPENDIX A

SUPPLEMENTARY MATERIALS

Table S1. Dangling concepts present only in the resultant notes and not the patient scenario description for the "Cough" case. The "Tool" column represents the clinical documentation tool used to record the dangling concept. "Both" represents both the dictation tool and the StarNotes tool.

Dangling Concept	**Tool**
abdominal pain neg	Both
activity intensity normal	Both
appetite intensity decreased	Both
cough quality productive of rusty-colored sputum	Both
cough quality productive of yellow sputum	Both
diarrhea neg	Both
drug allergies neg	Both
dyspnea neg	Both
ears tympanic membranes quality normal	Both
fever onset three days ago	Both
FHx lung problems neg	Both
general appearance quality well-appearing	Both
headaches neg	Both
hemoptysis neg	Both
lymphatics lymphadenopathy location supraclavicular neg	Both
nausea neg	Both
pharynx exudate neg	Both
PMHx allergies quality seasonal	Both
PMHx neg	Both
PMHx PPD testing result unknown	Both
PMHx tuberculosis exposure unknown	Both
pulmonary lungs percussion quality dullness neg	Both
rhinorrhea neg	Both
sinus pain neg	Both
sore throat neg	Both
vaccination Hx flu shot administered this year	Both
vomiting neg	Both
weight change decrease neg	Both
alcohol use frequency rare	Dictation

arthralgia neg	Dictation
cardiac heart sound S1	Dictation
cardiac heart sound S2	Dictation
cardiac murmur quality non-significant	Dictation
cardiac point of maximal impulse enlargement neg	Dictation
cheat pain quality pleuritic neg	Dictation
chest congestion neg	Dictation
chest pain neg	Dictation
chest pain quality pleuritic	Dictation
chest pain triggered by deep breathing	Dictation
cough associated with pain	Dictation
cough associated with prodromal symptoms neg	Dictation
cough frequency persistent	Dictation
cough onset three to four days ago	Dictation
cough onset two to three days ago	Dictation
ears quality normal	Dictation
ears tympanic membranes quality erythema neg	Dictation
extermities peripheral extremities edema neg	Dictation
extremities all limbs well-perfused	Dictation
extremities clubbing neg	Dictation
extremities cyanosis neg	Dictation
extremities edema location lower limbs neg	Dictation
extremities quality warm	Dictation
fever intensity low grade	Dictation
fever subjective neg	Dictation
FHx arthritis relative mother	Dictation
FHx dyslipidemia	Dictation
general appearance quality ill	Dictation
general appearance quality ill intensity mild	Dictation
general appearance quality stated age	Dictation
general appearance quality thin	Dictation
general distress intensity minimal	Dictation
general orientation quality oriented to person	Dictation
general orientation quality oriented to place	Dictation
general orientation quality oriented to time	Dictation
lymphatics lymphadenopathy location neck neg	Dictation
malaise	Dictation
medication Hx claritin prn	Dictation
medication Hx claritin prn indication allergies	Dictation

medication Hx cough syrup prn	Dictation
medication Hx herbals neg	Dictation
medication Hx over-the-counter neg	Dictation
medication Hx Sudafed frequency occassionally	Dictation
medication Hx Sudafed indication for allergies	Dictation
musculoskeletal joint abnormalities neg	Dictation
myalgia neg	Dictation
nasal congestion neg	Dictation
nausea intensity low	Dictation
neuro gross motor deficits neg	Dictation
neuro gross sensory deficits neg	Dictation
nose turbinates quality edematous	Dictation
nutrition fluid intake tolerable	Dictation
oropharynx erythema intensity mild	Dictation
oropharynx quality clear	Dictation
oropharynx quality moist	Dictation
oropharynx quality normal	Dictation
orthopnea neg	Dictation
paroxysmal nocturnal dyspnea neg	Dictation
pharynx erythema neg	Dictation
pharynx lesions neg	Dictation
pharynx posterior quality clear	Dictation
pharynx tonsils quality enlargement neg	Dictation
PMHx allergic rhinitis	Dictation
pulmonary breath sounds location lower left lung intensity decreased	Dictation
pulmonary breath sounds location upper respiratory quality coarse	Dictation
pulmonary breath sounds quality normal	Dictation
pulmonary cough frequency frequent	Dictation
pulmonary cough quality productive neg	Dictation
pulmonary fremitus intensity increased	Dictation
pulmonary fremitus intensity normal	Dictation
pulmonary fremitus location right lower lung	Dictation
pulmonary lungs location left lung clear to auscultation	Dictation
pulmonary lungs quality essentially clear	Dictation
pulmonary pleural rub quality questionable	Dictation
pulmonary rales intensity faint	Dictation
pulmonary rales location right lower lung	Dictation
pulmonary rales neg	Dictation
pulmonary rhonchi location lower left lung	Dictation

pulmonary rhonchi neg	Dictation
pulmonary wheezing neg	Dictation
pulmonary wheezing quality expiratory	Dictation
respiratory symptoms excluding cough neg	Dictation
review of systems 11 systems neg	Dictation
review of systems other systems neg	Dictation
sinus drainage neg	Dictation
sinus pressure neg	Dictation
skin petechiae neg	Dictation
skin quality intact	Dictation
skin rashes neg	Dictation
teeth dentition quality good	Dictation
throat pain quality scratchy	Dictation
tobacco use	Dictation
travel history neg	Dictation
vaccination Hx pneumonia neg	Dictation
vaccination Hx pneumovax neg	Dictation
vascular carotid bruits neg	Dictation
vascular dorsalis pedis pulses quality 2+	Dictation
vascular extremities pulses quality 2+	Dictation
vascular jugular venous distention neg	Dictation
vascular pulses location distal extremities quality palpable	Dictation
vomiting frequency once	Dictation
weakness location generalized	Dictation
weight change neg	Dictation
wrist soreness location right	Dictation
alcohol use context socially	StarNotes
chest tenderness aggravated by cough	StarNotes
chest tenderness location right lower ribs	StarNotes
chest tenderness neg	StarNotes
chest tenderness on palpation location right lower ribs neg	StarNotes
cough frequency all night	StarNotes
cough onset four days ago	StarNotes
eyes conjunctivae quality injected	StarNotes
fever onset four days ago	StarNotes
fever unknown	StarNotes
FHx cancer neg	StarNotes
FHx cardiovascular disease relative father	StarNotes
FHx diabetes mellitus non-specified neg	StarNotes

FHx tuberculosis neg	StarNotes
gastrointestinal symptoms neg	StarNotes
general activity quality speaking complete sentences	StarNotes
general appearance quality discomfort	StarNotes
hyperlipidemia	StarNotes
hypertension	StarNotes
nasal congestion	StarNotes
nose discharge neg	StarNotes
ocular drainage neg	StarNotes
ocular redness neg	StarNotes
oropharynx quality red	StarNotes
otalgia neg	StarNotes
pharynx mucous membranes quality moist	StarNotes
PMHx allergic rhinitis neg	StarNotes
PMHx allergies neg	StarNotes
PMHx asthma neg	StarNotes
PMHx PPD testing neg	StarNotes
PMHx reactive airway disease neg	StarNotes
pulmonary breathing quality comfortable	StarNotes
pulmonary fremitus neg	StarNotes
respirophasic pain neg	StarNotes
review of systems 10 systems neg	StarNotes
review of systems 4 systems neg	StarNotes
review of systems 5 systems neg	StarNotes
rhinorrhea	StarNotes
sick contact Hx son respiratory illness	StarNotes
skin lesions neg	StarNotes
skin quality dry	StarNotes
skin quality warm	StarNotes
skin turgor quality normal	StarNotes
sweats neg	StarNotes
wheezing neg	StarNotes

Table S2. Dangling concepts present only in the resultant notes and not the patient scenario description for the "Back Pain" case. The "Tool" column represents the clinical documentation tool used to record the dangling concept. "Both" represents both the dictation tool and the StarNotes tool.

Dangling Concept	Tool
abdomen tenderness location suprapubic neg	Both
back pain aggravated by cough	Both
back pain alleviated by lying down	Both
back pain intensity severe	Both
back pain location right lower back	Both
back tenderness location CVA neg	Both
back tenderness location lumbar	Both
back tenderness location spine negative	Both
back tenderness location thoracic neg	Both
bladder incontinence neg	Both
cardiac heart sound S1	Both
cardiac heart sound S2	Both
chest pain neg	Both
chills neg	Both
drug allergies neg	Both
dyspnea neg	Both
dysuria neg	Both
FHx cancer neg	Both
FHx diabetes mellitus non-specified neg	Both
general activity quality slow moving	Both
general appearance quality discomfort	Both
general appearance quality in pain	Both
headaches neg	Both
hematuria neg	Both
musculoskeletal cross straight leg raise result positive	Both
myasthenia location legs neg	Both
nausea neg	Both
neuro gait type heal-toe quality normal	Both
pharynx mucous membranes quality moist	Both
PMHx neg	Both
straight leg raise quality positive	Both
sweats neg	Both
urinary incontinence neg	Both
vomiting neg	Both
weakness neg	Both

abdomen bruit neg	Dictation
abdomen masses neg	Dictation
back pain location right back	Dictation
back pain radiation alleviated by sitting	Dictation
back pain radiation quality burning	Dictation
back pain radiation quality electric	Dictation
back pain radiation to right heel	Dictation
back quality scoliosis intensity slight	Dictation
back stepoff location spine neg	Dictation
back tenderness aggravated by standing	Dictation
back tenderness intensity mild	Dictation
back tenderness location lower lumbar spine	Dictation
back tenderness location lumbar spinous processes neg	Dictation
back tenderness location midline neg	Dictation
back tenderness location paralumbar neg	Dictation
back tenderness location perilumbar	Dictation
back tenderness location right CVA	Dictation
back tenderness location right flank	Dictation
back tenderness location right paralumbar	Dictation
back tenderness neg	Dictation
back tenderness quality mild	Dictation
back tenderness radiation to upper right pelvis	Dictation
buttocks pain radiation to heel	Dictation
calf numbness location right	Dictation
calf paresthesias location right	Dictation
extremities all limbs quality warm	Dictation
extremities all limbs quality well-perfused	Dictation
extremities clubbing neg	Dictation
extremities cyanosis neg	Dictation
extremities lower right extremity sensation intensity decreased	Dictation
extremities lower right extremity sensation quality decreased	Dictation
extremities motor strength quality 5 of 5	Dictation
extremities right lateral foot sensation intensity decreased	Dictation
eyes pupillary response quality normal	Dictation
eyes sclerae quality clear	Dictation
FHx cardiovascular disease relative grandmother	Dictation
FHx cerebrovascular disease	Dictation
FHx hypertension	Dictation
FHx nephrolithiasis neg	Dictation

general activity quality easily moves	Dictation
general activity quality slow to raise	Dictation
general behavior quality pleasant	Dictation
general distress	Dictation
general distress intensity minimal	Dictation
general distress onset acute	Dictation
general eye contact quality good	Dictation
general eye contact quality poor	Dictation
hips pain aggravated by range of motion neg	Dictation
hips pain location right neg	Dictation
injuries location lower extremities neg	Dictation
legs pain aggravated by adduction neg	Dictation
legs pain aggravated by extension neg	Dictation
legs pain aggravated by flexion neg	Dictation
legs pain aggravated by rotation neg	Dictation
legs right lateral calf light touch sensation quality decreased	Dictation
legs right lateral calf vibration sensation quality decreased	Dictation
lymphatics lymphadenopathy location neck neg	Dictation
musculoskeletal bilateral rotation quality normal	Dictation
musculoskeletal hips weakness neg	Dictation
musculoskeletal knees weakness neg	Dictation
musculoskeletal lower extremities strength intensity 5 of 5	Dictation
musculoskeletal lower extremities weakness neg	Dictation
musculoskeletal strength intensity normal	Dictation
musculoskeletal strength location lower extremities intensity 5 of 5	Dictation
musculoskeletal strength location upper extremities intensity 5 of 5	Dictation
musculoskeletal waist extension quality normal	Dictation
musculoskeletal waist flexion quality reduced	Dictation
musculoskletal right dorsiflexion quality 4+ or 4-	Dictation
neck tenderness aggravated by range of motion neg	Dictation
neuro focal weakness neg	Dictation
neuro gait giveaway	Dictation
neuro gait giveaway associated with heel	Dictation
neuro gait giveaway frequency intermittent	Dictation
neuro gait giveaway intensity mild	Dictation
neuro pin-prick sensation quality intact	Dictation
neuro pronator drift neg	Dictation
neuro proprioception quality intact	Dictation
neuro sensation quality intact	Dictation

neuro strength quality preserved	Dictation
neuro vibration quality intact	Dictation
neurologic symptoms neg	Dictation
nocturia	Dictation
numbness neg	Dictation
oropharynx quality clear	Dictation
PMHx back pain neg	Dictation
PMHx cancer neg	Dictation
PMHx pyelonephritis neg	Dictation
procedure Hx knee surgery	Dictation
procedure Hx neg	Dictation
pulmonary rales neg	Dictation
pulmonary respiratory rate quality regular	Dictation
pulmonary wheezing neg	Dictation
reflexes deep tendon location lower extremities quality 2 of 4	Dictation
reflexes deep tendon location patellar quality 2+	Dictation
reflexes deep tendon quality normal	Dictation
reflexes location heel quality normal	Dictation
reflexes location patellar quality normal	Dictation
reflexes location right ankle quality 0-1	Dictation
reflexes location right patellar quality 2+	Dictation
reflexes location throughout quality 2+	Dictation
reflexes location toes quality downgoing	Dictation
reflexes quality pathological neg	Dictation
reflexes quality symmetric	Dictation
straight leg raise quality neg	Dictation
straight leg raise quality positive at 20 degrees	Dictation
straight leg raise quality radicular pain at 30 degrees	Dictation
straight leg raise quality radicular pain radiation to posterior calf	Dictation
straight leg raise right quality positive	Dictation
treatment Hx heat therapy neg	Dictation
urinary frequency neg	Dictation
urinary urgency neg	Dictation
urine output quality foul-smelling neg	Dictation
vascular carotid bruits neg	Dictation
vascular distal pulses quality good	Dictation
vascular dorsalis pedis pulses quality 2+	Dictation
abdominal pain neg	StarNotes
arthralgia neg	StarNotes

back pain aggravated by bending	StarNotes
back pain aggravated by laughing	StarNotes
back pain aggravated by twisting	StarNotes
back pain aggravators neg	StarNotes
back pain location right flank	StarNotes
back pain location right lower lumbar	StarNotes
back pain radiation quality radicular	StarNotes
back pain radiation to leg	StarNotes
back pain radiation to lower lumbar	StarNotes
back pain triggers unknown	StarNotes
back palpable knots neg	StarNotes
back spasms neg	StarNotes
back spinous process tenderness neg	StarNotes
back tenderness aggravated by lumbar spine rotation	StarNotes
back tenderness aggravated by spine extension	StarNotes
back tenderness aggravated by spine flexion	StarNotes
back tenderness location flank neg	StarNotes
back tenderness location left flank	StarNotes
back tenderness location lumbar neg	StarNotes
back tenderness location paraspinous	StarNotes
back tenderness location right lower lumbar	StarNotes
back tenderness location right lower paraspinous	StarNotes
back tenderness location right lumbar	StarNotes
back tenderness location right paraspinous	StarNotes
back tenderness location sacrum neg	StarNotes
calf lateral right numbness mild	StarNotes
calf lateral right paresthesias	StarNotes
cough neg	StarNotes
extremities lower extremities cold sensation quality intact	StarNotes
extremities lower extremities motor strength quality 5 of 5	StarNotes
extremities lower extremities vibration sensation quality intact	StarNotes
extremities upper extremities motor strength quality 5 of 5	StarNotes
FHx back problems neg	StarNotes
FHx cardiovascular disease neg	StarNotes
FHx children healthy	StarNotes
FHx maternal gm heart disease in 70s	StarNotes
FHx muscle disease neg	StarNotes
FHx neurologic disease neg	StarNotes
general appearance quality discomfort aggravated by movement	StarNotes

general appearance quality obese neg	StarNotes
hemoptysis neg	StarNotes
hypertension	StarNotes
legs right leg sensation quality mild decrease	StarNotes
medication Hx pain meds neg	StarNotes
menstrual Hx menses regular	StarNotes
musculoskeletal plantars quality flexor	StarNotes
musculoskeletal quality moving all extremities	StarNotes
musculoskeletal right plantar extension quality diminished	StarNotes
musculoskeletal right plantar flexion quality diminished	StarNotes
neuro leg weakness neg	StarNotes
neuro saddle anesthesia neg	StarNotes
neuro sensation quality grossly intact	StarNotes
nose discharge neg	StarNotes
numbness location right leg lateral	StarNotes
physical injuries neg	StarNotes
PMHx diabetes mellitus type non-specified	StarNotes
PMHx hypertension neg	StarNotes
pregnancy neg	StarNotes
pulmonry respiratory excursion intensity limited	StarNotes
reflexes deep tendon quality 2+	StarNotes
reflexes deep tendon quality symmetric	StarNotes
sexual Hx unprotected sex	StarNotes
straight leg raise bilateral quality pain radiation to right leg	StarNotes
straight leg raise bilateral quality positive	StarNotes
straight leg raise right quality pain radiation to posterior thigh	StarNotes
straight leg raise seated knee extension quality negative	StarNotes
straight leg raise supine position quality positive	StarNotes
vision change neg	StarNotes
weakness location arms neg	StarNotes
weight change neg	StarNotes

Table S3. Dangling concepts present only in the resultant notes and not the patient scenario description for the "Diabetic Ketoacidosis" case. The "Tool" column represents the clinical documentation tool used to record the dangling concept. "Both" represents both the dictation tool and the StarNotes tool.

Dangling Concept	**Tool**
appetite intensity decreased	Both
depression	Both
drug allergies neg	Both
FHx diabetes mellitus non-specified neg	Both
medication Hx insulin type non-specified	Both
PMHx diabetes mellitus type non-specified	Both
review of systems 10 systems neg	Both
stressors	Both
suicidal ideation neg	Both
abdomen bruit neg	Dictation
abdomen insulin injection sites quality normal	Dictation
abdomen masses neg	Dictation
abdominal pain neg	Dictation
anxiety	Dictation
cardiac heart sound quality normal	Dictation
chest pain neg	Dictation
chills neg	Dictation
diabetes mellitus type 2	Dictation
diarrhea neg	Dictation
dyspnea neg	Dictation
ears external ears quality normal	Dictation
ears tympanic membranes quality normal	Dictation
energy decreased	Dictation
extremities clubbing neg	Dictation
extremities cyanosis neg	Dictation
extremities edema location lower limbs neg	Dictation
extremities foot examination quality normal	Dictation
extremities lower extremities motor strength quality 5 of 5	Dictation
eyes pupils quality arcus	Dictation
eyes quality nystagmus neg	Dictation
general appearance quality fatigued	Dictation
general appearance quality fit	Dictation
general appearance quality well-appearing	Dictation
general appearance quality well-hydrated	Dictation
general beahvior quality agitated	Dictation

general behavior quality answers appropriately	Dictation
general orientation quality oriented to person	Dictation
general orientation quality oriented to place	Dictation
general orientation quality oriented to situation	Dictation
general orientation quality oriented to time	Dictation
genitourinary symptoms neg	Dictation
headaches neg	Dictation
HEENT within normal limits	Dictation
insomnia	Dictation
lymphatics lymphadenopathy location neck neg	Dictation
nausea neg	Dictation
neck goiter neg	Dictation
neck meningismus neg	Dictation
neck pain neg	Dictation
neuro cranial nerves quality intact	Dictation
neuro focal weakness neg	Dictation
neuro light touch sensation location bilateral great toes quality normal	Dictation
nocturia	Dictation
numbness neg	Dictation
oropharynx exudate neg	Dictation
oropharynx quality clear	Dictation
oropharynx quality normal	Dictation
paresthesias neg	Dictation
PMHx neg	Dictation
psych affect quality very flat	Dictation
pulmonary breathing effort quality normal	Dictation
pulmonary lungs quality clear to auscultation	Dictation
pulmonary respiratory distress neg	Dictation
pulmonary wheezing neg	Dictation
reflexes location lower extremities quality intact	Dictation
review of systems 11 systems neg	Dictation
skin lesions neg	Dictation
skin quality diabetic signs neg	Dictation
skin quality dry	Dictation
skin quality warm	Dictation
sore throat neg	Dictation
sweats neg	Dictation
teeth dentition quality normal	Dictation
thirst intensity increased	Dictation

urinary frequency increased	Dictation
vaccination Hx flu shot unknown	Dictation
vascular dorsalis pedis pulses quality 2+	Dictation
vascular pedal pulses quality equal 2+	Dictation
vascular pulses quality strong	Dictation
vascular radial pulses quality equal 2+	Dictation
vision change neg	Dictation
vomiting neg	Dictation
cardiac murmur intensity 1 of 6	StarNotes
cardiac murmur onset early systolic	StarNotes
cardiac murmur quality very soft	StarNotes
constitutional symptoms neg	StarNotes
diabetes mellitus associated symptoms neg	StarNotes
diabetic ketoacidosis associated with fatigue	StarNotes
diabetic ketoacidosis associated with nausea	StarNotes
diabetic ketoacidosis associated with thrist	StarNotes
diabetic ketoacidosis episode onset one week ago	StarNotes
extremities lower extremities peripheral sensation quality	StarNotes
extremities motor strength quality 5 of 5	StarNotes
extremities upper extremities peripheral sensation quality intact	StarNotes
FHx cardiovascular disease neg	StarNotes
FHx hypertension neg	StarNotes
neuro quality grossly intact	StarNotes
PMHx depression quality unevaluated	StarNotes
psych affect quality angry	StarNotes
psych affect quality depressed	StarNotes
psych affect quality flat	StarNotes
pulmonary breath sounds quality normal	StarNotes
stressors type social	StarNotes
vascular bilateral dorsalis pedis pulses quality intact	StarNotes
vascular bilateral radial pulses quality intact	StarNotes

Table S4. Dangling concepts present only in the resultant notes and not the patient scenario description for the "Headache" case. The "Tool" column represents the clinical documentation tool used to record the dangling concept. "Both" represents both the dictation tool and the StarNotes tool.

Dangling Concept	Tool
chest pain neg	Both
chills neg	Both
drug allergies neg	Both
dyspnea neg	Both
extremities lower extremities motor strength quality 5 of 5	Both
extremities upper extremities motor strength quality 5 of 5	Both
headaches associated with aura	Both
headaches associated with photophobia	Both
neuro mental status quality normal	Both
neurologic symptoms neg	Both
review of systems 10 systems neg	Both
sinus symptoms neg	Both
vision change neg	Both
weakness neg	Both
abdominal pain neg	Dictation
alcohol use context socially	Dictation
balance issues neg	Dictation
ears tympanic membranes quality clear	Dictation
ears tympanic membranes quality intact	Dictation
extremities lower extremities motor strength quality 4 of 5	Dictation
extremities upper extremities motor strength quality 4 of 5	Dictation
eyes fundi quality arteriovenous nicking neg	Dictation
eyes fundi quality cotton wool spots neg	Dictation
eyes fundi quality hemorrhage neg	Dictation
eyes quality injection neg	Dictation
eyes sclerae quality clear	Dictation
eyes sclerae quality conjunctivitis neg	Dictation
eyes visual deficits neg	Dictation
facial pain neg	Dictation
FHx headaches relative grandmother	Dictation
FHx myocardial infarction relative grandfather	Dictation
general activity quality interactive	Dictation
general appearance quality thin	Dictation
general appearance quality toxic neg	Dictation
general appearance quality well-appearing	Dictation

general behavior quality pleasant	Dictation
general orientation quality oriented	Dictation
general orientation quality oriented to person	Dictation
general orientation quality oriented to place	Dictation
general orientation quality oriented to situation	Dictation
general orientation quality oriented to time	Dictation
head quality normal	Dictation
head quality point tenderness neg	Dictation
headaches aggravated by sound	Dictation
headaches associated with aura neg	Dictation
headaches associated with phonophobia	Dictation
headaches frequency 5 to 6 monthly	Dictation
headaches location unilateral	Dictation
headaches quality drilling sensation	Dictation
nasal congestion neg	Dictation
nasopharynx discharge neg	Dictation
nasopharynx erythema neg	Dictation
nasopharynx quality clear	Dictation
neck meningismus neg	Dictation
neuro consciousness quality altered neg	Dictation
neuro cranial nerves 2-12 quality normal	Dictation
neuro focal weakness neg	Dictation
neuro motor strength grossly normal	Dictation
neuro sensation quality grossly intact	Dictation
neuro sensation quality grossly normal	Dictation
nose discharge neg	Dictation
nose nasal mucosa color pink	Dictation
nose turbinates quality patent	Dictation
numbness neg	Dictation
oral ulceration neg	Dictation
oropharynx exudate neg	Dictation
oropharynx quality clear	Dictation
paresthesias neg	Dictation
PMHx neg	Dictation
procedure Hx appendectomy	Dictation
pulmonary lungs quality clear to auscultation	Dictation
pulmonary rales neg	Dictation
pulmonary rhonchi neg	Dictation
pulmonary wheezing neg	Dictation

reflexes deep tendon location patellar quality normal	Dictation
reflexes peripheral location lower extremities quality intact	Dictation
reflexes peripheral location upper extremities quality intact	Dictation
rhinorrhea neg	Dictation
sinus drainage neg	Dictation
skin changes neg	Dictation
skin lesions neg	Dictation
vaccination Hx flu shot neg	Dictation
vaccination Hx immunizations up-to-date	Dictation
vascular carotid bruits neg	Dictation
vascular jugular venous distention neg	Dictation
appetite intensity unchanged	StarNotes
concussions neg	StarNotes
cough neg	StarNotes
ENT symptoms neg	StarNotes
extremities lower extremities motor strength quality normal	StarNotes
extremities upper extremities motor strength quality normal	StarNotes
eyes quality nystagmus neg	StarNotes
FHx cardiovascular disease	StarNotes
FHx cardiovascular disease neg	StarNotes
FHx cardiovascular disease relative grandmother	StarNotes
FHx hypertension	StarNotes
FHx migraines	StarNotes
general appearance quality well-hydrated	StarNotes
headaches associated with phonophobia neg	StarNotes
headaches associated with photophobia neg	StarNotes
headaches associated with visual scotomas	StarNotes
headaches episode onset variable timing	StarNotes
headaches location unilateral generally	StarNotes
medication Hx analgesics	StarNotes
myasthenia neg	StarNotes
nausea	StarNotes
nausea neg	StarNotes
nausea with vomiting	StarNotes
neuro coordination quality normal	StarNotes
neuro cranial nerves quality intact	StarNotes
neuro cranial nerves quality normal	StarNotes
neuro finger-to-nose dysmetria neg	StarNotes
neuro gait quality symmetric	StarNotes

neuro gait quality unlabored	StarNotes
neuro heel-to-shin dysmetria neg	StarNotes
neuro pronator drift neg	StarNotes
neuro rhomberg quality normal	StarNotes
neuro strength quality normal	StarNotes
pharynx exudate neg	StarNotes
PMHx allergies neg	StarNotes
PMHx seizures neg	StarNotes
reflexes deep tendon location bilateral quality 2+	StarNotes
reflexes deep tendon location lower extremities quality 2+	StarNotes
reflexes deep tendon location lower extremities quality symmetric	StarNotes
reflexes deep tendon location upper extremities quality 2+	StarNotes
reflexes deep tendon location upper extremities quality symmetric	StarNotes
sinus pain neg	StarNotes
vomiting neg	StarNotes
weight change decrease neg	StarNotes
weight change neg	StarNotes

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