

INTEGRATING PROTOCOL-DRIVEN DECISION SUPPORT WITHIN E-  
REFERRAL SYSTEM: SUPPORTING PRIMARY CARE PRACTITIONERS  
FOR SPINAL CARE CONSULTATION AND TRIAGING

by

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To My Family;  
my only reason.

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## **ABSTRACT**

Referrals to the Halifax Infirmary Neurosurgery Department are submitted with regards to spinal conditions with different degrees of complications. Although there exists a Spinal Condition Consultation Protocol to standardize spinal referrals, the information provided from referring physicians is frequently inadequate to accurately triage the patient's condition, partly due to missing diagnostic therapies. The Neurosurgery Department receives a high volume of referrals each year, which imposes a significant administrative workload on the staff.

We propose to develop a protocol-driven decision support system to: 1) Provide primary care physicians with timely access to condition specific consultation treatment protocols; and 2) Automate the referral assessment process to eliminate processing delays and administration burden. To this aim, we transformed the Consultation Protocol into a semantic knowledgebase. The decision support services are integrated within a standardized electronic referral system. We believe this system can significantly improve the referral process at the Neurosurgery Division.

## LIST OF ABBREVIATIONS USED

API	Application Programming Interface
ACM	Application Control Module
ACS	Acute Coronary Syndrome
BFO	Basic Formal Ontology
BioTop	Top-Domain Ontology for the Life Sciences
CPG	Clinical Practice Guideline
CPR	Computer-Based Patient Record
DSM	Decision Support Module
DTR	Deep Tendon Reflexes
E-Referral	Electronic Referral System
HTML	HyperText Markup Language
MACSON	Management of Acute Coronary Syndrome Ontology
NICHE	Knowledge Intensive Computing for Health Care Enterprises
OWL	Web Ontology Language
PDF	Portable Document Format
RDF	Resource Description Framework
SCERef	Spinal Condition Electronic Referral System
SLR	Straight Leg Raise
SPSS	Statistical Package for the Social Sciences
SSCP	Spinal Condition Consultation Protocol
SSCPO	Spinal Condition Consultation Protocol Ontology
SNOMED	Systemized Nomenclature of Medicine
SWRL	Semantic Web Rule Language
TNM	Task Network Model

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# CHAPTER 1 Introduction

## 1.1 REFERRAL FOR CONSULTATION

In the clinical context, referral is the process initiated by a physician on behalf of the patient, in which the patient is referred to a consultant (e.g. specialist or subspecialist) to seek advice or receive management regarding one or more specific clinical problems. In this process responsibilities for some aspect of patient's care are transferred from the referring provider to a secondary provider [1]. Subsequently, the consultant communicates back the consultation results to the consulting physician [2]. The collaborative care between physicians can be classified as *Shared Care*, when the patient's care is shared by the primary physician and the specialist, and *Supportive Care*, when patient care is mainly managed by the specialist and the primary physician provides care coordination, as well as educational and emotional support for the patient [3].

The effective clinical referral is an important factor in successful clinical care, and has been examined increasingly in different medical contexts. For successful completion of the referral process, it is essential to provide the correct definition of need and purpose, effective communication of this information from referring physician to the consultant, attention of the consultant to the problem, and successful communication of the consultation result to the referring physician [4].

The validity and adequacy of consultation request medical information is an important factor in referral success. Ambiguous, insufficient and missing information is a common issue in referral process [5], [6]. Gathering medical information with sufficient quality for the purpose of referral requires appropriate clinical knowledge to be employed through pre-referral primary care investigations and during referral preparation. Utilizing this knowledge appropriately will enable the timely conduct of appropriate investigations and subsequent treatments. Medical information completeness can also be improved by the use of synoptic reporting [7], [8]. Synoptic reports are structured medical reports that collect information about a single patient encounter with a clinician. Synoptic reports has been successfully used be used to collect standardized information for spinal conditions

[9]. On the other hand, having a time consuming process in place for completing and submitting referrals can be another reason for inadequate information, by preventing referring physicians from providing complete referral notes [10].

Clearly, the key to a successful collaborative care model is optimal communication [10], [11]. However, communication between clinicians is sometimes absent or troubled [12], [13]. Miscommunication results in further difficulties throughout patients' care process. The lack of prior communication and communication timeliness may cause redundant testing and visits, which has an economic burden on the health care system. Prolonged communications often leaves referrals with inadequate information, leading to longer patients waiting time and possibly a deterioration patients' condition.

To improve referral effectiveness, clinical knowledge sources can be employed in the referral process through the use of Decision Supporting Services. These knowledge based services mainly aim to support referring physicians by recommending generic or case specific guidelines for patients' condition management. Furthermore, Electronic Referral Systems (E-Referral) have been utilized to collect standardized referrals and improve communication quality. Successful E-Referral systems are found to decrease missing or unclear information, thereby improving information quality and reducing patient risk. As a result of improved information quality and communication, E-Referral systems can decrease unnecessary visits, leading to more effective visits and a reduction in patient wait times [13]–[17]. The impact of e-Referrals has been analyzed in different disciplines, such as dermatology, gastroenterology, orthopedics, and outpatient surgery [18]–[21].

## **1.2 SPINAL CONDITION REFERRAL PROCESS AT HALIFAX INFIRMARY NEUROSURGERY DEPARTMENT**

Referrals to the Halifax Infirmary Neurosurgery Department are submitted with regards to spinal conditions with varying degrees of complexity. Referrals may be generated following an initial complaint specific interaction between the patient and the primary care-giver, or following an initial course of investigation and treatment. Generally the

process is initiated by a primary care physician for a patient with a spinal condition. During the initial visit, the physician obtains historical data specific to the current complaint. This information is typically augmented by a physical examination and any routine testing that is deemed necessary. In case the physician suspects an urgent condition, he/she may contact the Neurosurgery Department for an immediate verbal consultation; otherwise a referral letter is prepared. To compose a referral letter, the physician may use the Referral Letter Form published online (or available by fax) and mandated by the Neurosurgery Department, or include an EMR generated letter.

The submitted referrals are then managed by one of the staff at Neurosurgery Department (the triage coordinator). She manually assesses received referrals and contacts referring physicians with the result of assessment. For this purpose, she uses the Spinal Condition Consultation Protocol, while working in conjunction with staff neurosurgeons, to triage patients under one of four condition categories (see Appendix A – provided by Dr. Sean Christie). Based on the assigned category, in case the patient is a pediatric or has an emergency condition, the referring physician is asked to contact the appropriate department. On the other hand, if patient has an Axial or Radicular pain condition, a specialist appointment is scheduled for the patient, and the visit information is sent to the referring physician. To triage the patient for specialist appointments in the waiting queue, the triage coordinator extracts determining information from the referral letter into the Referral Summary Form, and uses this form to calculate the *Assessment Score*; a severity score that is considered to position the referral appropriately within the triage queue. Throughout this process, in case mandatory information is missing from the referral letter, prior to proceeding with referral assessment the referring physician is contacted for complementary information. Figure 1-1 summarizes the conventional spinal condition referral process in a workflow diagram.



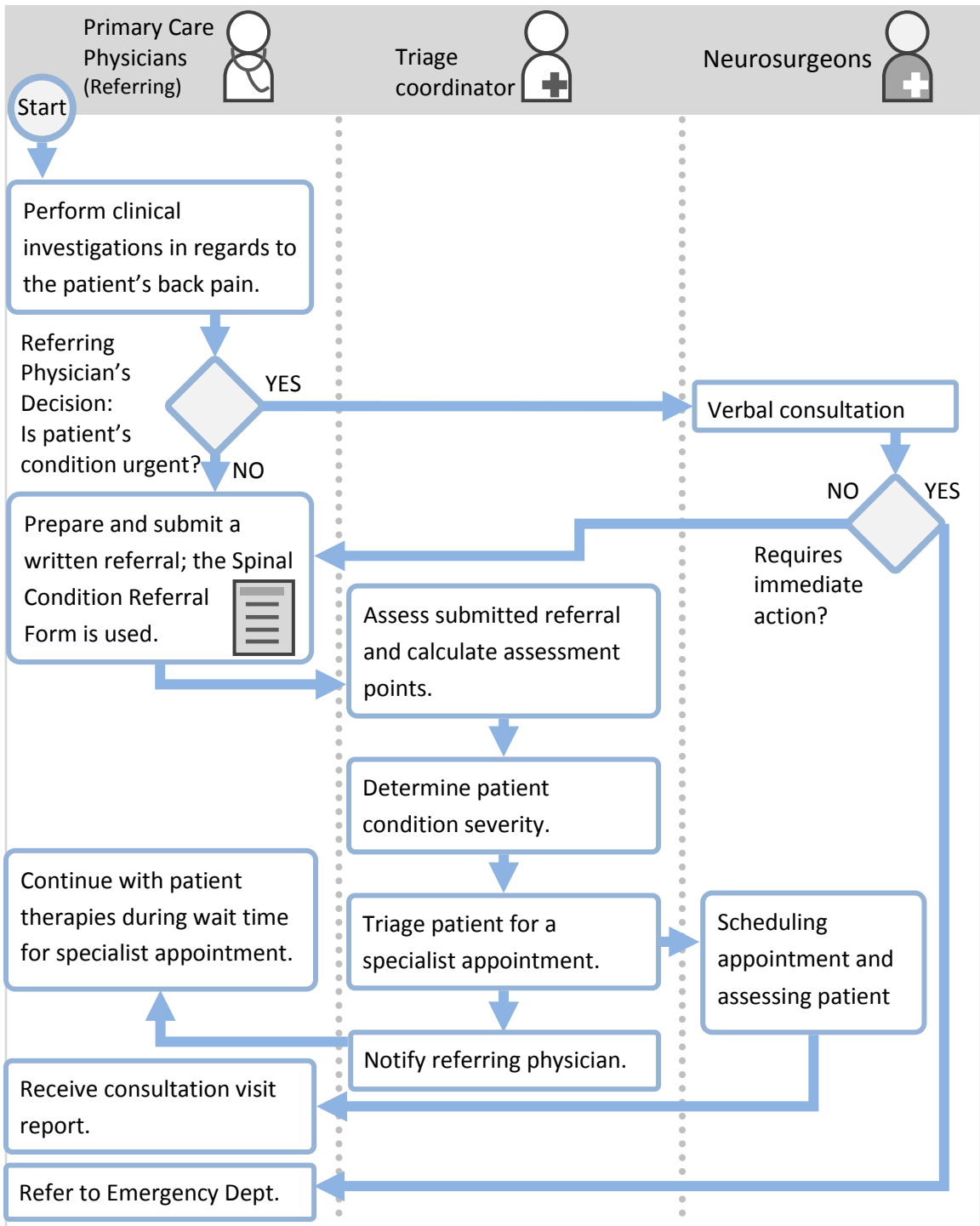


Figure 1-1 Workflow of the conventional spinal condition referral process. Each lane specifies actions performed by a specific actor.

### 1.2.1 Spinal Consultation Referral Forms

The referral letter form is a structured single page form that helps primary care physicians to prepare and submit a proper consultation request to the Neurosurgery Department. This form has separate sections for referring physician's identity, patient's demographics, presenting and past medical history, physical examination scores, and radiology results. The use of this form however imposes few drawbacks; the form collects parts of medical information in description of the problem and as free text. This imposes less constraints to collect all the required data for the calculation of Assessment Scores, and makes it more difficult to extract information from unstructured input. Also, form space considerations apply constraints on the size of the physical examination body image which makes it barely legible (see Appendix B for referral forms – provided by Dr. Sean Christie).

The Referral Summary Form is used internally by the triage coordinator in the hospital to extract and summarize essential information from referrals, and calculate Assessment Scores accordingly. This form is designed based on the surgical spine referral scoring system (Spine Severity Score) developed in the University of Calgary [22]. The Assessment Score is an aggregate of three constitutional subscores: Clinical score (derived from presenting medical history), Pathological score (past medical history), and Radiological score (radiology results). Each score can range from 0-5, resulting in a total score of 0-15. In case the referral assessment has been delayed due to missing mandatory content, the calculated Assessment Score is increased by the number of delayed months. The final Assessment Score provides a relative ranking of how urgent a case is, and can assist with prioritizing the case on a waiting list or be used as supporting information for Neurosurgeons throughout patient consultation.

## 1.3 PROBLEM STATEMENT

The current process of referral for spinal conditions entails a number of shortcomings:

- 1) Information included in submitted referral letters is often inadequate or lacks the sufficient quality; as an example missing description for quality and radiation of the

pain is numerously observed. This is partly due to the fact that there is an absence of a mechanism in place to verify the information against the consultation protocol requirements prior to submission.

- 2) Referring physicians occasionally fail to administer proper or adequate investigations before submitting referrals, as a consequence of lack of access to consultation protocols at the time of referral preparation. For instance, referrals sometimes lack necessary physical examination scores that can aid in determining patient condition severity. It is also common that primary care physicians are not aware of the best set of therapies (or pathways) to be followed during patients waiting time for specialist appointments.
- 3) High volume of incoming referrals and the manual referral assessment at the hospital implies much administration burden on the staff. Asynchronous assessment of referrals leads to prolonged and sometimes discontinued communications. For instance, in 2012 the Neurosurgery Department received nearly 1000 referrals. As a result of discontinued communication, in August 2012 the Neurosurgery Department has been waiting for answers from referring physicians regarding enquiries about 500 submitted referrals. The average waiting time in 2012 has been 150 days, with a maximum of 220 days.

In this research, we aim to address the above shortcomings by integrating the Spinal Condition Consultation Protocol (SCCP) in the referral process to improve referral outcomes. The resulting system is intended to improve pre-referral diagnostic interventions and post-referral therapeutic interventions by providing timely access to condition specific consultation protocols for referring physicians.

#### **1.4 RESEARCH GOALS AND OBJECTIVES**

Through this research we aim to promote primary care physicians' adherence to the Spinal Condition Consultation Protocol (SCCP) during the referral process. We also aim

to facilitate the referral administration process by incorporating the SCCP in an automated referral assessment process. To this aim, we pursue the following objectives:

- **Modeling and Computerizing the SCCP into a Knowledge Model to enable computerized referral assessment:** We attempt to transform the SCCP into a semantically rich model that embodies the workflow characteristics of the consultation protocol. This model serves as a computer interpretable knowledgebase for assessment of consultation referrals.
- **Integrating the SCCP in referral preparation process to improve referral content quality:** We employ a specialized electronic system designed based on SCCP requirements to collect standardized referrals. This mechanism is aimed to elevate the validity and completeness of referral information.
- **Developing a Decision Support System to improve primary care physicians' adherence to the SCCP:** We design and develop a Decision Support System which employs the SCCP Knowledge Model and uses standardized referral information to: 1) Provide primary care physicians with easy and timely access to condition specific consultation protocols; and 2) Automate the referral assessment process to eliminate processing delays.

## **1.5 RESEARCH CHALLENGES**

To accomplish the described objectives, we solved the following challenges:

- **Handling unclarities of the Consultation Protocol:** The SCCP entails much ambiguity in terms of decision point logics, scores calculations and steps modularity and flow, due to the fact that this protocol has been designed to be used as a quick reference by clinic staff and neurosurgeons who have familiarity with the disease processes, SCCP logics and workflow. The workflow of SCCP partly lacks the necessary coherence for translation into a conceptual model. Our challenge is to

eliminate unclearities and reach a coherent structure for SCCP by employing experts' tacit knowledge.

- **Creating a semantic model that can accommodate the SCCP:** To the extent of our knowledge there are no semantic models specialized enough to accommodate SCCP data elements and decision attributes. To develop such a model, we employed a previously developed semantic model with close similarities, and modified it to incorporate differences. In this case, the challenge is to map SCCP concepts and their relations to an existing semantic model to create a specialized knowledge model.
- **Ensuring standardized input information according to the SCCP requirements:** The proposed Decision Support System captures medical information from submitted spinal condition referrals and uses it as the input for processing. Valid and sufficient input for this system is determined based on SCCP requirements. One of our challenges is to employ a mechanism to collect valid and adequate information based on SCCP requirements, while keeping the referral preparation time short enough to be acceptable for referring physicians.
- **Ensuring an acceptable level of accuracy for score calculation and decision resolving by the Decision Support System:** We are designing the Decision Support System to resolve part of SCCP decisions based on score calculations. Any inaccurate results of system resolved decisions may produce improper medical recommendations or lead to longer patient waiting times, and increase patients risks. One of the critical challenges in our research is to minimize the level of inaccuracy in the Decision Support System referral processing results.

## **1.6 RESEARCH CONTRIBUTION**

To improve physicians' adherence to the consultation protocol and facilitate the referral administration process we developed a knowledge model incorporating the consultation

protocol, and implement a Decision Support System that utilizes the knowledge model to aid the referral process. Consequently, our contributions are as follow:

- **Enhanced SCCP Workflow:** We enhance the SCCP workflow in terms of decision logic formulation, management therapies clarity, and flow coherence. The enhanced SCCP conceptual model can be used for future SCCP updates.
- **Development of SCCP Semantic Knowledge Model:** This research presents development of SCCPO, a semantic knowledge model for formalization of SCCP. SCCPO considers all SCCP specific concepts and relations in computerization of the protocol. It incorporates a semantic patient medical record to preserve patients' medical history over time. Temporal characteristics have been considered in the design of this knowledge model which enables the employed execution engine to utilize temporal restrictions and scheduled events.
- **Implementation of SCCPO Knowledge Execution Engine:** We implement a workflow execution engine for execution of the SCCP ontology. The execution engine examines SCCPO comprising decision steps based on embedded decision logics, and by taking into account the patient's formalized medical records. This engine is customizable for other knowledge models with similar structures, and is capable of more complex execution functions such as model execution based on real-time physician input, and processing scheduled events.
- **Implementation of Customizable Electronic Referral System:** This research describes the implementation of a generic Electronic Referral System (E-Referral) as a manifestation of the proposed Decision Supporting Services. This system utilizes a modular architecture represented by other similar E-Referral systems, while it is expanded by the use of Spinal Condition Decision Supporting Module (i.e. Knowledge Execution Engine). The modular design makes it possible for this E-Referral system to be customizable according to application of different Decision Supporting Modules.

## **1.7 THESIS ORGANIZATION**

This thesis is organized according to the following description: Chapter 2 will include summary of the literature review performed as a background for this research; Chapter 3 will begin with an explanation for our solution approach and the methodology of Knowledgebase development; Chapter 4 will describe our methodology for implementation of the Decision Supporting Module and integration of the underlying E-Referral components; Chapter 5 will include results of evaluation for Spinal Condition Decision Supporting Services and the E-Referral system; and Chapter 6 will bring a discussion, our conclusion, and proposed future works.

## **CHAPTER 2      Background**

This chapter gives an overall overview of existing electronic referral systems (e-referral) and the use of decision support services in this context. This review is performed to familiarize our research with applied methods mainly in regards to e-referral knowledge base integration, communication quality, information quality and standardization. The outcome of this review aids us to refine our solution design and consider any potential challenges. A summary of this review can be found in Table 2-1.

### **2.1    ELECTRONIC REFERRAL SYSTEMS**

In contrast to traditional paper-based consultation referrals, electronic referrals use electronic means of communication to transfer information from primary care practitioners to secondary care specialists, and often vice versa.

Taking advantage of online communication through the referral process can considerably improve the inter-provider communication timeliness and effectiveness [6], [16], [23]. Different methods are used to establish the connection link between primary and secondary practitioners; Kaae reports implementation of a digital mailbox for referral submission in Denmark which reduces unacceptable referrals ratio by 50% [24]. Another form of communication uses iterative messaging between providers by the use of specialized softwares ([14], [16], [23]). A distinct forum based method has been utilized by Reinhart I. et.al, in which consultation requests are sent as forum threads and providers can contribute to referral threads with question-answers, appointments information, or consultation reports [25].

Employing electronic communication as a tool for referral submission provides the possibility of structuring the referral request input information to improve the referral data quality. Degree of input structure between different e-referral applications varies. Low structured referral forms collect referrals in free text or few open-ended questions (similar works done by [16], [26]). More structured input is collected by the use of structured electronic forms which collect the input using components such as text boxes,



checkboxes and drop-down menus (similar works by [6], [14], [27]–[29]). Studies show collecting well-structured information has the potential of lowering the ratio of missing required information, or distinguishing determining factors in referral letters [16]. In a similar context, structured electronic medical reports (synoptic reports) have been developed to improve adequacy of spinal information, and foster interoperability between systems [9].

Having health information systems already in place in clinics and physicians' offices provides the opportunity for data or message exchange between these systems and deployed e-referral systems. In this case, one function that is often incorporated into e-referral systems is automatic population of clinical data into electronic referral requests. This method diminishes the need for manual entry of patient demographics and clinical history data, consequently reducing spent time on letter preparation and possible manual entry errors [29]. Another service offered by integrated e-referral systems is tracking the progress of referral requests. Warren et al. report improved transparency of the referral process resulted from similar integrated referral services with clinics and physicians' offices information systems. In this study interviews reflect physicians' and clinicians' satisfaction with services such as referral assessment acknowledgment, tracking referral progress, tracking patients' visits, and accessing progress notes [30].

Scheduling specialists visit appointments has been offered by e-referral tools under specific circumstances in which scheduling is allowed by local policies, and integration with hospitals' scheduling systems is possible. In England the national referral and booking system, Choose and Book, gives the primary care physicians the flexibility of booking consultation appointments with specialists, based on their or patients' preferences. Using Choose and Book, physicians or delegated staffs are able to view and book specialists available timeslots, by the use of keyword search (e.g. their name), their distance, or their average waiting times. Booking can also be done by patients in a number of methods including their online accounts [31]. Other researchers also utilized similar approaches to delegate scheduling responsibility to referring physicians or patients [21], [32]. Studies show granting scheduling choices can decrease the

appointment changes, not-attending rates and consequently appointment waiting times [21], [31].

Moving towards electronic referral services offer benefits to secondary care clinics as well. In addition to improved communication and information quality, e-referral transforms all or part of the paper-based administrative tasks into computer-aided processes, causing a decrease in administrative burdens (e.g. triage on screens, paperless letter handling, and in some cases reducing the need for faxing and mailing). Timely two way communication using e-referrals makes it possible for clinics to send referring physicians further guides regarding patients' conditions, or in case of declined requests, send back notifications including referral criteria. Paperless request letters may also improve the timeliness and accessibility to referral information within the clinics [16], [23].

## **2.2 DECISION SUPPORTING IN E-REFERRAL SYSTEMS**

A number of studies in the context of e-referral systems attempt to implement methods to facilitate process of decision making for the two groups of involved practitioners; primary care physicians and secondary care practitioners. These attempts mainly lie within the following four categories: 1) Direct the referral preparation process through the consultation protocol, 2) Assist referring physicians or patients in choosing appropriate consultants, 3) Automate the referral assessment process, 4) Recommend condition specific clinical guidelines to support primary care therapies. This section reviews different approaches in this area.

Due to the lack of quality information in referral letters and missing pre-referral investigations, studies have aimed to direct referral preparation processes based on clinics consultation protocol frameworks. The principle aim is to integrate context specific consultation protocols in the referral data collection step. The result is structured referral forms that are designed based on consultation protocols, or embedded consultation protocols in forms of checklists. As an example, a distinctive approach has been used in

New Zealand Canterbury e-referral system in which referring physicians are able to explore the consultation protocol and triage scoring through an interactive protocol diagram [29]. These attempts direct referring physicians through the necessary investigations prior to referrals and ensures adequacy of referral information. This has been shown to decrease the portion of inappropriate referrals to clinics [16], [29], [33].

E-referral systems have been used to support primary care physicians in choosing consultation clinics or specialists who can better address their requests. In fact, physicians are usually concerned with difficulty of seeking information in this regard [6], [34], [35]. One method used to address this requirement is providing a directory of consultants' information, including distance and average wait times and making it possible to filter and search through the list. This method has been widely used in two national e-referral and scheduling systems *ZorgDomein* and *Choose and Book* [17]. More advanced approaches have been employed which applies intelligent matchmaking between patients' cases and proper consultants based on selected medical problems and requested interventions from the consultant [34], [36].

Secondary care clinics are often overwhelmed by the volume of incoming referrals. This may result in longer waiting times for referred patients. Few studies have attempted to use consultation protocols in automating the referral assessment process and triaging referral requests. Sittig et al. explain the design of a system incorporating a knowledge base to determine whether referral requests are approved or require further assessment [36]. Similarly, Jiwa et al. employ an interactive tool, based on *PROforma* language, to guide referring physicians about which cases need urgent referrals. Yet, there have been some concerns about possible increase in volume of urgent referrals due to the uncertainty in patient condition determination [28]. To the extent of our knowledge, there have been no formal studies which evaluate automatic e-referral assessment methods.

There are very limited studies reflecting the effect of clinical guideline dissemination on the referral process. Heimly et al. describe an e-referral system which provides diagnosis related clinical guidelines when diagnosis codes are entered by referring physicians.

Physicians who had access to case specific clinical guidelines state that their confidence about which cases to manage locally and which patients to refer to specialists have been increased [37].

Table 2-1 An overview of implemented e-Referral systems functionalities.

	Function	Study Reference
Communication Methods	Structured Electronic Forms	[23], [29]
	Email	[24]
	Iterative Messaging	[14], [16], [23]
	Forum	[25]
Decision Support	Integrated Guideline; in forms of Knowledge Base	[28], [36]
	Integrated Guideline; in forms of Structured Referral Form	[29]
	Integrated Guideline; in forms of Education	[37]
	Automated Referral Assessment	[28], [36]
	Recommendations based on Clinical Guidelines	[37], [38]
	Specialist Suggestion	[17], [34], [36]
E-Referral Functions	Referral Progress Tracking and Acknowledgment	[6], [30], [31]
	System generated Notifications: Referral assessment results, appointments, consultation summary	[6], [14], [32]
	External File Attachment	[30], [39], [40]
	Self Referral (by Patients)	[41]
Integration	Clinic Appointment Scheduling	[21], [31], [32]
	Integrated with other IS: EHR	[14], [16], [38], [42]
	Integrated with other IS: Radiology	[39]
Architecture	Interoperability with External Systems	[23]
	HL7 Compatibility	[30], [43]
	Web-based Architecture	[16], [32], [34], [40], [44], [45]
	Clinic Referral Management: Web-based tool	[30]

### **2.3 CONSIDERATIONS FOR THE IMPLEMENTATION OF E-REFERRAL SYSTEMS**

Correct design and implementation of electronic referral systems can benefit the consultation process from several aspects. E-referral systems have the potential to improve inter-provider communication and referral information availability and quality. They may also result in more effective visits and reduced patients wait times [14], [16], [17], [23], [30]. However, number of technical and socio-technical factors should be considered to improve the effectiveness of e-referral systems.

Utilization of electronic communication and structured forms per se do not necessarily lead to efficient e-referrals. Singh et al. describe the study of e-referral communications through a hospital EHR system. The result shows high volume of referrals lack follow-up action or are discontinued. Further investigations revealed in majority of cases, referral requests lack prerequisite workups or sufficient information to help specialists to make decisions [5]. These findings imply potential benefits of integrating consensual referral criteria in the referral process to ensure prerequisite referral protocols are followed properly and required information is include in requests. The outstanding results reported by Gu et al., from the study of a pathway integrated e-referral system [29], is a support to this idea. It is also recommended to regularly review and revise referral criteria and e-referral tools to maintain quality of system services and user satisfaction [23].

Typical of health information systems, technical issues have been one of the challenges in development and usability of e-referral systems. Part of the reported problems with e-referral systems are related to software program defects [31]. Other type of issues are raised from technical hitches in depending technologies, such as response delays caused by a low capacity underlying network [17], [46]. On top of that, some studies report technical difficulties regarding interoperability and integration with other health information systems (e.g. primary care information systems) [17], [23]. Often these technical issues transforms the e-referral submission into a time consuming process (i.e. irresponsive system, redoing the same work), which leads to less user satisfaction [31]. It is beneficial to consider detailed analysis of the context and used technologies, in

addition to sufficient testing, to spot and resolve possible issues prior to the usage of the system in practice.

In general, electronic systems are not successful when users are unwilling to accept the system. Low system adoption rates and usage disparity have been reported in a number of e-Referral systems studies [14], [28]. Often physicians are not content about replacing their current routine, which causes slower adoption of the new e-referral system [23]. One of the key reasons for low acceptance rates is increased referring physicians' efforts and time required to complete a referral request electronically, compared to a paper-based request, particularly when the system provides additional services to the users and extra effort is needed [28], [31]. Having a time intensive process in place for referrals submission can also result in ambiguous and insufficient information in referral requests [10].

Physicians occasionally state their concern about complexity of the referral submission task using the system, or express doubts regarding the accuracy of information provided by the system (e.g. by a decision support service) [28], [31]. A sound strategy to improve users' confidence in the system and increase system acceptance is to engage both primary and secondary practitioners in design and refinement of the system [18]. J. Warren et al. have applied this approach by involving primary and secondary parties in forming consensual consultation knowledge sources and transforming that knowledge in structured referral forms [23]. This created an environment which encouraged both parties to participate in appropriate care delivery based on the consensual knowledge and using constructive feedbacks and education loops. Those attempts resulted in significant uptake and acceptance of the system [23], [29].

## **2.4 SUMMARY**

We reviewed literature related to electronic referral systems (e-referrals) under four main topics; electronic communication, data input, integration with other systems, and services offered including decision support services. This review provided us with insights in

regards to integration of referral guidelines in the referral process and the use of referral criteria to standardize referral information collection. Existing practices have also been reviewed concerning the use of guidelines to form knowledge bases integration and provide decision support services to referring physicians. Furthermore, previous experiences in regards to communication methods and other e-referral functions such as tracking and notifications have been reviewed. Finally, this review has yielded a number of lessons learned from past experiences, and considerations regarding future research challenges.

## **CHAPTER 3      Methodology: Knowledge Modeling and Ontology Development**

### **3.1 INTRODUCTION**

As it has been discussed in Chapter 1, the process of paper-based spinal condition referral entails limitations due to the lack of referring physicians' access to consultation protocols, which may result in insufficient pre-referral investigations and low information quality. Moreover, absence of readily accessible condition management protocols during patient consultation waiting time may lead to administration of inefficient therapies, leading to deteriorated patients' condition and/or increased healthcare costs. It is expected that incorporation of spinal condition consultation protocols as a source of knowledge in the referral process, during physicians' preliminary investigations and post-referral waiting times can improve physicians adherence to protocols resulting in enhanced patients care.

Employment of consultation protocols for assessment of referrals is currently limited to manual usage by the triage coordinator. Receiving high volume of referrals enforce much workload on referral managers to extract information and assess referrals. We argue that the use of consultation protocol for automation of the assessment process can considerably facilitate this administrative process.

To answer the limitations of spinal conditions paper-based referral process our proposed solution is to provide decision support services based on the Spinal Condition Consultation Protocol. For this purpose we operationalize the consultation protocol by transforming it into a knowledgebase. For the proposed decision support services to become functional, standardized information need to be collected to be used as an input for knowledge based request processing. Therefore, a software application is needed to be developed aiming to collect standardized input information and to host the decision support services incorporating the knowledgebase.



## 3.2 SOLUTION APPROACH

The goal of this study is to employ a mechanism to: First, improve the referral management efficiency; and second, increases physicians' adherence to the consultation protocol. We define our solution approach according to the following steps:

**1. Development of a Knowledgebase and Decision Supporting Engine, incorporating the Spinal Condition Consultation Protocol:** To incorporate the Spinal Condition Consultation Protocol (SCCP) in both referral preparation and referral assessment processes, we construct a knowledgebase using the SCCP. For this purpose, a semantic web approach [47] is employed in which the protocol is transformed into an ontology model. The semantic web approach is preferred over other methods of clinical pathway computerization such as Rule-based or Decision model due to the following facts: 1) Ontologies are able to create semantically rich models that transform semantic relations among the protocol concepts. This facilitates the execution of the model by decision supporting engines. 2) Ontologies can model workflow structure of clinical pathways (in this case SCCP) that enables execution of resulting models, while other methods mainly focus on transformation of segments of pathways such as decision points and logics. We propose to develop a Decision Supporting Engine that provides the following services to assist the referral process: 1) Automatic referral assessment and patient triaging, which can decrease the administrative burden for hospital staff, improve referral management, and decrease patients waiting times [30]; 2) Clinical guideline recommendation to referring physicians, to improve pre and post referral therapies, and support physicians in forms of educational contents. For this purpose, the Decision Supporting Engine incorporates the described Knowledgebase to analyze referrals based on the SCCP model and provide intended decision supporting services during the referral process.

To transform the SCCP into a knowledgebase, we formulate our methodology based on the ontology engineering methodology introduced by Pinto et al [48]. This methodology is formed around the idea of merging and integration of existing

ontologies for the reusability purpose. The methodology comprises the following ten activities, as we employ throughout this research step:

- a) **Identify integration possibilities:** In this step the possibilities of ontology reuse and integration is investigated. Also any barrier to integration is identified.
- b) **Identify modules:** Identify building blocks (modules) that will be used to create the ontology. These modules can be sub-ontologies.
- c) **Identify assumptions and ontological commitments:** Identify assumptions and commitments that each ontology module should comply to. These assumptions should stay the same throughout ontology reuse.
- d) **Identify knowledge to be presented in each module:** Investigate the knowledge that should be presented by each module in the future ontology. It is also determined whether modules with proper assumptions exist to accommodate this knowledge. For this purpose a list of essential concepts are identified by the use of ontology conceptual models.
- e) **Identify candidate ontologies:** For this purpose it is required to find ontologies, and choose from available ontologies (filter unsuitable ontologies). Finding ontologies can be done by searching ontology repositories or relevant literature, taking into account attributes such as domain, formalism paradigm, main assumptions, concepts represented, and the level of availability.
- f) **Getting candidate ontologies:** Getting the candidate ontologies includes their representation and all the available documentations which should be publicly available.
- g) **Study and analysis of candidate ontologies:** Candidate ontologies should be analyzed by domain experts to ensure those ontologies represent necessary and sufficient knowledge, and whether they incorporate proper documentation and terminologies. Candidate ontologies also have to be analyzed by ontologies from different aspects such as ontological structure.
- h) **Choose source ontologies:** To choose among candidate ontologies, ontologies are selected that better suit the purpose, based on the result of analysis step (g). The

best candidates are ontologies that can better adapt to the purpose with less operation.

- i) **Apply integration operations:** To integrate selected ontologies, integration operations are performed. These operations may include composing, combining, modifying or assembling.
- j) **Analyze resulting ontology:** The resulting ontology is evaluated against evaluation criteria. The ontology is also analyzed to ensure it entails a proper level of detail.

The above framework assumes that multiple ontologies are selected as integration candidates. In our research however, we employ MACSON ontology (an ACS clinical practice guideline ontology [49]) as the knowledge reuse candidate. The reasons for this selection are ontology domain, formalism paradigm, concepts represented, and the level of availability. This candidate is favored due to fewer modification operations required to create the ontology model of interest.

**2. Implementation of an Electronic Referral System as a substructure for the Decision Supporting Engine:** To operationalize the suggested decision support services, we develop an Electronic Referral System (E-Referral) acting as a substructure for the Decision Supporting Engine. The final composed E-Referral system entails the following main components:

- i) *Graphical User Interface:* Provides the point of interaction with users to receive input and present output. This is an essential component of decision supporting systems [50, p. 34]. This component is responsible for collecting standardized referrals.
- ii) *Decision Supporting Engine:* Offers decision support services as described above.
- iii) *Data Storage and Management:* Preserves medical and non-medical data, and manages data storages.

To implement the described e-referral system, we employ a prototyping software engineering methodology [51, p. 43]. This includes the following steps:

- 1) **Requirements gathering:** Gathering e-referral system requirements by frequent interviews with domain experts; incorporating best practices and lessons learned derived from related literature review;
- 2) **Prototyping cycle:** Prototyping e-referral system Graphical User Interface component, gathering domain experts suggestions, repeating the cycle until an agreed interface is resulted;
- 3) **Design:** Finalizing software application internal components design and architecture, including integration of the Decision Support component with the User Interface and Data Storage components;
- 4) **Implementation:** Implementation of application components;
- 5) **Evaluation:** Evaluation of the e-referral system with regard to its reliability, performance, accuracy of results and user acceptability.

The methodology of developing the E-Referral system is expanded under three main sections. In this chapter we discuss the construction of system Knowledgebase. This explains the process of SCCP transformation into its representing ontology. In Chapter 2 the development of the Decision Supporting Engine is extensively described. This is followed by description of other E-Referral modules and its integration with the decision supporting mechanism.

### **3.3 SUBJECT-SPECIFIC KNOWLEDGE SOURCE ANALYSIS**

Our first step in the process of knowledgebase development is identification of knowledge sources applicable to the project scope. We have identified the following knowledge sources according to our requirements:

- Existing consultation protocol;
- Tacit knowledge of clinical experts in the area of research.

In the first case, as a requirement for this project we have taken into account the Spinal Condition Consultation Protocol (SCCP). SCCP is developed by neurosurgeons at the Halifax Infirmary Neurosurgery Division, and is mainly recommended to the Nova Scotia primary care physicians as a reference for management and referral of uncomplicated spinal conditions. The guideline is most recently revised in 2012. SCCP is described in details through following sections.

During the process of knowledge source analysis we had taken into account the tacit knowledge of neurosurgeons to clarify the ambiguities in SCCP. For this, we had several meetings with clinical experts who had been involved in the protocol development process.

### 3.3.1 Subject-Specific Knowledge Source: Spinal Condition Management Protocol (SCCP)

The SCCP is designed in a one page workflow style. It consists of initial medical investigations, followed by four key decision points in which patient condition severity is specified and patient is classified into one of three severity groups. According to the answer to these decisions, the patient will then pass a sequence of condition management interventions. Eventually the patient may be improved, or she can be referred to the Neurosurgery clinic (refer to Figure 3-1 to see a workflow of the protocol).

The first step prior to patient triage in SCCP is initial investigations regarding the patient's current problem. This step requires collecting information about patient's demographics, presenting medical history, past medical history, physical examination, and any radiology results.

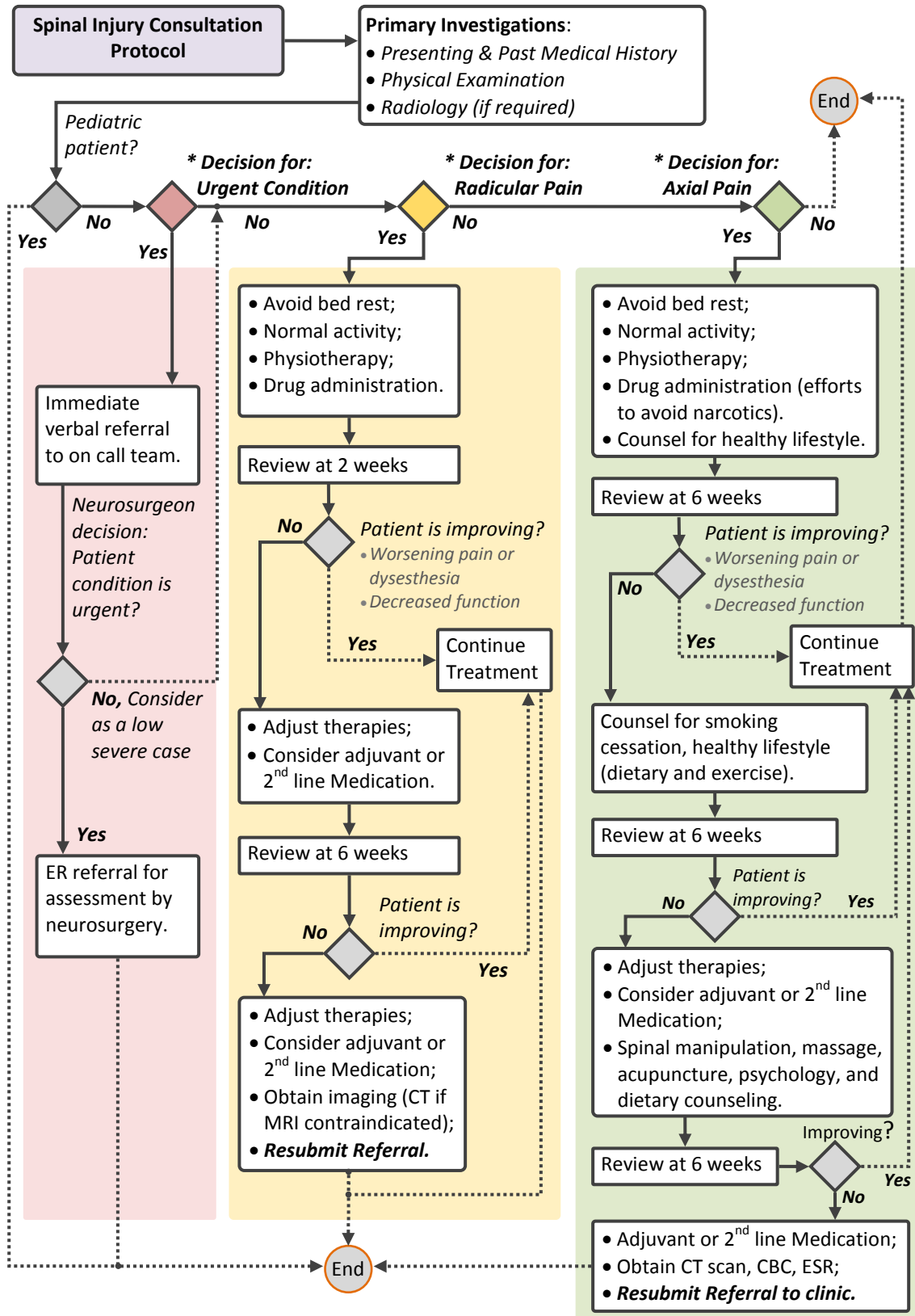


Figure 3-1 The Spinal Condition Consultation Protocol (SCCP) workflow diagram, following the refinement of the SCCP document.

The protocol then specifies a set of logical rules, to first calculate a severity score, and then categorize the patient in one of three severity classes (Axial pain, Radicular pain, or Urgent/Emergent). Severity categories define separate pathways for management of the patient's condition (Figure 3-1). Each pathway breaks in smaller course of actions which comprise of recommendations about appropriate physical activities, drug administration interventions, radiological imaging, physical therapy, and lifestyle counseling. Every set of interventions is bound to timeframe in which this collection of interventions should be accomplished. By the end of the specified period of treatments, in case not enough improvement is resulted in the spinal condition, patient should be referred to the Neurosurgery clinic for further investigations.

### 3.3.2 Conceptual Modeling

To formalize the domain knowledge, conceptualization of the domain concepts is performed. A conceptual model is abstract description of domain concepts which is explicitly defined [52]. This as well include attributes and constrains imposed on those concepts [53], [54].










Conceptual modeling is an essential step in the design of ontology based knowledge bases. Gruber defined an ontology as “an explicit specification of a conceptualization” [55]. Borst takes it to another level and defined it as a “formal specification of shared conceptualization” [56], in which formal indicates machine readability and shared denotes inclusion of consensual knowledge [57].

For the purpose of conceptual modeling in information systems, structured graphical methods are preferred [53]. For modeling the SCCP, most conceptual modeling conventions (e.g. UML) do not provide sufficient level of details.

We define a modeling convention of the type Task Network Model. In this method, building blocks of guideline hierarchy are modeled as network of tasks which are clearly defined [58]. Table 3-1 shows a list of elements used for modeling the SCCP. Most of

these elements are derived from well-known CPG computerization formalisms (e.g. GLIF, PROforma) [59], [60].

Table 3-1 Defined conceptual model symbol list.

Symbol	Description	Symbol	Description
	Start/End		Referral Step
	Diagnostic Step		Visit Step
	Treatment Step		Visit Schedule Step
	Branch Step		Decision Step
	Synchronization Step		

Conceptualization of SCCP required further refinement and clarification of the initial protocol. Therefore, as the first step we used domain experts' knowledge to revise the existing protocol. Specifically we tried to (examples refer to the original SCCP document):

1. Split large steps to produce desired granularity. For instance SCCP document included the step 'Order MRI and Request Specialist Consultation' that has been broken into two smaller steps: 'Order Imaging' and 'Refer for Consultation (subject: image review)'.
2. Merge similar steps to avoid repetition where applicable. As an example, both steps 'Order MRI and Request Specialist Consultation' and 'Refer to Pain Clinic' share the referral action, which has been merged in a single separate step.



3. Reorder steps, reduce unnecessary connections between steps and refine patient path throughout the guideline.
4. Diversify the care categories to cover all the possible patient conditions in SCCP scope to a possible extent. This yielded to three non-urgent categories and one urgent category. Further, we tried to modularize these categories and reduce the interconnections between them.

Following the refinement of SCCP and when all steps are in proper level of granularity, the SCCP passes an abstraction process. At this stage, each step in SCCP is annotated with the corresponding conceptual modeling element (Table 3-1). The final conceptual model of SCCP is outlined in Figure 3-2, Figure 3-3 and Figure 3-4.

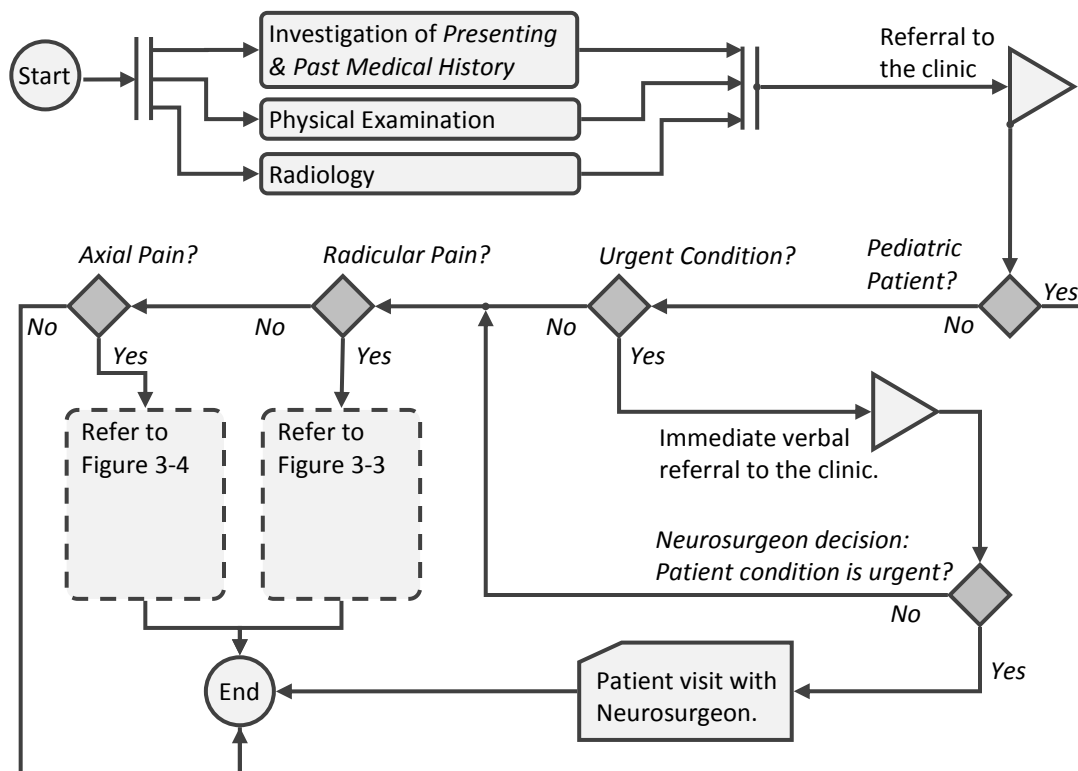


Figure 3-2 Conceptual model of SCCP (view 1)

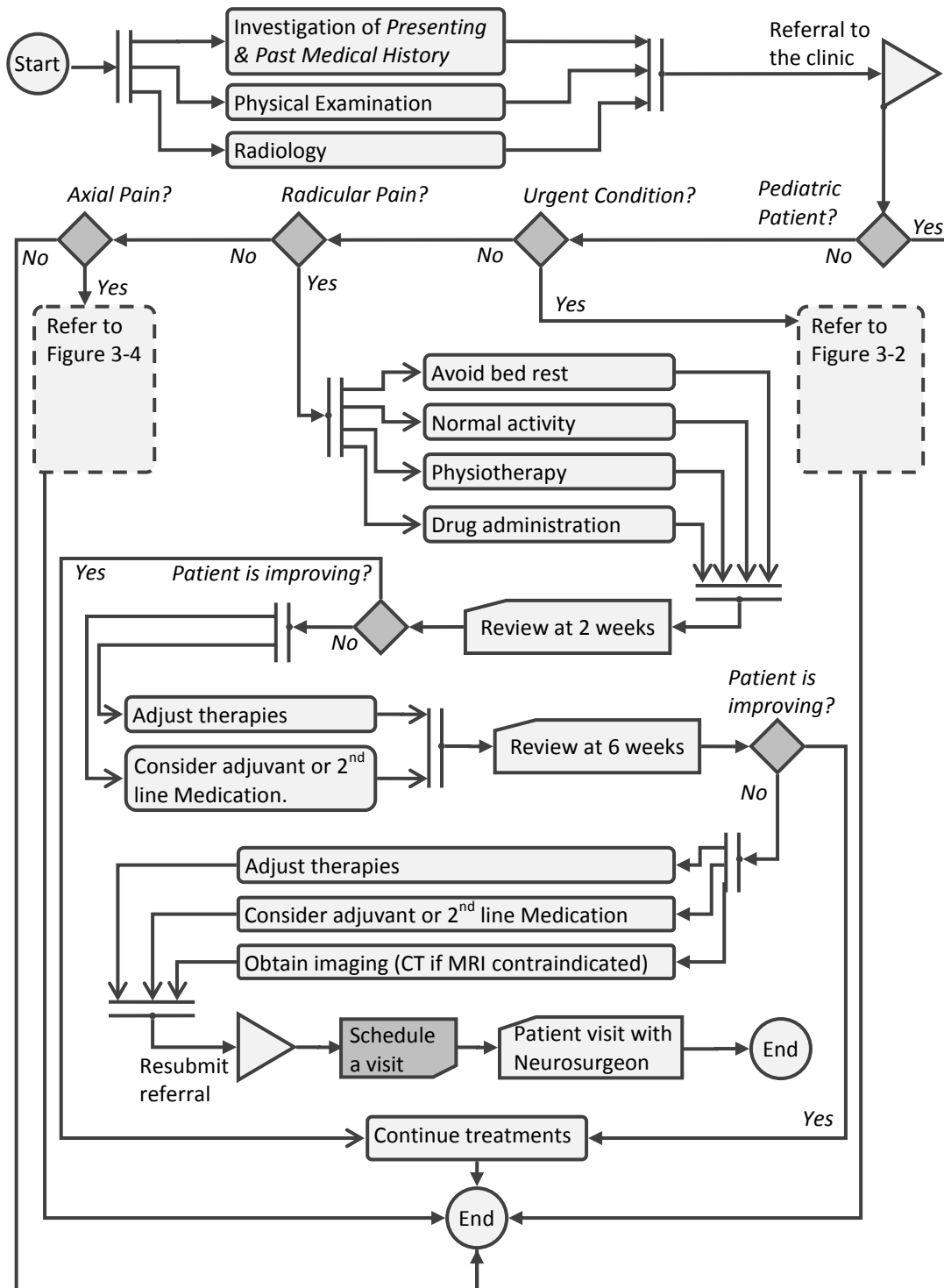


Figure 3-3 Conceptual model of SCCP (view 2)

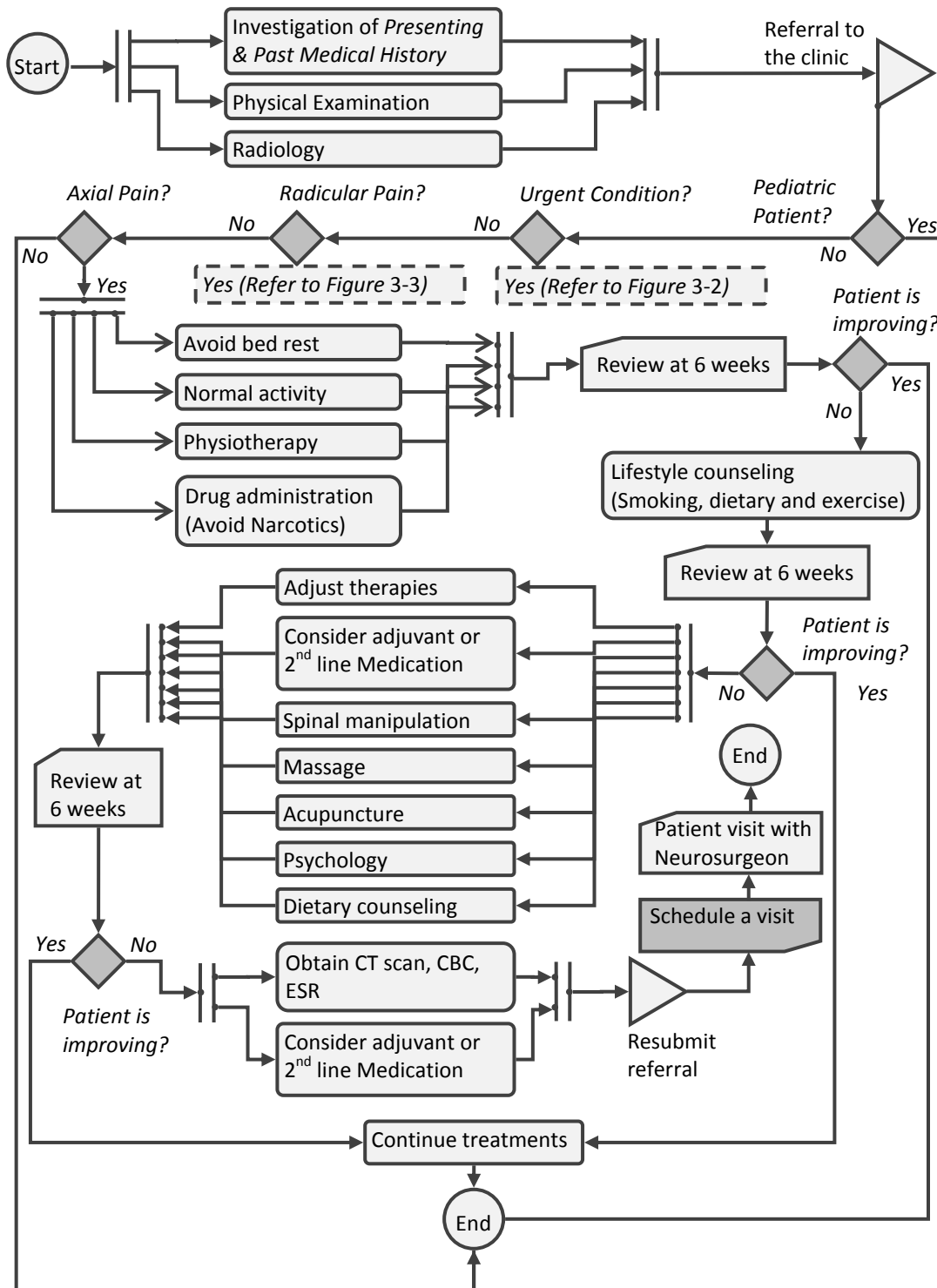


Figure 3-4 Conceptual model of SCCP (view 3)

The following is the description of elements comprising the SCCP conceptual model:

- *Diagnostic step*: In this step a diagnostic intervention is performed to collect diagnostic information about the patient's condition. Few examples are Physical Examination and Radiology Imaging.
- *Treatment step*: Represents a treatment intervention that is performed as a part of the patient's pathway in SCCP. Few instances are 2<sup>nd</sup> line Medication that is performed after one round of Drug Administration, Physiotherapy and Massage therapy.
- *Referral step*: Shows the act of composing and submitting a referral request for a patient spinal condition, to the Neurosurgery clinic. The referral step specifies how the referral is sent (e.g. verbal or via web), and to whom the referral is sent. Referral step includes specific referral subjects or questions.
- *Visit step*: A patient visit (either scheduled or unscheduled) with primary care physician or Neurologist/Neurosurgeon. This may result in a change in ongoing patient therapies. A visit step may come following a referral step to the Neurosurgery clinic.
- *Decision step*: In these steps a decision is made based on the patient's current medical status or medical history. Depending on the answer to the decision, only one of the decision options will be followed as the therapy pathway for the patient. An example for decision step is assessment for Radicular back pain. This decision is performed based on patient's pain characteristics. In case of positive answer, patient will be assigned to Radicular pain category and will follow the therapies for this category. A negative answer leads to another decision step which further assesses the patient's condition.
- *Branch step*: Specifies a group of steps to be performed simultaneously. Branching steps are always followed by Synchronization steps. For instance the branch step following positive answer to the Axial pain decision leads to a set of treatment steps to fulfill patient's first course of treatments.
- *Synchronization step*: Ensures all connected incoming steps are completed before the next step is started. This step defines no priority or order for the preceding steps.

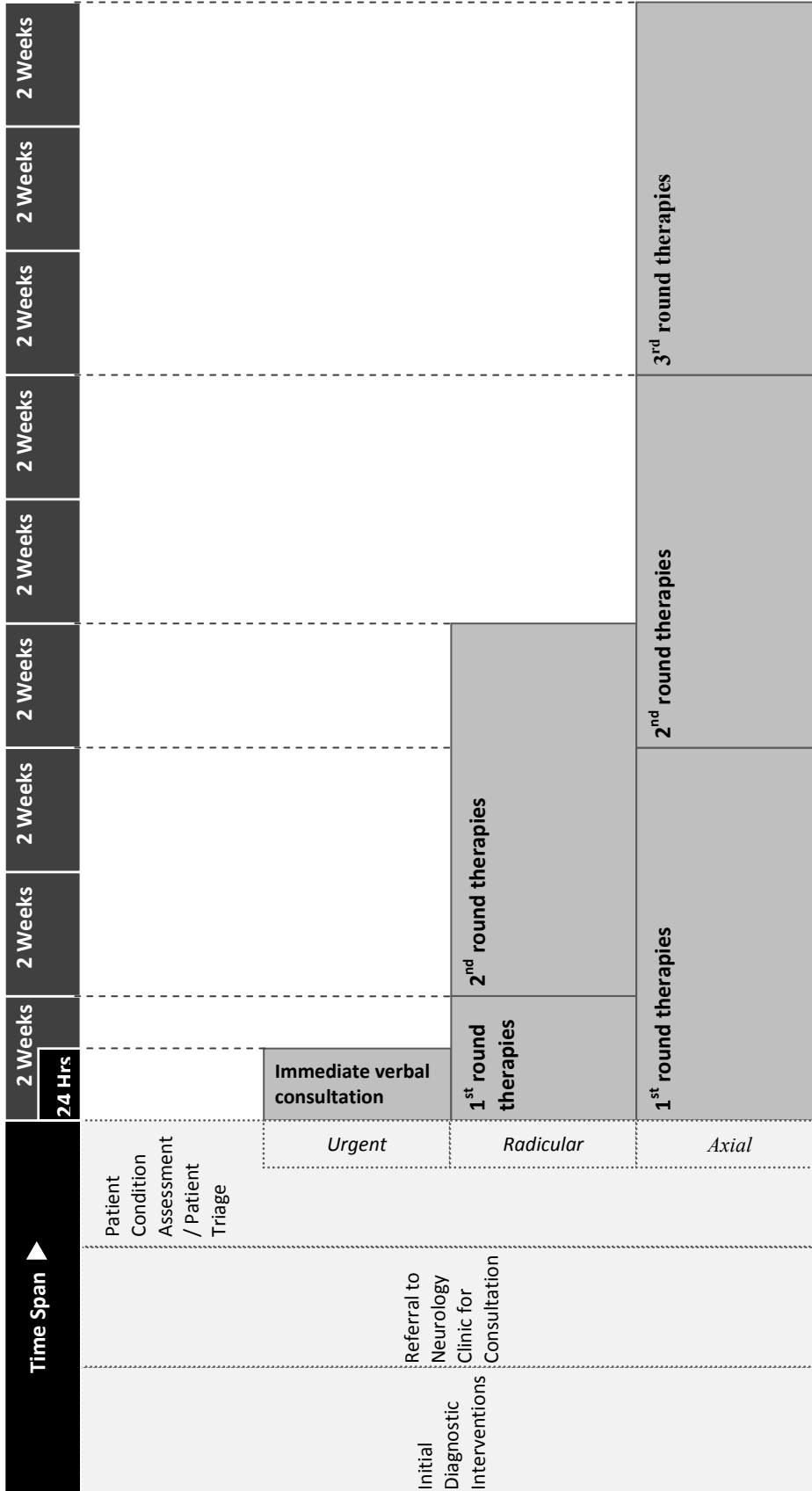


Figure 3-5 Illustration of time dimension in the SCM Protocol

The SCCP binds comprised therapy pathways to the time dimension. Time aspect is often used to specify an acceptable delay before starting an action, or the duration in which the action should be carried out. Figure 3-5 illustrates how time dimension is bound to different steps in SCCP.

Hours and Weeks are two granularity levels of time dimension that are considered in this protocol. Hours are used to apply restrictions on urgent actions (i.e. immediate consultation for urgent cases), and Weeks are used to specify therapy course durations.

### 3.4 KNOWLEDGE REPRESENTATION FORMALISM

To formalize the SCCP into a structured knowledgebase, we have employed the model developed by Omaish et al. for computerization of Acute Coronary Syndrome (ACS) clinical practice guideline (CPG) [49]. Their research resulted in a computer interpretable guideline implemented based on OWL ontology language. The ACS ontology is a detailed modification of earlier version of CPG ontology developed by Abidi et al. [61].

The developers of ACS ontology have taken into account the concept of modularization. The ACS ontology comprises 7 modules based on functional and structural similarities<sup>1</sup>. A description of different modules in this ontology is brought below:

1. **Task Network Model Module:** This module's classes are designed to implement patients' pathways in the ontology. The parent class *Guideline\_Step* captures different actions and routing steps that are present in the clinical guideline (see Figure 3-6). These steps interconnect by the object property *next\_step*, and form a workflow structure. The following is a description of subclasses:
  - I. *Action\_Step*: This class represents a parent class for all action steps used in the clinical guideline. Each type of Action can be done by *Actors* who have specific *Roles* (refer to Actors Module section). Responsible roles are assigned to actions by the object property *Responsible*. Some of the subclasses which distinguish

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<sup>1</sup> ACS ontology comprises of 113 classes and 161 properties.

different actions are: *Diagnostic\_Step*, *Treatment\_Step*, *Consultation\_Step* and *Disposition\_Step*.

- II. *Decision\_Step*: This class implements the act of decision making in the clinical guideline. Decisions will be further categorized under *Provider\_Decision\_Step*, for the decisions that a provider is responsible for, or *System\_Decision\_Step*, which will be processed by the decision support system. The available decision options for each decision instance are assigned by the use of object property *decision\_options*, with a domain from *Decision\_Option* class.
- III. *Decision\_Option*: The class holds options assigned to decision steps. They further connect to other *Guideline\_Steps* by the use of *next\_step* property.



Figure 3-6 ACS ontology Task Network module. Taken with permission from [62].

- IV. *Prioritization\_Step*: This class provides the possibility of supporting users in choosing the best recommended action from a set of interventions. The object property *has\_item\_to\_prioritize* connects possible interventions (as options to choose from) to the prioritization step.
  - V. *Root\_Step*: The subclasses of root step provide the possibility of branching, synchronizing and looping in the workflow. *Branch* and *Sync* allow occurrence of multiple interventions simultaneously. The *Loop* step allows iterations over the same step for a specific number of times (controlled by *iterations* data property).
2. **Intervention Module**: This module implements all the possible interventions through the clinical guideline (Figure 3-7). Interventions in this module use *has\_evidence\_update* object property to show the resulting evidence of the intervention (see Evidence Module section). The allowable Roles for Actors who can perform the defined interventions are also specified by the property *allowed\_roles\_to\_request*. All modeled interventions are descended from two higher level classes:
- I. *Intervention\_For\_Diagnosis*: Descended subclasses hold diagnostic interventions from the clinical guideline, such as *Diagnostic\_Imaging*, *Laboratory\_Exam* and *Physical\_Exam*. This class is also the range for the property *has\_diagnostic\_intervention*, which specifies a specific intervention for a *Diagnostic\_Step*.
  - II. *Intervention\_For\_Treatment*: Treatment interventions from the clinical guideline are instantiated using subclasses here. A few samples are *Drug\_Administration* and *Procedure\_For\_Treatment*. The property *has\_treatment\_intervention* uses this class as the range to assign interventions to *Treatment\_Step* instances. The object property *has\_expected\_adverse\_effect* is used to specify morbidity conditions as possible adverse effects of the included treatments.



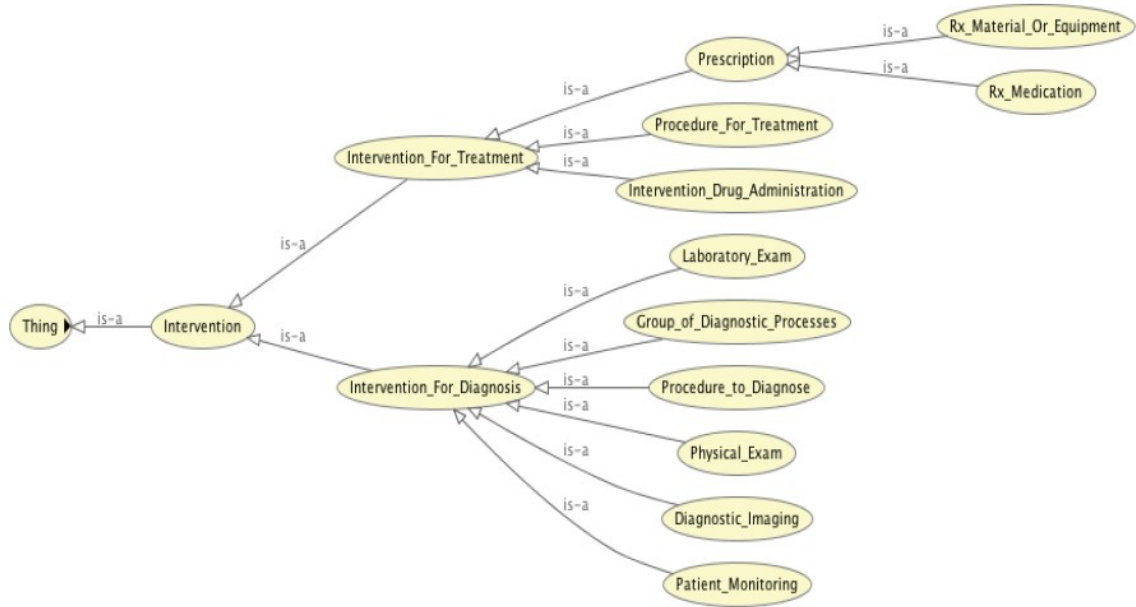


Figure 3-7 ACS ontology Intervention module. Taken with permission from [62].

3. **Evidence Module:** This module keeps the knowledge to support the evidence based medicine practice (*EBM* class). It uses classes *Evidence\_Scenario* and *Intervention\_Evidence\_Update* to record evidence scenarios and any published updates. This module has not been used during computerization of SCCP.
4. **Drugs Module:** Instantiation of drugs used in the clinical guideline is done in this module. Classification of different drug categories (e.g. Analgesic) is performed by utilizing subclasses for those categories. However this module does not provide appropriate subclasses to cover drug categories used by SCCP.
5. **Data Module:** Data module gather all datatype properties in the ontology under one single reusable module. It organizes the data mainly in two categories: 1) subclasses with EMR data that contain data related to patient medical record, such as patient's medical problems; 2) subclasses with CDSS data that include data required for CDSS logic execution, for instance severity score threshold. The ACS Data Module lacks appropriate granularity to hold SCCP data entities, which led us to develop additional classes for this purpose (refer to section 3.5.2).
6. **External Resource Module:** This module is designed to connect the ontology to external resources such as database tables.

7. **Actors Module:** This models different actors who may take part in patient pathway according to the clinical guideline. Each subclass in this module represents an individual with a specific role, such as *Patient* and *Physician*. The role for each subclass is assigned using the property *Provider\_Role*, with a range from class *Role*.

The ACS ontology has been developed to adapt the ACS 2011 version guideline; thus a portion of the classes and relations defined in this ontology do not apply to SCCP. On the other hand, we identified concepts in the SCCP model that do not have any match in ACS ontology. Therefore, modifications have been applied to the existing ACS ontology. These modifications are discussed through the following section.

### **3.5 ONTOLOGY MODIFICATION AND MODULE MAPPING**

As previously mentioned, we have utilized the ACS ontology [49] as a start point to develop a knowledge representation formalism to computerize SCCP. Considering functional and semantic characteristics of concepts in ACS ontology, most of the modules and classes in this ontology keep the same initial nature and intend (as explained by [49], [61]) through the transformation. However, certain changes have to be made to accommodate the computerized SCCP perfectly. The result of this process is SCCP Ontology (SCCPO). We followed three main steps to develop SCCPO: 1) final clarification of SCCP, 2) concept mapping, and 3) ontology modification.

#### **3.5.1 Final clarification of SCCP:**

Despite the initial clarifications in SCCP, to continue with complete computerization of the protocol we involved domain experts in a detailed analysis of this protocol. This process specifically aimed at obtaining clear definitions of *decisions steps and routing logics* present in SCCP.

The existing decision steps in SCCP can be categorized as provider decision steps and system decision steps. Execution of existing provider decision steps in SCCP has been determined to be out of scope of this system. We were able to spot four system decision

steps, which we attempted to analyze further and formulate their attached decision logics. The result of our analysis can be found in Figure 3-8.

Through four decision steps, named A, B, C and D for simplicity, the decision support engine assesses the patient's condition sequentially. In case the answer for any of the decisions is positive, the engine roots to relevant therapies; otherwise the following decision step is processed. The first decision step that is resolved (A) checks whether the patient is pediatric, considering the patient's age. Decision B determines if the patient has an urgent condition. For this, the system calculates a Severity Score based on patient's pain characteristics and medical history, comparing it to 1.0 as a specified threshold based on SCCP. For instance if the patient has either malignant disease or cancer, the Severity Score will be increased by 0.75 once. In case the patient has Neurogenic Bladder symptoms, the score will get increased by 1.0, which will exceed the threshold and patient's condition will be indicated as Urgent. Decision step C assesses the condition for Radicular Pain. For this to hold true, the pain should be arm/leg dominant, and radiates into hand(s) or one leg (with abnormal physical exam scores). The last decision step (D) determines whether patient has Axial Pain condition. This is determined by patient having neck/back dominant pain. Finally, in case all decision steps lead to negative answers, the pathway is ended with a termination step. This means the presenting patient's condition is not eligible for spinal condition consultation, based on the consultation protocol.

### 3.5.2 Concept Mapping and Ontology Modification

To employ an ontology which is a good fit to accommodate SCCP, we identified and applied required modifications to ACS ontology, by mapping the SCCP conceptual model to ACS ontology. This section explains the mapping process and the resulting changes to the ontology.

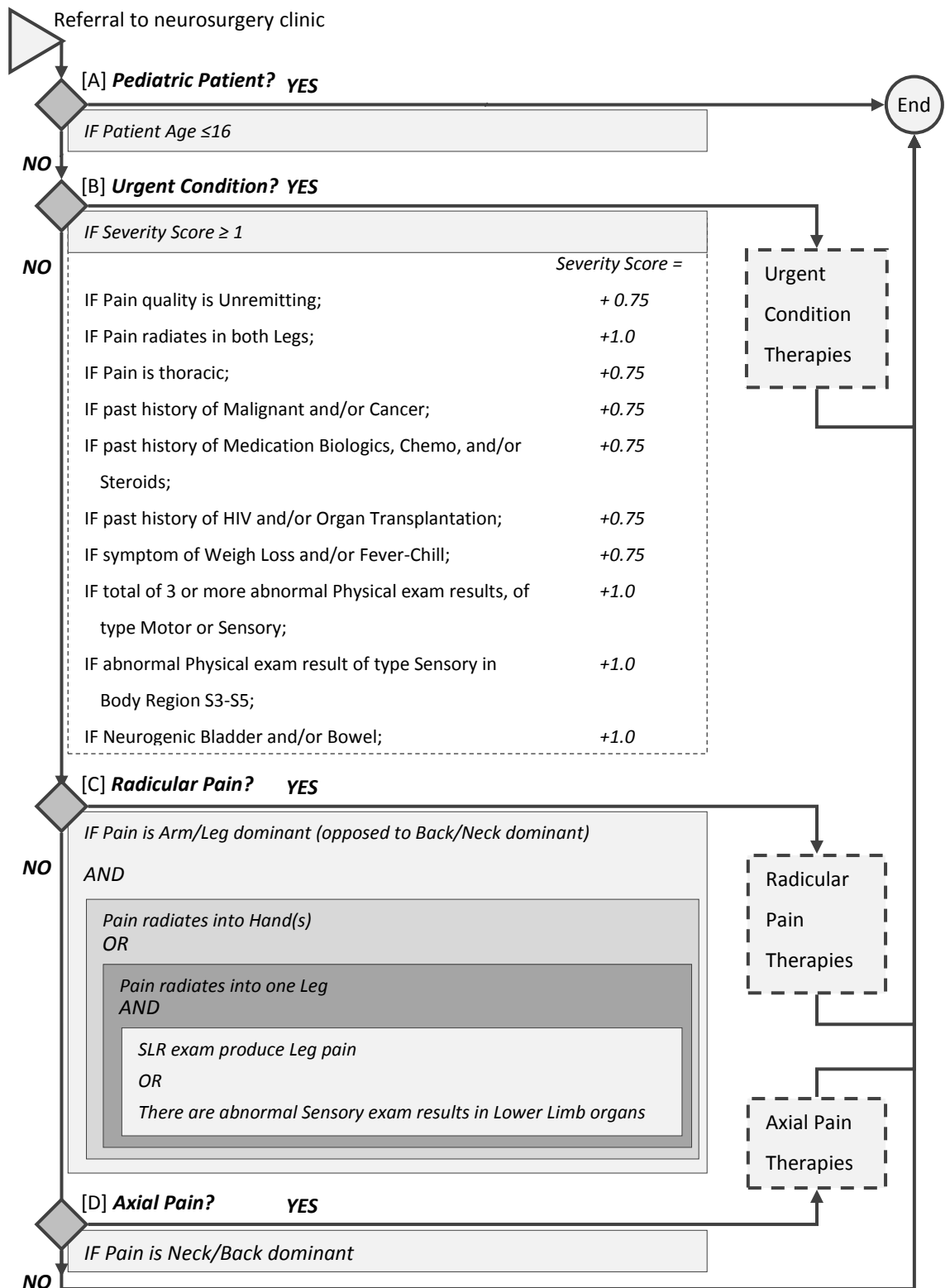


Figure 3-8 Overview of System Decision Steps and logics in SCCP

In this process we mainly used Protégé Desktop version 4.1 with support for OWL 2 [63]. This enabled us to apply restrictions that are not available in previous OWL specifications. We also utilized Pellet reasoner, embedded in the Protégé tool, to assess consistency of the ontology, and OntoGraf to visualize ontology diagrams.

To map the conceptual model to the ontology, we scanned and skimmed through the model. That is, starting from the ‘Start’ step, analyzing each step and proceeding to following steps. The process is ended when all the steps in the model have been analyzed successfully. In each step, we performed three actions: i) extracting, ii) mapping, and iii) applying ontology modifications.

- i) In each step of the conceptual model, we captured related concepts and their relations by referring to the relevant part in SCCP. For instance, in the step ‘Investigation of Presenting History’, the physician measures the patient’s age, weight and body temperature. Analysis of this step derives concepts such as: Acquiring Presenting History (an Action), Investigation (an Action), Physician, Patient, Age, Weight, Body Temperature; as well as following relations: Presenting History *is an* Investigation; Presenting History *is performed by* a Physician; it *results in* determination of Patient’s attributes; Age, Weight and Body Temperature *are some attributes* of Patients.
- ii) We mapped the extracted concepts and relations to the ACS ontology resources and properties based on functional or semantic similarities. To continue with our example, the Investigation action is mapped to Diagnostic\_Step due to its purpose. For map extracted relations we have taken into account the definition of triples from Resource Description Framework [64] (Figure 3-9). Accordingly, extracted relations and attached concepts were fit into triples as properties, their domains and ranges; in more general view subjects, predicates and objects. For instance, the relation: ‘the Investigation action is *performed by* a Physician’, can be mapped to triple (a) in Figure 3-10. In this relation, Subject and Object are classes of types Diagnostic\_Step and Physician connected with the object property Responsible. Similarly, the relation:

‘Age is an attribute of Patient’ is mapped to triple (b) with a data value of type Date as its range.



Figure 3-9 Mapping concepts and relations to triple patterns: subject-predicate-object

iii) While mapping extracted concepts to the ACS ontology, we have found number of concepts and relations that could not be mapped to any existing ACS classes and properties. In those cases, we have created additional resources in relevant modules. The majority of modifications have been made in Task-Network-Model, Intervention, and Data modules.

To bring an example, the main referral step in the SCCP (‘Referral to the Clinic’ in Figure 3-2) represents referrals from primary care physicians to the Neurosurgery clinic about spinal conditions. The instantiated ontology needs to hold attributes such as the referring physician, referred patient, responsible specialist, and condition triage category. The reference ACS ontology lacks the relevant step in the Task-Network-Module to implement a referral step with the described characteristics. Therefore, *Referral\_Step* has been added to this module with new properties including: *referredByIndividual*, *referredIndividual*, *referredToIndividual*, and *triageCategory*.

There is a part of extracted concepts that captures data regarding patient clinical history. The collection of these concepts forms a clinical record for the patient. The purpose of this clinical record is very similar to the ACS ontology Data module; however the implementation of the Data module lacks the sufficient granularity to accommodate those concepts. A notable example is patient’s pain that is characterized with detailed attributes; these include pain onset, pain quality, affecting body regions, radiating body regions, aggravating and relieving factors, and pain severity. The comprehensiveness of these attributes is crucial for application-based decision processing in SCCP. To handle

similar cases of clinical history in SCCPO, we implemented new classes and properties to form a clinical patient record.

For the purpose of implementing an integrated clinical patient record, we have taken into consideration the Computer-Based Patient Record (CPR) ontology [65] as a reference for new classes and properties in SCCPO. CPR ontology is a set of uniform core medical data elements which are captured and semantically bound together based on few medical and non-medical knowledge sources and terminologies, including SNOMED-CT (medical terminology), BFO (top-level philosophical ontology), BioTop (top-level life science ontology), and OWL Time (temporal concepts ontology) [66]. We searched the CPR ontology to find ontology resources that can implement the necessary clinical history structure in SCCPO. We have spotted four classes and four properties as listed in Table 3-2.

Table 3-2 Collection of concepts and properties used to form a patient medical record structure from the CPR ontology.

<b>Classes</b>	<i>Clinical_Finding</i>	Representation of pathological signs and findings, such as vital signs.
	<i>Medical_Problem</i>	Medical problems that require health provider intervention, such as chronic or acute problems.
	<i>Physical_Anatomical_Entity</i>	Anatomical components of physical body, such as limbs.
	<i>Temporal_Interval</i>	Any temporal duration greater than a single moment, such as 10 seconds or 2 hours.
<b>Properties</b>	<i>findingSite</i>	Relates an anatomical entity to a clinical finding as the point of focus.
	<i>outputOf</i>	Relates a clinical finding to the process that results in diagnosing it.
	<i>subjectOfDescription</i>	Relates a fact in medical record to the patient whom that record is about.

	<i>composedBy</i>	Relates a fact in medical record to the provider who creates that.
--	-------------------	--

To continue with our recent example, patient’s pain can be categorized under the *Clinical\_Finding* class. Due to comprehensive attributes of this type of finding, we place the pain under a subclass of *Clinical\_Finding* to distinguish it from other types of clinical findings (i.e. physical exam findings, and vital sign findings). Section 3.6 describes the result of these modifications in the final SCCPO.

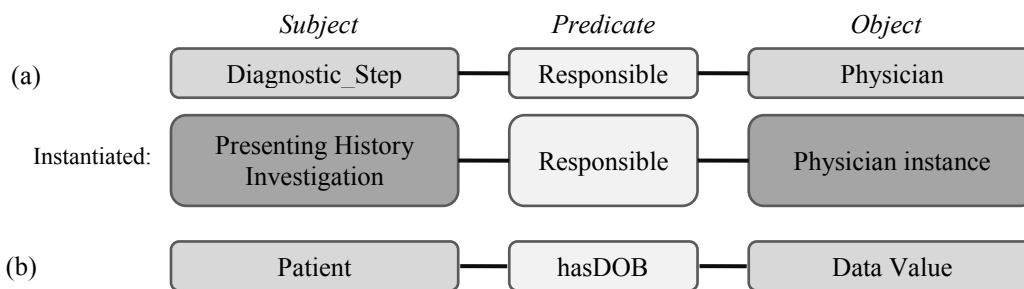


Figure 3-10 Mapping extracted SCCP concepts and relations to RDF resource-property triples. (a) a triple containing object property; (b) a triple containing data-type property.

### 3.6 THE FINAL SCCP ONTOLOGY (SCCPO)

SCCPO is the product of a three step process: extraction of concepts and relations from SCCP, mapping extracted concepts to ACS ontology, applying modifications to the ontology where needed.

The SCCPO utilizes number of additional classes and properties compared to its origin ontology. Based on SCCP, new restrictions have also been defined to improve ontology consistency. The ontology does not use number of modules and classes from ACS ontology; those mainly are: *Data\_Element*, *EMB*, *External\_Resources*, *Disposition\_Step*, *Education\_Step*, *Prioritization\_Step*, *Loop\_Step*, and *Morbidity\_Condition*.



### 3.6.1 Concepts and Classes

The final SCCPO can be viewed as the combination of two main modules:

1. **Task Network Model (TNM):** The purpose of this module is similar to its identical module in ACS ontology. We consider functional similarity to realign the classes in this module. SCCP ontology TNM module is outlined in Figure 3-11 (a).

The top-level class *Action\_Step* now is connected to new properties that add temporal characteristics to the module. The object property *durationExpected* specifies allowed time durations for processing of different action steps. It connects action steps to instances of the *Temporal\_Interval* class (described later). Object properties *time\_start* and *time\_end* specify start and end times for action steps (of type *DateTime*). Furthermore, the object property *hasParticipant* relates an action to its participants by making connections to individual actors (instances of class *Individuals\_Involved*). These attributes are inherited to all child steps as members of TNM module.

Table 3-3 Direct object and data properties for the class *Referral\_Step*

	URI	Description	Range
Object Properties	<i>referredByIndividual</i>	Referring physician	<i>Physician</i>
	<i>referredIndividual</i>	The patient whose condition is the subject of referral	<i>Patient</i>
	<i>referredToindividual</i>	Clinic staff or subspecialist who receives the referral	<i>Individuals_Involved</i>
Data Properties	<i>hasReferralQuestion</i>	Specific referral questions which is asked by the referring physician	<i>String</i>
	<i>referralLink</i>	the communication method used for referral (e.g. verbal, electronic)	<i>String</i>
	<i>triageAsmntScore_clinical</i>	Calculated clinical assessment points, used for patient triaging	<i>Integer</i>

<i>triageAsmntScore_pathology</i>	Calculated pathology assessment points, used for patient triaging	<i>Integer</i>
<i>triageAsmntScore_radiology</i>	Calculated radiology assessment points, used for patient triaging	<i>Integer</i>
<i>traigeCategory</i>	The category under which the patient is triaged (i.e. urgent, radicular, axial).	<i>String</i>

A number of subclasses have been added to the *Action\_Step* to model distinct actions. Referral, one of the key actions in SCCP, is modeled by the use of *Referral\_Step* class. This class is the domain for properties that define the referral characteristics. These attributes are listed in Table 3-3. Moreover, two other new classes, *Schedule\_Step* and *Visit\_Step*, are added to the *Action\_Step* to model appointments scheduling and primary/secondary practitioners' visits.

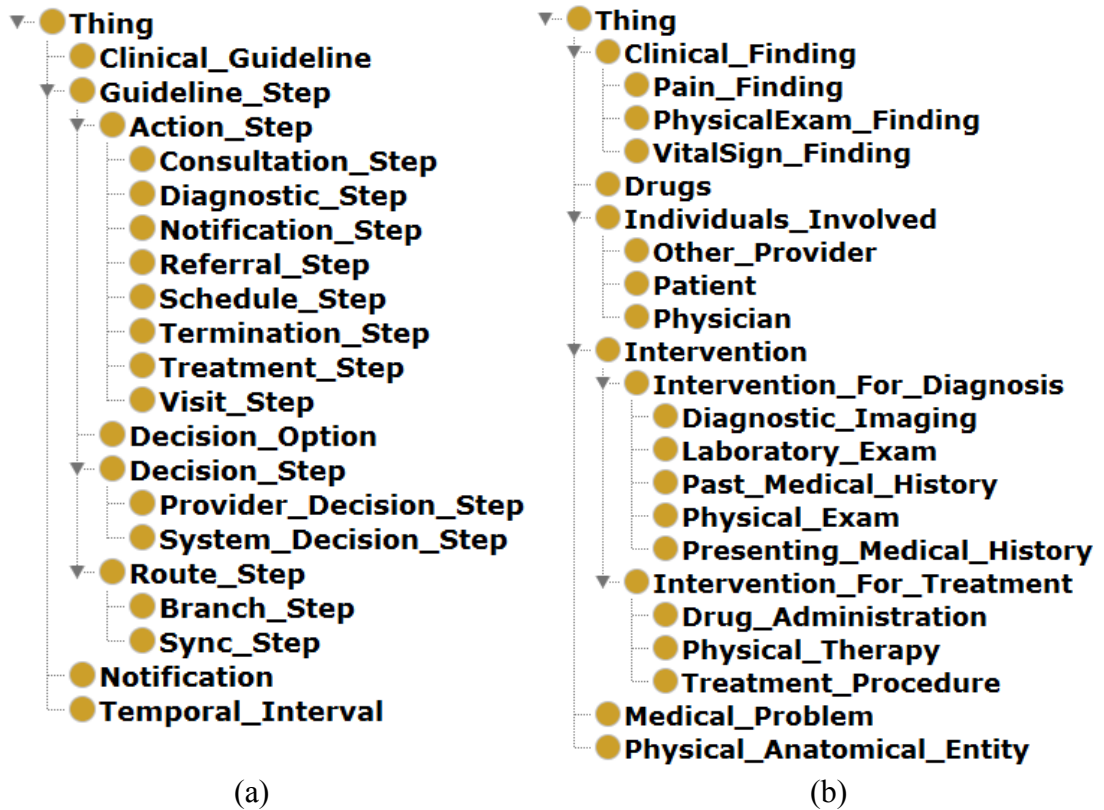


Figure 3-11 Tree diagram of SCCP ontology, in two different views:  
 (a) Task-Network-Model module; (b) Clinical Patient Record module

We have modeled the temporal characteristics of SCCP by creating the *Temporal\_Interval* Class. An instance of this class represents single continues time interval, based on a time length and its associated time unit. Accordingly, the data-property *intervalValue* represents length of the interval using an integer value, and the data-property *intervalUnit* specifies the time unit using a string value. *intervalUnit* accepts Hours or Weeks, based on temporal duration types in SCCP (smallest duration of 24 hours and longest of 6 weeks).

2. **Clinical Patient Record Module:** This module implements a model to capture patient’s medical history information throughout the course of treatment. It introduces new classes based on the CPR ontology (see section 3.5.2) in addition to the existing classes taken from the ACS ontology. Figure 3-12 outlines a network of comprising classes and interconnecting properties.

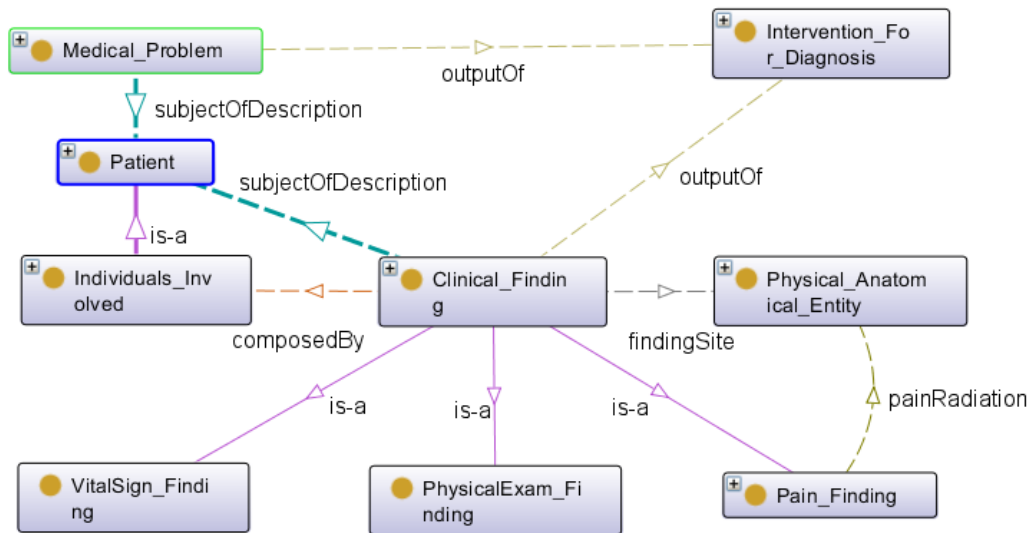


Figure 3-12 Clinical Patient Record Module and related object-properties

The *Cinical\_Finding* class is created to store a record about patients’ signs and symptoms. Each instance is composed by a provider (property *composedBy*), relates to a patient as the subject of this record (property *subjectOfDescription*), and is recorded following a diagnostic intervention (property *outputOf*). Clinical finding

instances are also connected to body areas that are being affected by these findings (property *findingSite*). Figure 3-11 (b) outlines the *Cinical\_Finding* class and related properties.

The class *Pain\_Finding* models pain symptoms in a fine level of details. A number of data and object properties are used to capture pain attributes, such as pain location, quality, and severity (see Table 3-4).

Table 3-4 Direct data and object properties for class *Pain\_Finding*

	URI	Description	Range
Object Properties	<i>painAggravatingFactor</i>	Factors that aggravate patient's pain	<i>Intervention</i>
	<i>painRadiation</i>	Radiation of the pain into body limbs	<i>Physical_Anatomical_Entity</i>
	<i>painRelievingFactor</i>	Factors that relieve patient's pain	<i>Intervention</i>
Data Properties	<i>painOnset</i>	The time at which patient problem has started	<i>String</i>
	<i>painQuality</i>	The quality of the pain; e.g. ache, burning, electric shock	<i>String</i>
	<i>painSeverity_average</i>	The pain average severity score; value from 1-10	<i>Integer</i>
	<i>painSeverity_best</i>	The pain best severity score; value from 1-10	<i>Integer</i>
	<i>painSeverity_worst</i>	The pain worst severity score; value from 1-10	<i>Integer</i>

The *PhysicalExam\_Finding* and *VitalSign\_Finding* classes hold two other types of clinical finding. Results from four types of spine physical examinations (Motor, Sensory, DTR and Mechanical) are stored as instances of *PhysicalExam\_Finding*. This class stores examination score values and associated normal values by the use of two data properties: *value* and *value\_normal*. Other vital signs of patients are stored using *VitalSign\_Finding* class, and two data properties *value* and *unit*.

Each clinical finding requires recording of the physical body area that is related to this finding. This is modeled by employing *Physical\_Anatomical\_Entity* class. Instances of this class represent different physical body areas.

The class *Medical\_Problem* represents records of medical problems which patients are diagnosed with. Each record is documented as a result of a diagnostic step (*Diagnostic\_Step*) or a consultation step (*Consultation\_Step*) that is connected using object property *outputOf*. The property *subjectOfDescription* relates the record to the person whom this record is describing, and *time\_start* and *time\_end* specify the time frame in which the medical problem exists.

Different individuals who are involved in patients' pathways have instantiated instances under the class *Individuals\_Involved*. This class stores an individual's names, address, telephone and email by utilizing according data properties. Furthermore, a role is assigned to each individual using data property *hasRole* of type string (e.g. 'patient', 'physician\_generalPractice', 'specialist\_neurosurgeon'). Patients and physicians are modeled using two separate subclasses due to their distinctive identity information. Patients require date of birth, gender and insurance number/provider in addition to the typical identity information, while physicians require valid fax numbers for the purpose of communication (see Table 3-5).

We have added two new subclasses, *Presenting\_Medical\_History* and *Past\_Medical\_History*, to the *Intervention\_For\_Diagnosis* class. These classes represent interventions that are performed to document patients' presenting medical history and past medical history.

Table 3-5 Object and data properties for the class *Individuals\_Involved* and its subclasses

Domain	URI	Range	URI	Range
<i>Individuals_Involved</i>	<i>hasRole</i>	<i>string</i>	<i>person_address</i>	<i>string</i>
	<i>person_city</i>	<i>string</i>	<i>person_postalCode</i>	<i>string</i>
	<i>person_email</i>	<i>string</i>	<i>person_name_first</i>	<i>string</i>
	<i>person_name_last</i>	<i>string</i>	<i>person_telNum</i>	<i>string</i>
<i>Patient</i>	<i>isSubjectOfDescription</i>	<i>Clinical_Finding and Medical_Problem</i>	<i>participatesIn</i>	<i>Action_Step</i>
	<i>patient_dateOfBirth</i>	<i>dateTime</i>	<i>patient_gender</i>	<i>string</i>
	<i>patient_insuranceNum</i>	<i>string</i>	<i>patient_insuranceProvider</i>	<i>string</i>
	<i>patient_cellNum</i>	<i>string</i>		
<i>Physician</i>	<i>participatesIn</i>	<i>Action_Step</i>	<i>person_faxNum</i>	<i>string</i>

### 3.6.2 OWL Restrictions and Property Characteristics

To improve reasoner inference over the SCCP ontology and increase ontology consistency we have defined OWL restrictions and property characteristics. In this section we describe the usage of necessary and sufficient conditions, cardinalities and property characteristics. All the expressions are listed as they appear in Protégé 4.

**Necessary and Sufficient Conditions:** We used OWL existential restrictions over ontology properties to restrictedly specify sets of values or entities that are acceptable as properties' ranges (necessary conditions). An example of a necessary condition in SCCPO is restrictions applied over individuals involved in referral actions. For this, existential restrictions apply on properties: *referredByIndividual*, *referredIndividual*, and *referredToIndividual* with the domain: *Referral\_Step*. Expressions defining those necessary conditions are listed below:

```
referredByIndividual some (Physician and (hasRole value
"physician_generalPractice"^^string))
```

```
referredIndividual some Patient
```

```
referredToIndividual some (Physician and (hasRole only
{"specialist_neurologist"^^string , "specialist_neurosurgeon"^^string}))
```

Another example is restriction over roles who can create a *Clinical\_Finding* record. This restriction is defined on *Clinical\_Finding* class using the following expression:

```
composedBy some (Physician and (hasRole only
{"physician_generalPractice"^^string , "specialist_neurologist"^^string ,
"specialist_neurosurgeon"^^string}))
```

Due to the open world assumption of OWL language, definition of primitive classes (classes with at least one necessary condition) results in inference of properties ranges that are not intended. To avoid this behavior we added universal restrictions as closing axioms to the ontology. To continue with our previous example, the *Clinical\_Finding* class has the following sufficient condition applied:

```
composedBy only (Physician and (hasRole only
{"physician_generalPractice"^^string , "specialist_neurologist"^^string ,
"specialist_neurosurgeon"^^string}))
```

As another example, *Visit\_Step* requires participants only from patients or physicians:

```
hasParticipant some Patient
hasParticipant some Physician
hasParticipant only (Patient or Physician)
```

**Cardinalities:** Minimum, maximum and exact cardinality attributes are used to restrict the number of elements in properties ranges. Minimum cardinality has been used for properties which represent mandatory attributes for concepts. For instance pain finding records (*Pain\_Finding*) require at least one assigned radiation body part and one assigned pain quality:

*painQuality* **min** 1 Literal

*painRadiation* **min** 1 Thing

There are attributes that are not mandatory, yet can only relate to at most one entity. For example it is possible that an action step (from class *Action\_Step*) is in an ongoing state (no end time is recorded) but it can only accept one end time when the action has ended:

*time\_start* **max** 1 Literal

*time\_end* **max** 1 Literal

However some instances cannot exist without exactly one relation over their properties. As an example temporal intervals require only one interval unit and interval value:

*intervalValue* **exactly** 1 Literal

*intervalUnit* **exactly** 1 Literal

To have a comprehensive understanding of the key classes in SCCP ontology we bring a full list of property relations and restrictions for two classes: *Pain\_Finding* and *Referral\_Step*; please see Table 3-6 and Table 3-7.



Table 3-6 Restriction on SCCP ontology class *Pain\_Finding*

	Restriction
Sub Class of	<i>Clinical_Finding</i>
	<i>findingSite</i> <b>min</b> 1 Thing
	<i>findingSite</i> <b>only</b> <i>Physical_Anatomical_Entity</i>
	<i>findingSite</i> <b>some</b> <i>Physical_Anatomical_Entity</i>
	<i>painAggravatingFactor</i> <b>only</b> ( <i>Clinical_Finding</i> <b>or</b> <i>Intervetion</i> )
	<i>painAggravatingFactor</i> <b>some</b> ( <i>Clinical_Finding</i> <b>or</b> <i>Intervetion</i> )
	<i>painOnset</i> <b>exactly</b> 1 Literal
	<i>painQuality</i> <b>min</b> 1 Literal
	<i>painRadiation</i> <b>min</b> 1 Thing
	<i>painRadiation</i> <b>only</b> <i>Physical_Anatomical_Entity</i>
	<i>painRadiation</i> <b>some</b> <i>Physical_Anatomical_Entity</i>
	<i>painRelievingFactor</i> <b>min</b> 1 Thing
	<i>painRelievingFactor</i> <b>only</b> <i>Intervention</i>
	<i>painRelievingFactor</i> <b>some</b> <i>Intervention</i>
	<i>painSeverity_average</i> <b>exactly</b> 1 Literal
<i>painSeverity_best</i> <b>exactly</b> 1 Literal	
<i>painSeverity_worst</i> <b>exactly</b> 1 Literal	
Sub Class of (inherited)	<i>SubjectOfDescription</i> <b>some</b> <i>Patient</i>
	<i>composedBy</i> <b>some</b> ( <i>Physician</i> <b>and</b> ( <i>hasRole</i> <b>only</b> {"physician_generalPractice"^^string , "specialist_neurologist"^^string , "specialist_neurosurgeon"^^string}))
	<i>composedBy</i> <b>only</b> ( <i>Physician</i> <b>and</b> ( <i>hasRole</i> <b>only</b> {"physician_generalPractice"^^string , "specialist_neurologist"^^string , "specialist_neurosurgeon"^^string}))
	<i>subjectOfDescription</i> <b>only</b> <i>Patient</i>
	<i>composedBy</i> <b>exactly</b> 1 Thing

Table 3-7 Restriction on SCCP ontology class *Referral\_Step*

	Restriction
Sub Class of	<i>Action_Step</i>
	<i>Has_treatment</i> <b>some</b> <i>Intervention_For_Treatment</i>
	<i>referralSubject</i> <b>only</b> ( <i>Clinical_Finding</i> <b>or</b> <i>Intervention</i> <b>or</b> <i>Medical_Problem</i> )
	<i>referralSubject</i> <b>some</b> ( <i>Clinical_Finding</i> <b>or</b> <i>Intervention</i> <b>or</b> <i>Medical_Problem</i> )
	<i>referredByIndividual</i> <b>exactly</b> 1 Thing
	<i>referredByIndividual</i> <b>only</b> ( <i>Physician</i> <b>and</b> ( <i>hasRole</i> <b>value</b> "physician_generalPractice"^^string))
	<i>referredByIndividual</i> <b>some</b> ( <i>Physician</i> <b>and</b> ( <i>hasRole</i> <b>value</b> "physician_generalPractice"^^string))
	<i>referredIndividual</i> <b>exactly</b> 1 Thing
	<i>referredIndividual</i> <b>only</b> <i>Patient</i>
	<i>referredIndividual</i> <b>some</b> <i>Patient</i>
	<i>referredToIndividual</i> <b>exactly</b> 1 Thing
	<i>referredToIndividual</i> <b>only</b> ( <i>Other_Provider</i> <b>or</b> ( <i>Physician</i> <b>and</b> ( <i>hasRole</i> <b>only</b> {"specialist_neurologist"^^string , "specialist_neurosurgeon"^^string})))
	<i>referredToIndividual</i> <b>some</b> ( <i>Other_Provider</i> <b>or</b> ( <i>Physician</i> <b>and</b> ( <i>hasRole</i> <b>only</b> {"specialist_neurologist"^^string , "specialist_neurosurgeon"^^string})))
Sub Class of (inherited)	<i>hasParticipant</i> <b>some</b> <i>Individuals_Involved</i>
	<i>nextStep</i> <b>max</b> 1 Thing
	<i>time_start</i> <b>max</b> 1 Literal
	<i>durationExpected</i> <b>only</b> <i>Temporal_Interval</i>
	<i>time_end</i> <b>max</b> 1 Literal
	<i>durationExpected</i> <b>max</b> 1 Thing
	<i>hasParticipant</i> <b>only</b> <i>Individuals_Involved</i>

### 3.6.3 Ontology Instantiation

The final SCCP ontology comprises 42 ontology classes, 27 object properties and 48 data properties. Number of individuals however, is not definite due to different approaches in which the instantiation is performed. In action, SCCPO is instantiated through two approaches:

**Manual instantiation:** In the first approach we instantiated the SCCPO manually once through the software development life cycle. This process added instances that are commonly used throughout patients' care pathways, and remain mostly unchanged. These instances lie under two groups: 1) commonly used domain knowledge instances; such as physical body areas, drug classifications. 2) TNM related instances; including guideline steps, and temporal intervals. A graph of TNM instances and their relations is outlined in Figure 3-13. Manual instantiation of the ontology resulted in 132 instances, which are extensively listed in Table C-1.

**Automatic instantiation:** Second mode of ontology instantiation takes place in each execution cycle of SCCPO by the Decision Supporting Module (see Section 4.7.1). In other words, the process of automatic instantiation and instance modifications is a task dynamically performed during the automated referral processing and execution. The majority of these instances belong to Clinical Patient Record module classes; i.e. clinical findings and medical problems. An example of automatically created instance would be a physical examination finding for left knee extension with a value of 2 and exam type of motor. A single execution of ontology can dynamically add up to 180 instances to the ontology. Table C-2 shows a sample list of instances that can be created during automatic instantiation.

## 3.7 CONCLUSION

In the first part of this chapter we described our solution approach for our research problem. In the second part, we discussed how the SCCP ontology (SCCPO) is designed and developed, as an essential component of our proposed decision support services. The

second part starts with a review of Spinal Condition Management Protocol (SCCP) as our subject-specific knowledge source. We then had a brief overview of ACS ontology as a ground knowledgebase schema. Afterwards it is explained how SCCP conceptual model is mapped to our base ontology, and what modifications have been applied to transform ACS ontology into the SCCPO. The chapter ends with a comprehensive overview of the final SCCPO, including classes, properties, restrictions, and instantiation methods.

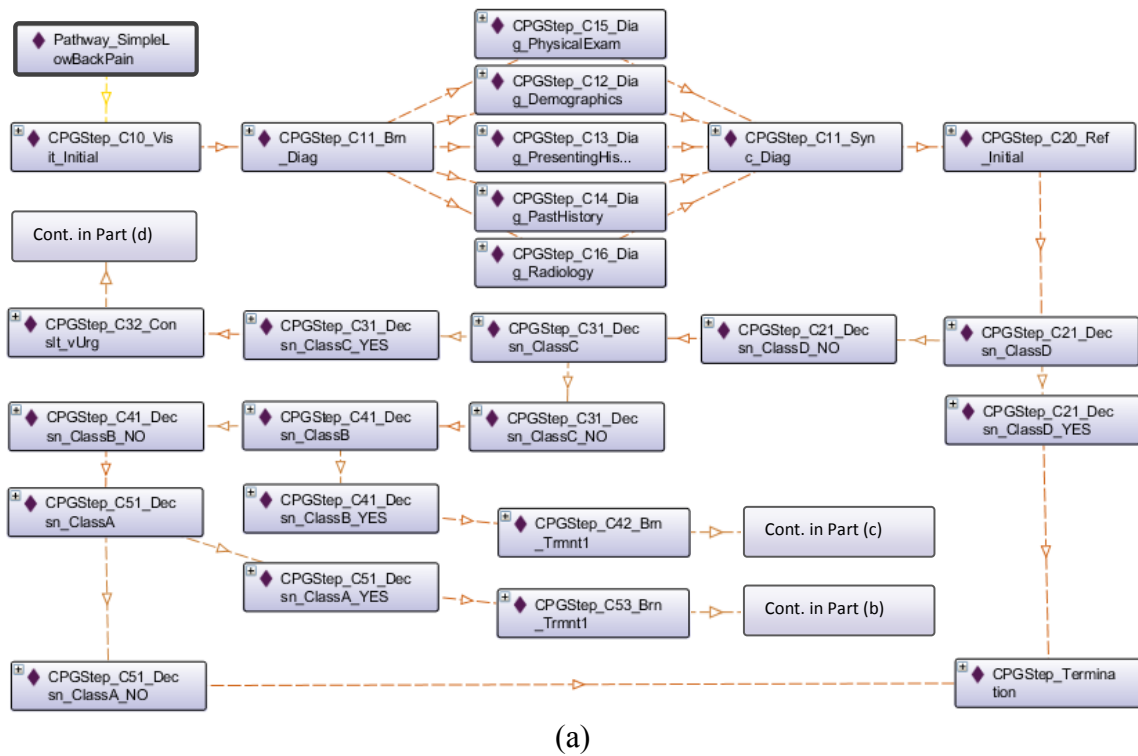
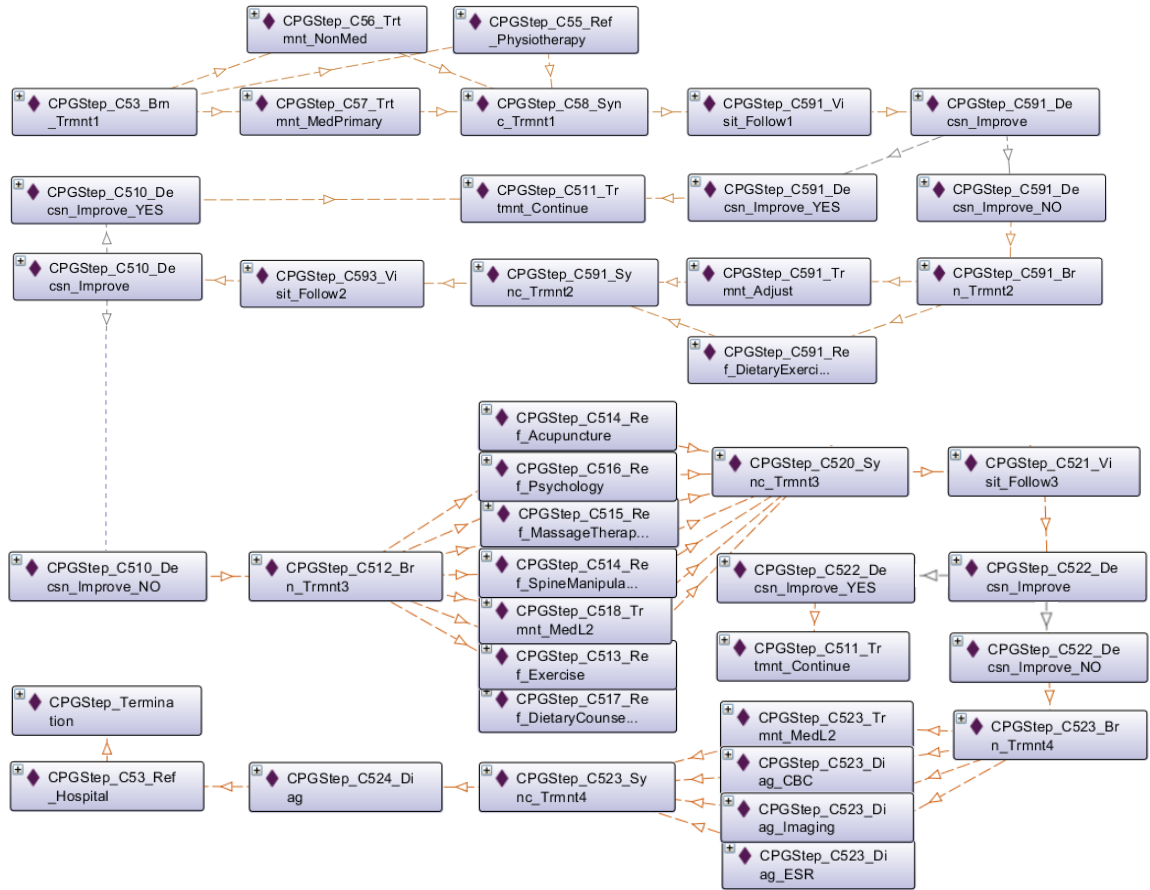


Figure 1-13 SCCP ontology TNM module instances graph. This graph provides a top-level view of the SCCP workflow.



(b)

Figure 1-13 SCCP ontology TNM module instances graph. This graph provides a top-level view of the SCCP workflow.

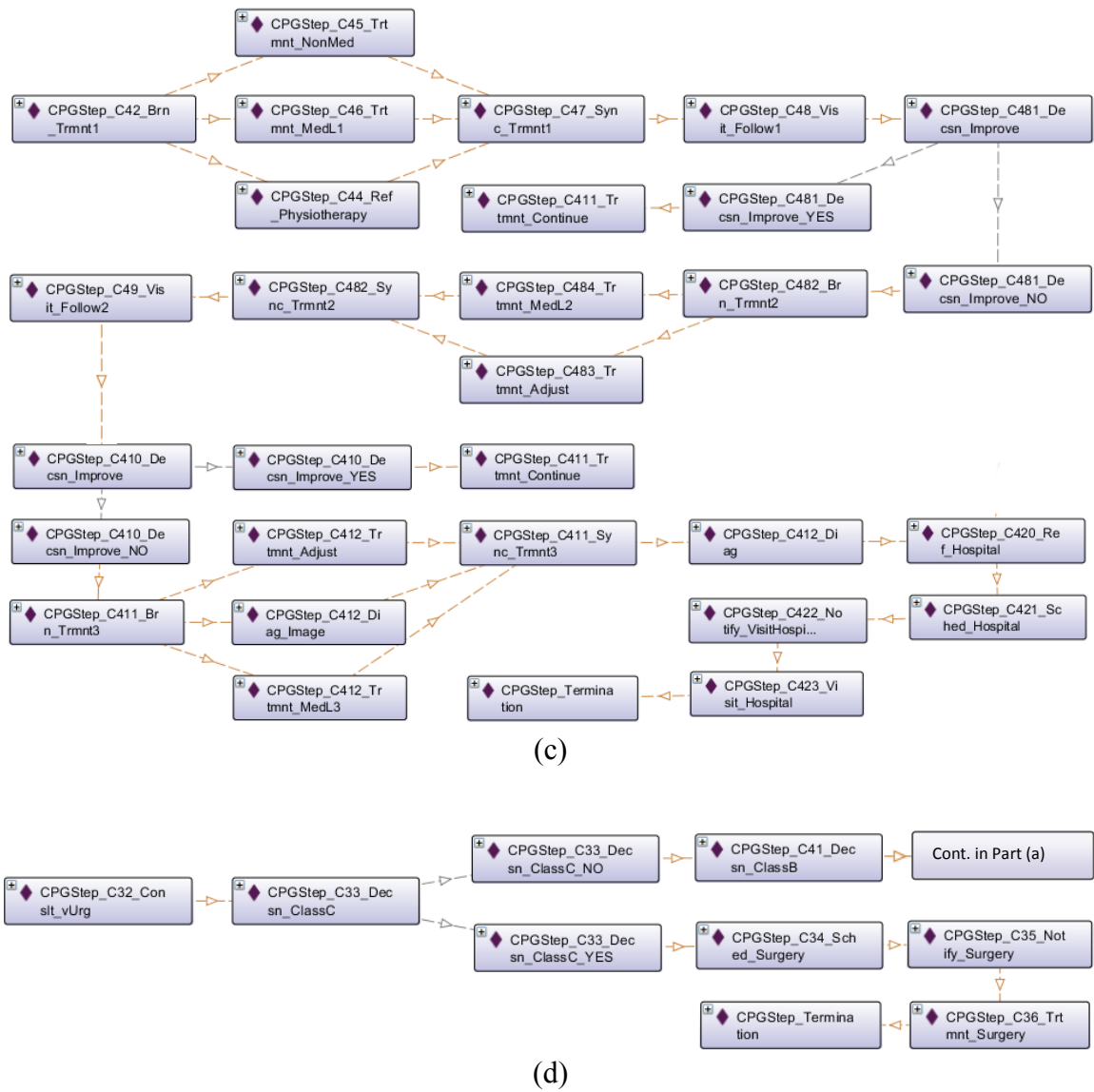


Figure 3-13 SCCP ontology TNM module instances graph. This graph provides a top-level view of the SCCP workflow.

## **CHAPTER 4      System Development**

### **4.1    INTRODUCTION**

To provide decision support services through the spinal condition referral process, we propose the implementation of a Decision Supporting Module. To enable this Module, the use of a substructure Electronic Referral System (E-Referral) is essential (see Section 3.2). We integrate the Decision Supporting Module with a specialized E-Referral system, using it as the processing unit of the E-Referral system. Result of this integration is the Spinal Condition E-Referral system (SCERef). In this chapter we describe function and design of the Decision Supporting Module. This is then followed by the details of Decision Supporting Module integration with the E-Referral system (the system architecture). The rest of the chapter explains two main modules of the E-Referral system. Finally, two sample scenarios are added to better clarify how different modules function in relation to one another.

### **4.2    SPINAL CONDITION DECISION SUPPORTING MODULE AND E-REFERRAL INTEGRATION**

The Spinal Condition Decision Supporting Module is designed to analyze submitted spinal condition referrals to assist the referral process by providing following services: 1) Aid the referral administration process by automatically assess and triage referrals; 2) Assist referring physicians in patients condition management by providing simple spinal conditions management protocols specific to patients conditions. For analysis of submitted referrals, the Decision Supporting Module employs medical information included in referrals, and utilizes the incorporated Knowledgebase. This necessitates that the submitted referrals be collected in a standardized computer interpretable format. It is also required that historical patients' information be available for reference in referral analysis (i.e. patients' medical history records). This urges the need for integration of an underlying E-Referral system which performs following functions: 1) Collects standardized electronic referrals through a structured user interface; 2) Preserves submitted patients' medical and non-medical information.

### **4.3 DECISION SUPPORTING FOR SPINAL CONDITION REFERRALS: THE PROCESS WORKFLOW**

To describe the decision supporting process workflow, we consider the Decision Supporting Module and the underlying E-Referral system as a single integrated system: the Spinal Condition E-Referral system (SCERef). The workflow can be divided in the following three steps according to SCERef main functions. Figure 4-1 outlines the spinal condition referral process when SCERef is in use.

1) **Collecting Referrals:** The process is initiated by a primary care physician intending to refer a patient with a spinal condition to the Halifax Neurosurgery Division for pain management or further investigations. The referring physician starts to prepare a consultation request by the use of electronic forms operated by SCERef interface. To complete a referral request, the referring physician navigates through separate forms, and fills in identification and medical information under different categories. The E-Referral forms are structured and standardized. When all the mandatory information for the new referral request is completed with valid data, the referring physician may submit the referral request. Referral collection by the use of the SCERef interface and electronic forms are further described in Section 4.5.

2) **Referral Processing:** Following the submission of the referral request, the request is transferred to the Decision Support Module for assessment. This module is responsible for automatic assessment of referrals through the execution of consultation protocol. It operates based on spinal condition assessment rules, and employs SCCPO (the Knowledgebase schema described in CHAPTER 3) to formalize the referral information and conduct protocol execution. Throughout this process, Decision Support Module calculates assessment points and triages the patient accordingly. The result of this phase is the updated patient's medical record and condition management protocol, which is then used to produce referral assessment reports. Referral processing and decision support operations are described in details in Section 4.7 and Figure 4-3.



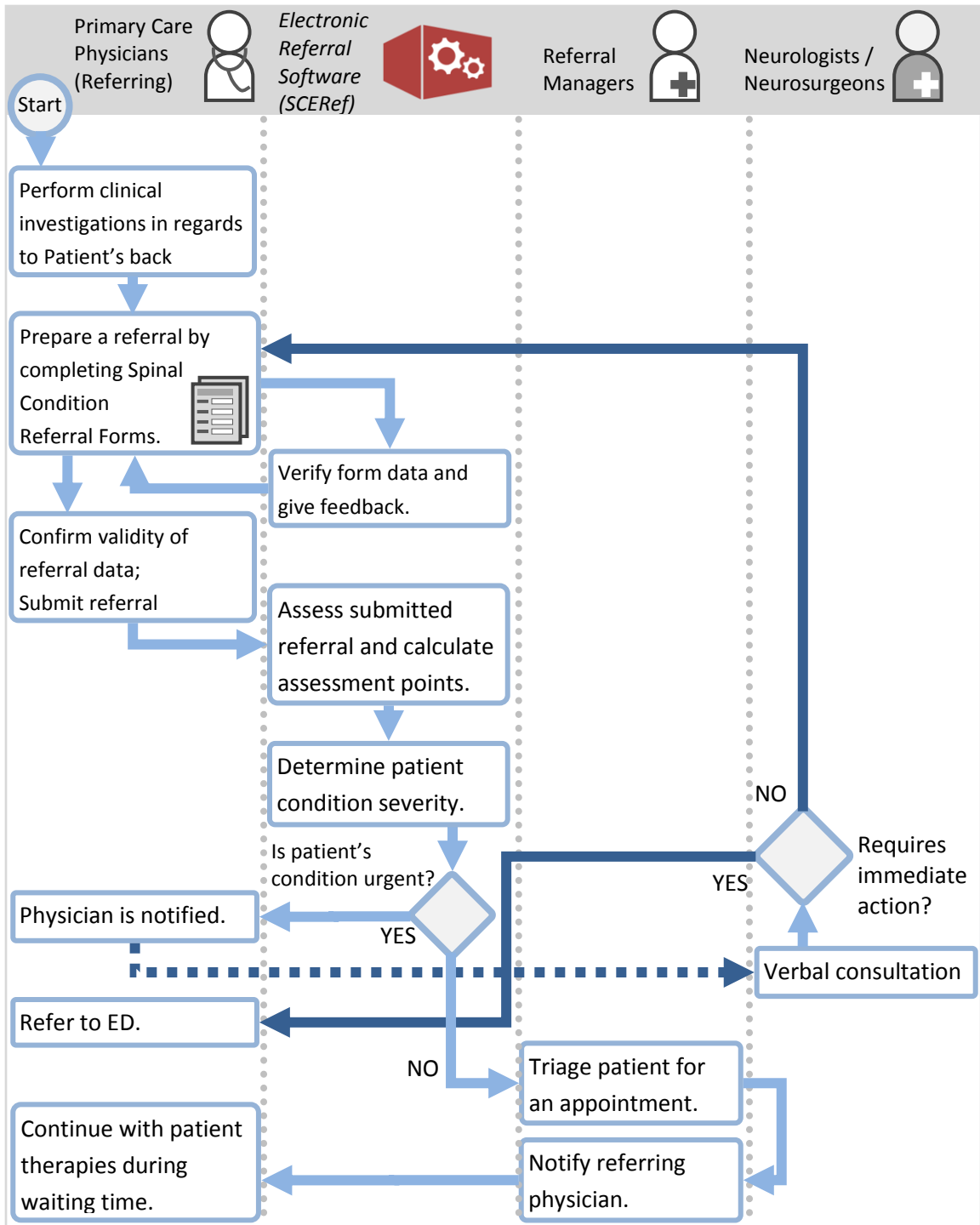


Figure 4-1 Process diagram of spinal condition referrals in presence of the proposed e-referral system (SCERef)

3) **Presenting Results and Preserving Information:** The referring physician receives an assessment summary report. The report is automatically generated, and includes the condition triage category and the recommended pathway for management of the patients' condition. On the hospital side, a notification along with a detailed referral assessment report is sent to the triage coordinator to inform her about the new referral. Based on the calculated scores and expected outcomes of the recommended pathway, hospital clinicians are able to specify a proper appointment schedule for the patient, and inform the referring physician about the scheduled appointment. Finally, the information included in the received referral in addition to all referral assessment outputs are preserved in the system long-term storage for future reference. Section 4.9 further explains SCERef information persistence functions.

#### **4.4 SCEREF ARCHITECTURE**

To develop the SCERef as a functional decision supporting system for spinal condition referrals, we employ two main components: a *Decision Support* component, and an E-Referral system. The E-Referral system comprises of subcomponents that are essential for proper operation of the Decision Support component; those include a *User Interface* component as a point of interaction with clinicians, and a *Data Management* component to preserve and manage referral data. In the design of E-Referral system a web-based modular architecture has been taken into consideration to provide improved system maintenance and component reusability [67]. The Decision Support component is well integrated with the E-Referral system, and its interconnections with other system components are established. We present the SCERef architecture in a multilayered approach to contrast its unique characteristics with typical web-applications (the architecture model is outlined in Figure 4-2). Each layer in this architecture represents one of the main system components:

1) **Presentation Layer:** This layer provides the point of system interaction with clinicians by assembling and managing web-based interfaces. This layer comprise of two main system interfaces: *Referral Collector (referring physician) Interface*, and *Referral*

*Manager (Hospital) Interface.* These interfaces are responsible for performing following tasks: i) Collecting spinal condition referrals which contain valid and sufficient information. This is done by the use of standardized referral forms; ii) Presenting referral results and system generated notifications to referring physicians and hospital clinicians; iii) provide a tool for hospital clinicians to access and manage submitted referrals; iv) Managing user access to information; that is, customizing information presentation based on user authentication.

**2) Decision Support Layer:** This layer is the point of the Decision Support component integration with the E-Referral system. This layer incorporates three main modules which serve application's key functions: 1) The *Decision Support Module (DSM)* has the key role in providing decision support services. This module takes into practice the developed Knowledgebase and processes submitted electronic referrals. 2) The *Application Control Module (ACM)* supports DSM procedures by providing following services: i) establishing a mean of communication between DSM and other system modules, and ii) preparing referral assessment reports. In general, ACM has the role of managing and monitoring system activities, ensuring successful flow of tasks. 3) The *User Authentication Module* controls access of users to submitted referrals data and assessment results by the use of user credentials.

**3) Data Manager Layer:** This layer accommodates and maintains system medical and non-medical information in a relational database. It answers data access and modification requests, received from the Decision Support layer, by performing data queries. It also provides a mean for persisting the application Knowledgebase (refer to Section 4.9).

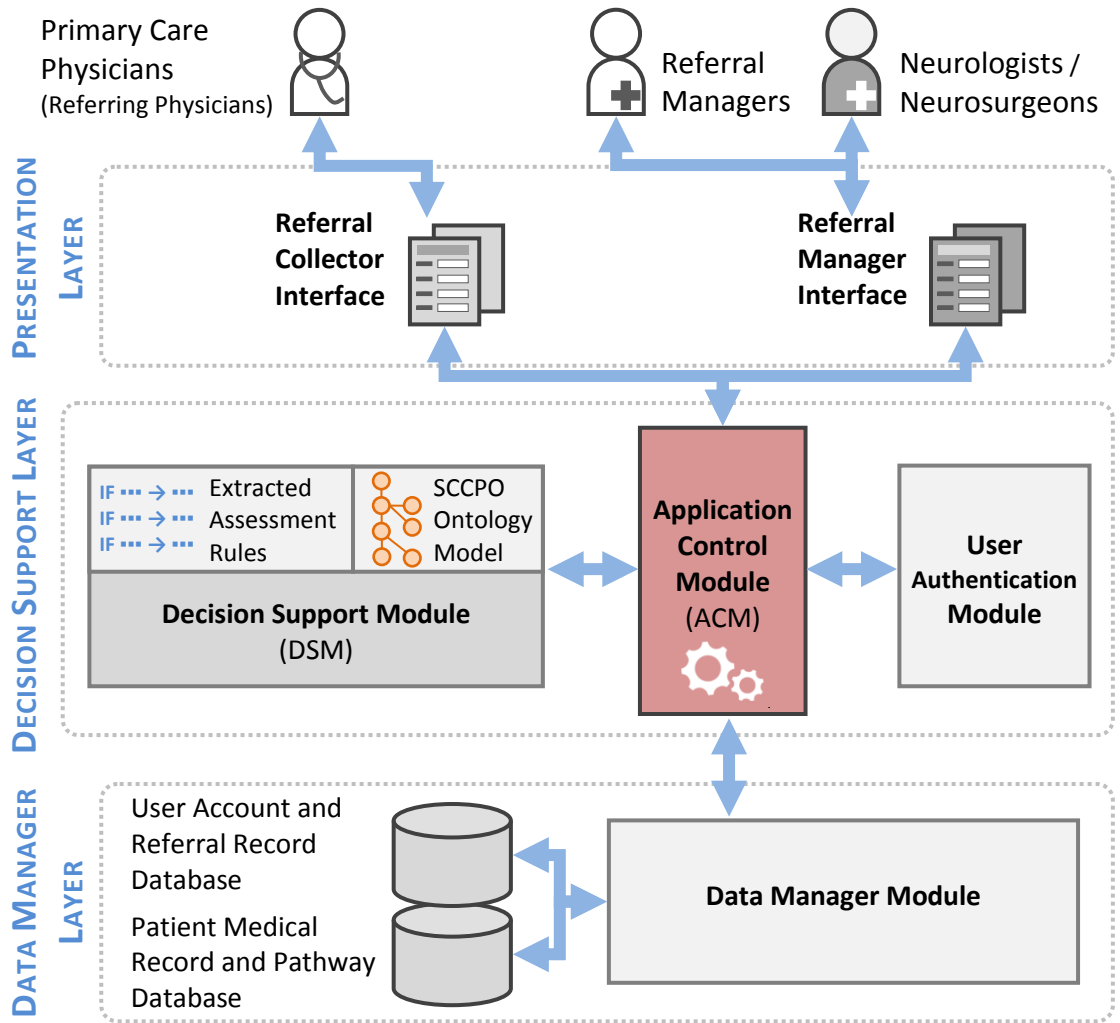


Figure 4-2 Architectural design of the SCERef system.

#### 4.5 PRESENTATION LAYER: INTERFACES AND FORMS

SCERef interfaces are building blocks of the Presentation Layer. They act as tools for creating and managing referrals, presenting application processing results and notifications to users and customizing information view. SCERef interfaces divide into two types; E-Referral Collector and E-Referral Manager.

#### 4.5.1 E-Referral Collector Interface

E-Referral Collector Interface provides a standardized web-based interface for primary care physicians (users of this interface) to create and submit spinal condition referrals. This interface specifically is responsible for collecting referral data, validating data, communicating input data or user responses to Application Control Module, and presenting Application Control Module messages to the user.

E-Referral Collector Interface comprises of seven forms which comprehensively collects referral information under different medical and non-medical categories. These forms are composed of structured input fields, restrictedly designed based on SCCP requirements. Some forms also allow attachment of external data files (e.g. text documents, images). During referral preparation sessions, input data is checked for validity and completeness in real-time (dynamically upon each change in data). The criteria for this verification are also extracted from SCCP. Accordingly, users would be notified about required changes in referral data.

The interface formats and communicates user input data to ACM. This data may be either referral forms data, user credentials and account information queries, or user responses to system notifications. ACM generates messages and responses to the interface, often based on the communicated data, which will be presented to the user by the use of the interface; these include users (referring physicians) account information, results of e-referral assessment, and system notifications.

#### 4.5.2 E-Referral Collector Interface: Design and Development

Through the design and implementation of the e-referral collector interface, we mainly followed the goal of improving referral data validity and sufficiency. Accordingly, the use of structured inputs and input verification can increase data validity. Moreover, data is sufficient when necessary values are available to resolve decisions during the referral assessment procedure; either decisions that are resolved by practitioners, or decisions that are processed by the application system.

Our first attempt in designing e-referral collector forms was to determine a set of data elements that have to be collected to construct electronic referrals with sufficiently structured data. For this purpose, we extracted all specific data elements that are already being collected by the Referral Letter Form. This produced our initial set of data elements which have to be collected by the use of e-referral interface. Afterwards we merged this initial set with two complimentary set of required data elements: extracted concepts from the SCCP, and mandatory data elements from the Referral Summary Form. Following each comparison, missing data fields were added to our initial set (see Section 1.2.1 for further description of paper referral forms).

During the analysis of SCCP for required concepts, we considered the concepts which directly contribute in resolving SCCP decisions. This leads us to restrict our selection to four key triaging decision steps: Pediatric patient, Urgent condition, Radicular pain, and Axial pain. These concepts were obtained from the set of SCCP extracted concepts in Section 3.5.2. We also examined the Referral Summary Form to determine data elements that are necessary for calculation of assessment points. Extracted complementary data elements were merged with the initial set to form a more comprehensive set of data elements. Afterwards, we sought specialists' opinion to further improve our results. These steps enhanced our set of data elements by adding missing elements, applying additional structure, or specifying permitted values for some elements. This resulted in final set of 74 data elements that have to be collected by the e-referral collector interface in order to have electronic referrals with sufficient data. Finally we specified appropriate data types for extracted data elements, and arranged them under 6 identifiable categories: physician's identification, patient's demographics, presenting medical history, past medical history, physical examination results, and radiology results. Table D-1 shows the final set of categorized data elements.

In our second attempt, we developed a prototype interface based on the required data elements that were obtained during the previous step. The prototype interface was iteratively revised based on practitioners' feedbacks. This evolved the prototype into the functional E-Referral Collector Interface.

The final version of E-Referral Collector Interface uses 6 separate forms to collect referral data under the categories described earlier. The forms are ordered under tabs and can be browsed in a wizard-like manner using two navigation buttons (or alternatively using the form tabs). All forms use basic components to collect data from users; data elements with text data types are implemented using text boxes, while drop-down boxes or radio-buttons are used for elements with specified permitted values and numeric values, and check-boxes or radio-buttons are used for binary data. All forms function similar to typical electronic forms; however few points should be further discussed: first, we have tried to reduce the spent time and facilitate completion of physical examination results page by designing an intuitive interactive tool for the Physical Examination form. Through this tool, referring physicians can navigate between four different physical exams, and use interactive body maps to complete exam scores. This can be done by clicking on relevant body areas on the body map and select a score from the drop-down menu which appears for this area, or alternatively switching to the tabular view and completing the score table based on matching areas on the body map. Second, the Radiology Form allows referring physicians to add diagnosis from radiology reports to the referral letter; yet, this is permitted only when radiology reports are available and uploaded. Overall three forms allow attachment of external files: The Past Medical History form to include medication history, The Radiology form to include radiology reports, and the Submit form to include miscellaneous files. Finally, two additional forms are added; the Submit form provides a summary of input data for final verification and submission of the e-referral, and the Sign-in form provides a mean for authenticating returning referring physicians.

The E-Referral Collector Interface maintains the quality of input data by the means of: verification of data completeness, verification of data validity, and final confirmation of data accuracy by referring physicians. Majority of data fields in physicians' identity, patients' demographics, presenting medical history and physical examination forms are necessary for a complete referral. Therefore, these fields are marked as mandatory and are checked by the interface to be filled out before submission of referrals. In addition, data validity is checked for fields with text values, specifically in physicians' identity and

patients' demographics forms. Some examples of validity verifications are checking for invalid characters in names, as well as format checking of postal codes, phone numbers, and health card numbers. Lastly, the Submit form is used to examine the accuracy of input data by providing a summary of data to referring physicians and asking them for their confirmation. In the case verification of completeness, validity, or accuracy of data fails, the interface disables submission of the referral, ensuring that only verified referrals go through.

Generating notifications is a part of the interface operations to communicate referral related and operation related messages to users. These notifications may be of following the types: i. Data validity notifications (e.g. an invalid data format notification that also activates a related mouse hover guide); ii. Data completeness notifications (e.g. notification for a blank mandatory data field); iii. Clinical notifications (e.g. alert of an urgent condition or notification of pediatric patient); iv. Operational notifications (e.g. notifications for connection timeout, or error during automatic referral processing). Moreover, some system notifications are overridable, such as urgent condition notifications, while others need to be resolved by the referring physician prior to submission of the referral.

The E-Referral Collector Interface also acts a tool for returning primary care physicians to sign-in and access their account information. The Sign-in form used for this purpose is a simple interface which asks for physicians' username and password for authentication. Authentication keys are selected by referring physicians upon submitting their first referral through SCERef (usernames and passwords are asked as mandatory fields in physicians' identity form). The interface communicates credentials to Application Control Module for authentication. For authenticated physicians, the physician's identity form is pre-populated with the stored physician's information. It also provides access to a list of previously referred patients by this physician, and enables the option to select a patient for re-sending a referral while pre-populating the patient's demographics and past medical history information.



E-referral interfaces are designed based on web technologies for better compatibility and easier maintenance compared to desktop application technologies. To develop interfaces we have employed Google Web Toolkit (GWT) [68] to implement pages based on HTML and JavaScript language for client-side processing (functions such as data validation). Interfaces use Asynchronous Communication to communicate data to the server in background. This method prevents the interface from freezing while communicating with the server, which improves user experience.

#### 4.5.3 E-Referral Manager Interface

The e-referral manager interface is intended to help Neurosurgery Division practitioners to access and manage previously received electronic referrals. The purpose is to allow referral managers to perform manual case triaging (i.e. override automatic triaging), scheduling appointments, and communicate back with referring physicians from a single online tool. Moreover, specialists would be able to review their assigned referrals including details of automatic case assessment. All clinic users are authenticated prior to accessing their account information. However, implementation of the e-referral manager interface has not been accomplished due to the limited scope of this project. This step is considered as a future work (see Section 6.3.2).

### **4.6 DECISION SUPPORT LAYER: APPLICATION CONTROL MODULE**

The Application Control Module (ACM) controls the order of tasks and the flow of data within the Decision Support Layer and between three different layers, based on the application logic. Specifically, ACM: a) responses to requests that require collaboration between different application layers, b) applies any required data formatting prior to data usage by different modules, c) coordinates communication between different modules, and d) handles errors occurring through application operations.

Few examples can better clarify the purpose of this module: The E-referral Collector Interface sends a request regarding a specific patient past medical history for the purpose of pre-populating referral forms. This request is submitted to ACM from which a series

of tasks are initiated. First, a data query is requested from the Data Manager Module based on the patient identifier, which results in the past medical history record of the patient. This data is then re-formatted in a representable form, and transmitted back to the interface. Another notable example is preparation of referral assessment reports for presentation to referring physicians. For this purpose, after referral assessment results are produced by the Decision Support Module, ACM collects the results and applies extensive formatting on data to convert it into an HTML page and a PDF report format. The HTML page is then transmitted to the interface for presentation, and the PDF report is transmitted in case of receiving a request from the referring physician (i.e. pushing the download button). The HTML version is a short report containing the condition specific guideline in forms of a diagram. The PDF report is more comprehensive and includes complete referral data in addition to the condition management guideline and few other general complementary guidelines.

#### **4.7 DECISION SUPPORT LAYER: DECISION SUPPORT MODULE**

The Decision Support Module (DSM) is designed for automatic assessment of submitted electronic referrals. This module is responsible for a great portion of data processing tasks which takes place during SCERef operations. To assess electronic referrals, DSM acts as a computerized clinical pathway execution engine; that is, DSM analyzes the computerized consultation protocol (SCCPO), considering patients' current demographics and medical information (derived from the submitted referral), to check constrains, resolve decisions, and present information and notifications to referring physicians where required. DSM includes two principal building blocks: 1) embedded referral assessment rules, and 2) the developed SCCP Ontology (SCCPO).

Referral assessment rules are conditions extracted from referral assessment protocols which are taken into account by decision makers when resolving decision steps throughout referral assessment. We extracted referral assessment rules from two sources: 1) Decision steps in SCCP, as we previously discussed in Section 3.5.1 and Figure 3-8; and 2) the conditions included in the Referral Summary Form that result in calculation of

assessment points. All extracted rules are formulated in forms of deductive logics. Table 4-1 lists extracted referral assessment rules, and facts they deduce.

Java language has been used to implement DSM, as well as embedding the referral assessment rules. SCCPO is stored as a separate ontology file, which is imported in memory once processing is required. DSM utilizes Jena Framework API [69] to handle ontology related operations. Ontology based outputs that need to be recorded in a database are persisted as RDF triples using Jena Database API.

Table 4-1 Extracted referral assessment rules from the Referral Summary Form, and SCCP

Source	Rule (IF)	Inference (THEN)
Referral Summary Form	<b>IF</b> Pain Location includes: Neck or Back dominant [Midline Pain]	<i>Clinical Assessment Points +1</i>
	<b>IF</b> Sensory exam score 0 or 1 in any of: S4-5 <b>AND</b> any of: L2-5,S1 [Numbness perianal and both legs]	<i>Clinical Assessment Points +5</i>
	<b>IF</b> Presenting history: Neurogenic Claudication	<i>Clinical Assessment Points +2</i>
	<b>IF</b> Sensory exam score 0 or 1 in any of: C5-8,T1 <b>OR</b> any of: L2-5,S1 [Pain/Numbness in Arm or Leg]	<i>Clinical Assessment Points +3</i>
	<b>IF</b> Motor exam score 0-3 in any of: S4-5 <b>AND</b> any of: L2-5,S1 [Focal Myotomal Weakness]	<i>Clinical Assessment Points +4</i>
	<b>IF</b> DTR exam score 3 or 4 for Biceps <b>OR</b> Y for Clonus <b>OR</b> + for Babinski [Myelopathy or Spasticity]	<i>Clinical Assessment Points +5</i>
	Cancer <b>OR</b> Malignant Spine Tumor	<i>Pathology Assessment Pnts. +5</i>
	Benign Spine Tumor	<i>Pathology Assessment Pnts. +3</i>
	Infection/ Inflammatory	<i>Pathology Assessment Pnts. +4</i>
	Degenerative Spine	<i>Pathology Assessment Pnts. +1</i>
	Congenital Spine Abnormality	<i>Pathology Assessment Pnts. +3</i>
	Low impact/ Remote Trauma	<i>Pathology Assessment Pnts. +1</i>
	High Impact Trauma	<i>Pathology Assessment Pnts. +4</i>
	Spondylolisthesis	<i>Radiology Assessment Pnts. +3</i>
	Signal Change/ Myelomalacia	<i>Radiology Assessment Pnts. +5</i>
	Syrinx/ Spinal Cord Cyst/ Cavitation	<i>Radiology Assessment Pnts. +5</i>
	Severe Canal Stenosis	<i>Radiology Assessment Pnts. +3</i>

	Mild Canal Stenosis	<i>Radiology Assessment Pnts. +1</i>
	Moderate Canal Stenosis	<i>Radiology Assessment Pnts. +1</i>
	Root Compression	<i>Radiology Assessment Pnts. +1</i>
	Foraminal Narrowing/ Stenosis/ Compression	<i>Radiology Assessment Pnts. +1</i>
	Instability	<i>Radiology Assessment Pnts. +5</i>
	Deformity/ Scoliosis	<i>Radiology Assessment Pnts. +3</i>
	Spinal Cord Compression	<i>Radiology Assessment Pnts. +5</i>
<b>Spinal Condition Consultation Protocol (SCCP)</b>	<b>IF</b> Patient's Age ≤ 16	<b>Pediatric Patient</b>
	<b>IF</b> Pain Quality: Unremitting	<i>Severity Score + 0.75</i>
	<b>IF</b> Pain Radiation: Legs-both	<i>Severity Score +1.0</i>
	<b>IF</b> Pain Location: Thoracic	<i>Severity Score +0.75</i>
	<b>IF</b> Past History includes: Malignant <b>AND/OR</b> Cancer	<i>Severity Score +0.75</i>
	<b>IF</b> Past History includes Medication: Biologics <b>AND/OR</b> Chemotherapy <b>AND/OR</b> Steroids	
	<b>IF</b> Past History includes: HIV <b>AND/OR</b> Organ Transplantation	<i>Severity Score +0.75</i>
	<b>IF</b> Presenting History includes: Weight Loss <b>AND/OR</b> Fever-Chill	<i>Severity Score +0.75</i>
	<b>IF</b> Count Abnormal Physical exam results Motor <b>OR</b> Sensory ≥ 3	<i>Severity Score +1.0</i>
	<b>IF</b> Sensory exam score 0 or 1 in any of: S3-5	<i>Severity Score +1.0</i>
	<b>IF</b> Presenting History includes: Neurogenic Bladder <b>AND/OR</b> Neurogenic Bowel	<i>Severity Score +1.0</i>
	<b>IF</b> Severity Score ≥ 1	<b>Triage: Urgent Condition</b>
	<b>IF</b> Pain Location Includes: Arm/Leg dominant <b>AND</b> (Pain Radiation: Hand L/R/both <b>OR</b> (Pain Radiation: Leg <b>AND</b> (SLR exam score: + <b>OR</b> Sensory exam score 0 or 1 in any of: L2-5,S1)))	<b>Triage: Radicular Pain</b>
	<b>IF</b> Pain Location includes: Neck or Back dominant	<b>Triage: Axial Pain</b>

#### 4.7.1 Consultation Protocol Execution and Referral Assessment

To execute the consultation protocol, DSM employs a certain iterative algorithm; the process of execution starts from an initial step in SCCPO Task Network Module, and a first-come first-serve queue containing only the initial step. In each iteration, DSM picks a step (N) from the queue, executes N, adds next step(s) of N to the queue (using the

*next\_step* property), and removes N from the queue. When N is being executed, required instances are created in the ontology model and related properties are parameterized; this process is the *automatic instantiation* of the ontology (see Section 3.6.3). In case N is a *System\_Decision\_Step*, embedded rules related to this decision are executed, and based on the result unwanted decision options are pruned. Execution may pause in case not enough information is available to execute next steps from the queue (e.g. a *Provider\_Decision\_Step*), until information is received from an external source (e.g. referring physician input). The execution ends when the queue is empty or only contains a *Termination\_Step*.

Execution of the consultation protocol starts when a new referral is initialized by a referring physician, and is carried out in two stages with different configurations: pre-submission execution (A), and post-submission execution (B). The following steps explain the execution of the consultation protocol in details (see Figure 4-3):

A.1) During stage A the scope of protocol execution is limited to two decision steps, ‘Pediatric patient’ and ‘Urgent condition’ (steps *CPGStep\_C21\_Decsn\_ClassD* and *CPGStep\_C21\_Dcsn\_ClassC* in SCCPO TNM; refer to Figure 3-13). To process these steps, specific data elements are required to be used with decision rules (Table D-1, data elements from SCCP). As a result, execution is paused until DSM receives the necessary part of primary investigations results from the referring physician. For this purpose, the referral collector interface watches any changes in the forms data fields. Once these data fields are completed or updated, the interface automatically submits the data to DSM in background.

A.2) Once patient data is received, DSM proceeds to ‘Pediatric patient’ decision step, in which it examines whether patient age is less than 16 years. In case the patient is specified as a pediatric, appropriate notification is shown to the referring physician, the referral is discarded and the interface redirects the physician to the pediatric hospital website. If patient is adult, execution continues to the next decision step. In ‘Urgent condition’ decision step, a severity score is calculated based on a set of rules. In case the

severity score exceeds a threshold, the patient condition is considered urgent and the referring physician is asked to verbally consult with a specialist. Following the verbal consultation, the referring physician may complete and submit the referral.

A.3) Since the referral is not completed at the time of this execution and the physician may change any part of referral data, it is probable that considering these updates during the processing will result in completely different decision answers. Therefore, when execution of both decision steps yield to negative answers, the execution is paused until it receives updated patient data. If new data become available, execution starts at step A.2. This iterative process continues until the referral is submitted by the referring physician.

B.1) From when the final referral is submitted, protocol execution is launched with a new configuration. In this stage DSM employs two ontology models; a patient medical record model that holds patient's medical record (historical data), and a separate pathway model that represents executable protocol for the patient's latest ongoing consultation request. The use of two separate models makes it more efficient to reinitiate the pathway model for each new consultation request. The medical record model is initiated once for each patient based on SCCPO CPR module, and is updated when a new referral is received. Furthermore, the pathway model holds entities and relations that are needed for the execution of the consultation protocol workflow, and is initiated once for every consultation request based on SCCPO TNM module.

Once a referral is received, DSM starts the execution by forming a recent patient medical record. This process is performed by using a base medical record model, and formalizing the referral data into the model. For a patient who has no previous records in the system, the base model is initialized as an empty model using the SCCPO CPR module; otherwise, the latest patient's medical record is retrieved from the Data Manager Module in an ontology model. The retrieval mechanism reads the complete medical record in RDF triples. The RDF data model is then bound to the default ontology model (uninstantiated SCCPO) to create a semantically rich structure. Following this, new records are added to the base medical record model based on the submitted referral data, by creating instances in the medical record ontology and parameterizing properties using

instances or data values. As an example, an instance of *Pain\_Finding* is added to the model and its properties are set (e.g. pain onset, pain location, etc) to represent part of presenting history data. Three assessment points are also calculated in this step using the embedded rules (Table 4-1) based on the presenting and past medical history, and are related to the *Pain\_Finding* instance through relevant properties. Prior to the execution of consultation protocol, a pathway model is initiated based on the manually instantiated SCCPO TNM module. The scope of execution is extended to the complete SCCPO, starting from the initial referral step (*CPGStep\_C20\_Ref\_Initial*).

B.2) DSM starts the execution of the consultation protocol from the initial referral step (an instance of *Referral\_Step*). At this point, properties of the initial referral step are unparameterized. Therefore, as a part of the execution, DSM parameterizes related properties, including *referredByIndividual*, *referredIndividual*, and *time\_start* using values *Physician* instance, *Patient* instance, and a *dateTime* representing the submission timestamp. The initial referral step is followed by four triaging decision steps. The execution of the ‘Pediatric patient’ result in the negative option chosen (referral is submitted for an adult patient). A positive option for the next step specifies the patient has been diagnosed with Urgent condition. This leads to the verbal consultation step which will be parameterized by start and end time properties (time of verbal consultation) and the execution ends as the next step is not executable by DSM (a *Provider\_Decision\_Step*). On the other hand, a negative option leads to the next two triaging decision steps, in which patient’s condition will be determined as either radicular pain or axial pain. Keeping a positive option on either decision steps directs the execution engine to condition management therapies for that triaging category (Radicular pain therapies, or Axial pain therapies). Execution of the consultation protocol ends when therapies are determined, since therapies have not been administered yet and no input is available from the primary care physician in this regard (e.g. the result of first round of interventions, or the time of first follow-up visit). In the case both decision steps are determined to have negative answers, the execution ends because the patient cannot be triaged in one of the defined categories.

B.3) The result of consultation protocol execution is the updated medical record model and pathway model, including ontology entities and property values which represent new medical records for the patient and updated protocol steps for this referral. As previously discussed, the process of formalizing the medical information and modifying TNM instantiation accordingly is the *automatic instantiation* of SCCPO model. Following the execution, ACM accesses two ontology models to: first, preserve the execution results by persisting updated ontology models into the database; and second, producing formatted outputs which are representable to users.

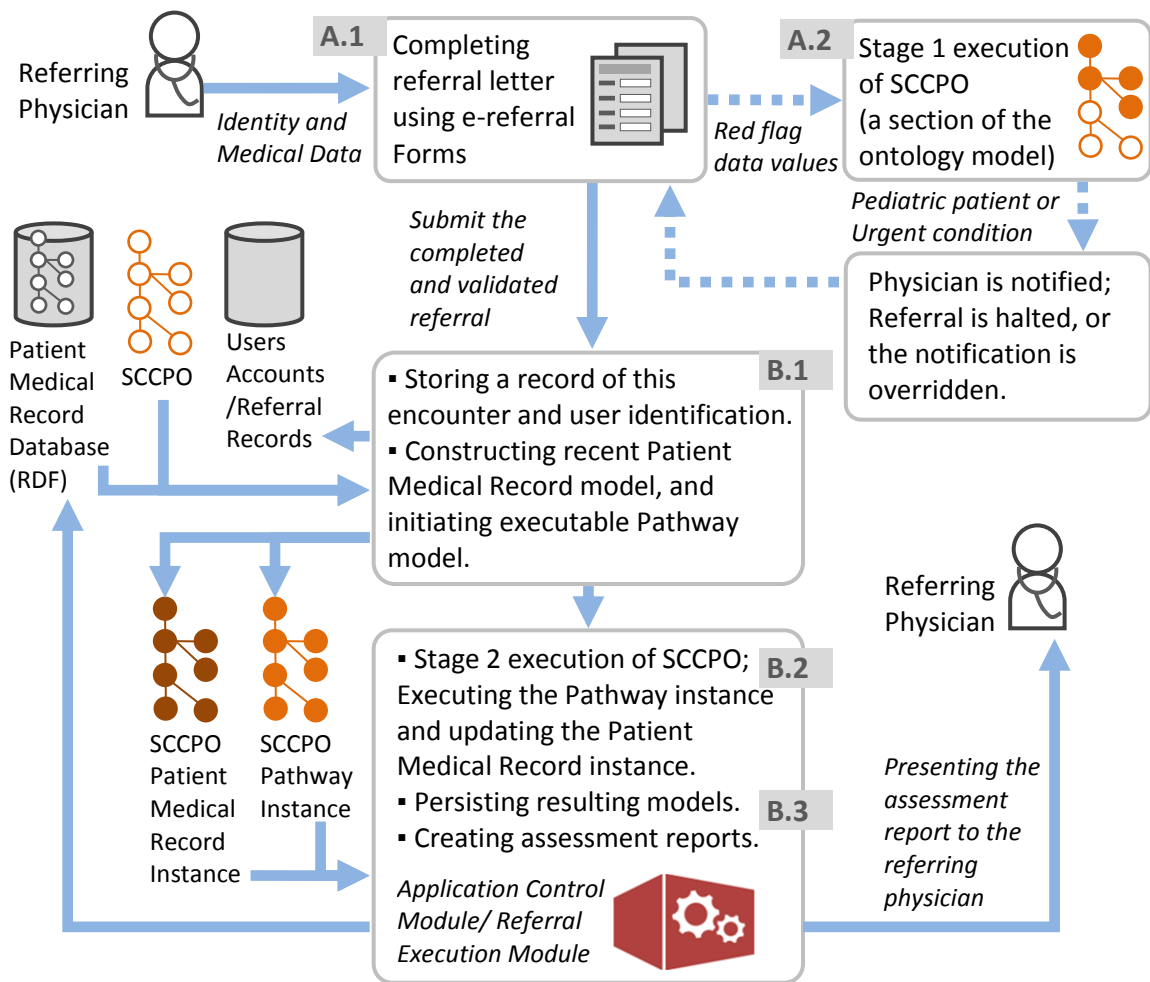


Figure 4-3 E-Referral execution workflow. Steps specified by numbered tags correspond to descriptions in Section 4.7.1.



It worth mentioning the execution of determined patient therapies in step B.2 is out of scope of this project. This is because SCERef is designed to assist with collecting and managing referrals at the current stage of the project. Execution of the therapies model is beneficial when the tool also aims at supporting referring physicians throughout the patient condition management following the referral.

#### 4.7.2 Sample Scenario: Consultation Protocol Execution

Dr. Johnson is submitting a referral for his patient with low back pain using the SCERef website. On the form Clinical History I, he chooses ‘Lumbar/Sacral’ as the location and marks the pain radiating into ‘Legs-both’ and ‘Unremitting’. There are number of data fields that impact the calculation of the triaging score; these fields are perceived as red flags by the e-referral interface and are submitted to DSM automatically when their values are changed. In this case, two red flags, both leg radiation and unremitting pain are submitted to DSM in the background. Using the received data object, DSM starts the first stage (A) of referral assessment. The first decision step (‘Pediatric Patient’) on the pathway model is executed, in which the patient is determined as an Adult. Through the second decision step (‘Urgent Condition’) DSM calculates the Severity Score, required for specification of an urgent condition. The calculated Severity Score based on the current data exceeds the threshold ( $1.75 > 1.0$ ) which indicates that the patient may have an urgent condition. As a result a notification is shown to Dr. Johnson, asking him to verbally consult with the on call neurosurgery team. During the consultation Dr. Johnson is asked to change the pain attributes from unremitting both legs to left leg, since it is not accurately reflecting the patient’s condition. Therefore, Dr. Johnson overrides the notification and modifies the form values. Eventually, the presenting medical history form has values such as a pain onset of less than 6 weeks, radiating into left leg with a sharp pain quality, aggravated by lifting and relieved by rest. Once all forms are completed, he submits the referral and awaits the referral assessment result.

When DSM receives the final referral letter data, it attempts to prepare the patient medical record and the executable pathway ontology models. Since medical records exist

for this patient in the database (patient has been referred previously), the existing patient's medical record is retrieved from Data Manager Module, and recently received medical records are instantiated into the model. For instance the pain is instantiated from Pain\_Finding class (named *pain\_instance*) with the following properties (values in brackets represent originating class or data type):

```

pain_instance → painOnset → 'Less than 6 wk.' [string data value]
pain_instance → findingSite → anatomy_lumbar [Physical_Anatomical_Entity instance]
pain_instance → painRadiation → anatomy_leg_L [Physical_Anatomical_Entity instance]
pain_instance → painQuality → 'Sharp' [string data value]
pain_instance → painAggravatingFactor → intrv_lift [Intervention instance]
pain_instance → painRelievingFactor → intrv_rest [Intervention_For_Treatment instance]

```

The author and subject of the *pain\_instance* record are also set and the diagnostic intervention is specified:

```

pain_instance → subjectOfDescription → indiv_patient [Patient class instance]
pain_instance → composedBy → indiv_physician [Physician class instance]
pain_instance → outputOf → intrv_presentMedHist [Presenting_Medical_History instance]

```

Another example is the instantiation of physical examination results, in which one instance of *PhysicalExam\_Finding* is created for each exam score with the following assigned properties:

```

indiv_patient → isSubjectOfDescription → ExamFnd_MOTOR_L2_HipFlex_L
indiv_patient → isSubjectOfDescription → ExamFnd_SENSORY_L2_L [PhysicalExam_Finding]
...
ExamFnd_SENSORY_L2_L → value → '1' [string data value]
ExamFnd_SENSORY_L2_L → value_normal → '2' [string data value]
ExamFnd_SENSORY_L2_L → findingSite → anatomy_L2_L [Physical_Anatomical_Entity]

```

When referral data is instantiated and ontology models are prepared, DSM starts executing the first step of the pathway model, the initial referral step. Execution of the initial referral step results in new properties values for this step:

```
CPGStep_C20_Ref_Initial → referredByIndividual → indiv_physician
CPGStep_C20_Ref_Initial → referredIndividual → indiv_patient
CPGStep_C20_Ref_Initial → referredSubject → pain_instance
CPGStep_C20_Ref_Initial → time_start → '01-01-2013 10:45:00' [datetime data type]
CPGStep_C20_Ref_Initial → time_end → '01-01-2013 11:00:00' [datetime data type]
```

Next, 'Pediatric Patient' decision step is executed in which the negative option is chosen (patient had been distinguished as an adult prior to submission). Execution of the following step, 'Urgent Condition' decision step, by re-calculating severity scores leads to negative option since red flags has been changed by the referring physician during the verbal consultation. Therefore, execution proceeds to 'Radicular Pain' decision step, in which the following conditions hold true:

```
IF Pain Location Includes: Arm/Leg dominant AND
Pain Radiation: Leg AND Sensory exam score 0 or 1 in any of: L2-5,S1
```

Since the condition holds true, the positive decision option is chosen and the negative decision option is pruned. This specifies radicular pain therapies as the appropriate management protocol for patient's condition. This result is submitted to ACM to prepare assessment reports.

## **4.8 USER AUTHENTICATION MODULE**

The User Authentication Module implements procedures to authenticate users based on credential pairs. This module authorizes users under three policy groups: primary care physicians (referring physicians), referral managers (hospital staff), and specialists. Referring physicians can choose their credentials upon submitting their first referral, while for other users accounts are created by the Database Administrator.

To authenticate users using User-ID and User-Password pairs, this module compares the given User-Password with the password for the specific User-ID stored in the database. Passwords are encrypted (using jBCrypt hash function [70]) before storing in the database to improve users credentials security. In case the provided User-ID exists in the database and the User-Password is matching, user is authenticated and the user accessible information will be provided to the user through the appropriate interface.

#### **4.9 DATA MANAGER MODULE**

The Data Manager Module comprises of database queries which read, write, modify and delete clinical and non-clinical data. Data is stored in two separate MySQL databases:

1) **Users' accounts and referral records database:** stores system users' identity (referring physicians, referral managers, and specialists), historical records of submitted referrals, and external files attached to referrals. Table F-1 summaries description of database tables and columns for system databases.

2) **Patients' medical records and referral pathways database:** holds ontology models containing patients' medical records and executed referral pathways. These models are stored as RDF triples using Jena framework database API. Generally, a patient-centered approach is taken into account while persisting medical records and pathway models into the database; i.e. for each referred patient, one medical record model and one pathway model is stored in the database. If other referrals are sent for the same patient in the future, the medical record model is updated with new records, and the pathway model is re-written with a model specific to the recent referral.

#### **4.10 SUMMARY**

In this chapter, we described the spinal condition referral Decision Supporting component and the underlying E-Referral system. For this purpose, first we expanded the idea of using a specialized E-Referral system as a substructure for the Decision Supporting component. This was followed by the explanation of the SCERef system architecture and

our approach for integrating the Decision Supporting Module with the E-Referral system. Afterwards, each module of the SCERef system was described in details. Finally, sample scenarios were included to better clarify how system modules operate.

## CHAPTER 5 Evaluation

### 5.1 INTRODUCTION

We have developed SCERef, a decision supporting system comprising of an electronic referral system and an integrated decision support component. SCERef aims to improve the spinal condition referral process by increasing referring physicians' adherence to consultation protocols and facilitating referral administration.

We design an evaluation process to assess the SCERef system by answering the following questions:

#### I) **What are the existing gaps in domain representation of SCCP Ontology?**

To answer this question we evaluate the domain representation of SCCPO for spinal referrals through a qualitative approach. Specifically, we use the following two tests:

- i) Referral concepts accommodation; Assess whether SCCPO is able to accommodate concepts included in spinal referrals, and detect existing gaps for ontology improvements.
- ii) Referrals model consistency; Assess whether referral models represented based on SCCPO are consistent. This includes consistency testing of the TNM module model as well as the PCR module. Any identified inconsistency is considered for ontology improvements.

#### II) **How close are the results of SCCPO execution engine and manual assessment?**

To evaluate the SCCPO execution engine we consider association of calculated Assessment Points compared to manual assessment results (see section 5.2.2). We also assess the ratio of referral cases that have been successfully triaged in one of the three severity categories.

#### III) **Is the length of referral time acceptable?**

We evaluate the average referral time using the SCERef system. For this aim, we assess the average time that referring physicians spend to prepare referrals and receive results. The result of this question allows us to investigate any existing inefficiencies throughout the software aided referral process.

**IV) Is there an association between the Assessment Score inaccuracy and the time spent to complete the referral?**

We are interested to investigate whether there is an association between the time spent to complete a referral and the inaccuracy of Assessment Score (compared to the gold standard). The outcome of this test helps us to understand whether less time in completing referrals lead to more errors or vice versa.

**V) Examine Users' satisfaction with the SCERef system.**

We use two short questionnaires to capture participants' opinion in regards to the followings:

- i) How appropriate is the interface design?
- ii) How reliable is the system?
- iii) How appealing is the system performance?
- iv) How the use of the system affects the referral information quality?
- v) How the use of the system affects the knowledge accessibility and appropriateness?
- vi) Does the use of e-referral system affect the workload in a positive manner (the amount of workload for staff and general practitioners, the improvement in referral processing workload due to the use of automatic assessment)?

## 5.2 METHODS

### 5.2.1 Participants

This evaluation is performed by participants from NICHE (Knowledge Intensive Computing for Health Care Enterprises) research group and Halifax Infirmary Neurosurgery Department members. Total of 8 participants were recruited from different areas of practice. The included participants have had sufficient knowledge of working with computer systems and with using web-based forms. Table 5-1 lists numbers of participants in each area.

Table 5-1 Number of participants in different areas of practice

Area of Practice	Number of Participants
General Practice	4
Health Informatics	3
Referral Administration	1

### 5.2.2 Study Design

We aim to answer our evaluation questions by analyzing information resulted from submission and processing of sample referrals using the SCERef system. Figure 5-1 illustrates a workflow of this evaluation process.

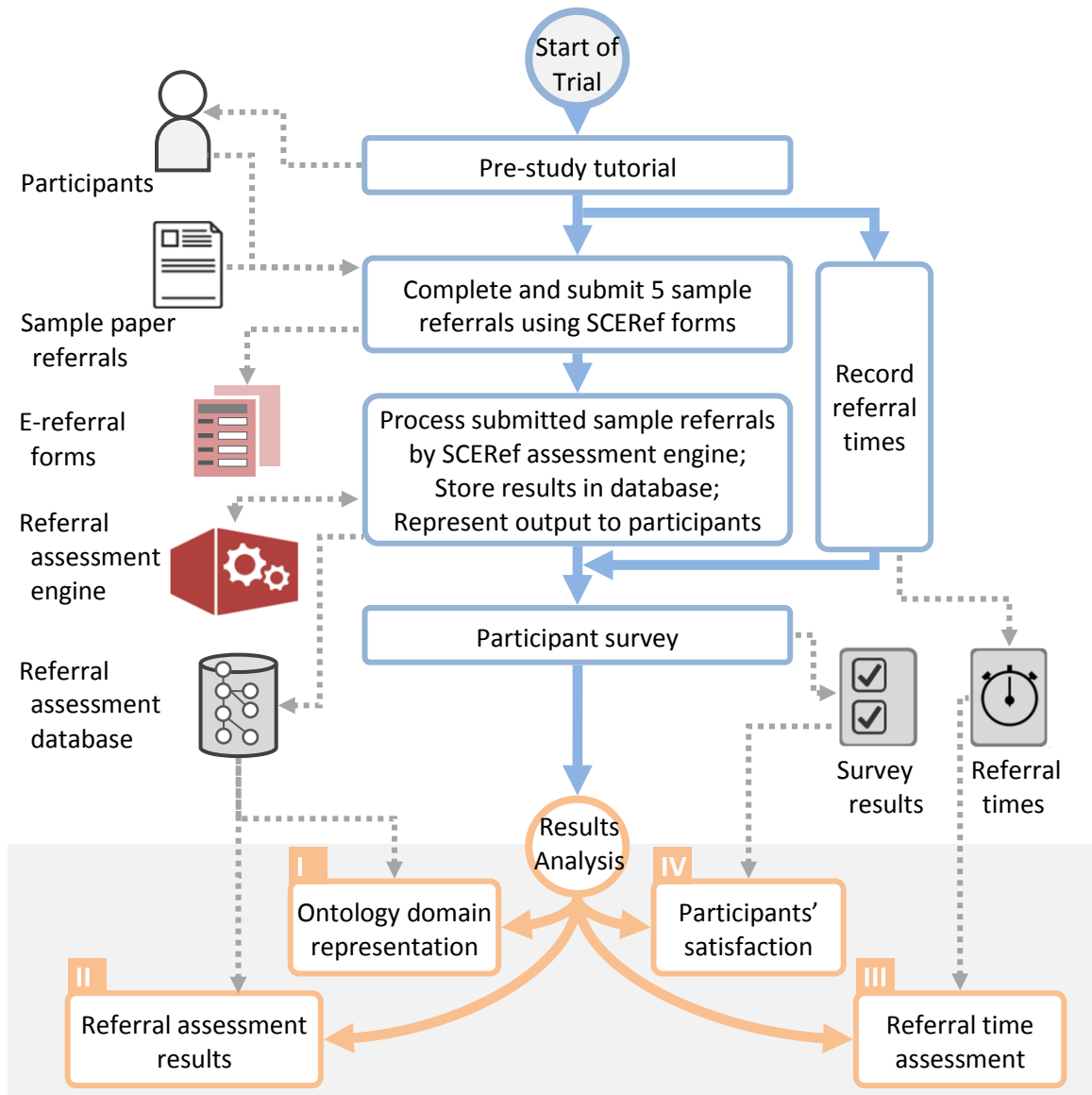
At the beginning of the trial each participant was invited for a short tutorial session to become familiar with the purpose of the system and how to submit referrals in simple steps. This tutorial has been designed to be similar to system guide contents available on the SCERef website for practical use.

Following the introductory session, each participant is asked to electronically submit 5 referrals using the online e-referral forms (SCERef). Each participant is given 5 paper



referral forms (Figure A-1) which has been previously submitted by primary care physicians and have been processed manually by the Neurosurgery Division staff.

Figure 5-1 Our evaluation process flowchart (solid lines is the process flow and dotted lines represent data flows). Each result analysis step is labeled in accordance with the relevant evaluation question (Section 5.1).



The sample referrals have been selected randomly from spinal condition referrals submitted to the Neurosurgery Department during the years 2012 and 2013. To maintain

information confidentiality, patients' and referring physicians' identification information have been detached and forms have been labeled using three digit numbers. Participants are allowed to submit referrals at any convenient time during a two weeks period. We also keep a record of time durations that participants spend to complete referrals. After submitting all referral forms, each participant completes a short questionnaire capturing participant's opinion regarding the system efficiency and interface design.

When sample referrals are submitted, they are processed by SCERef referral assessment engine, and the results are stored in the referral database. We use these results, along with records of trial referral time durations and result of participants' surveys to evaluate the SCERef system in regards to the evaluation questions described in Section 5.1. For this purpose, we use SPSS for statistical analysis and also MediCalc for graphical illustrations. Below we further explain how our evaluation process answers the described questions.

- I) **SCCP Ontology domain representation:** During this step we use the instantiated ontology models resulted from SCERef assessment of submitted referrals to evaluate SCCPO domain representation in respect to:
  - i) Referrals concepts accommodation: We identify concept representation gaps by manually extracting concepts from submitted referrals, and attempting to cross match these concepts with corresponding SCCPO concepts. In case of an unmatched extracted concept, the concept is reported as a concept representation gap in SCCPO.
  - ii) Referral model consistency: We use an ontology reasoner to examine the consistency of referral models instantiated using the SCCPO. For this purpose we employ FaCT++ reasoner (OWL 2 version) and Protégé tool. Any inconsistencies in workflow representations are reported as the result of this test.

- II) Association of the SCCPO execution engine results with manual assessment results:** Through this test we test the association between software calculated Assessment Points and manual calculations for same cases. The Assessment Points are numeric values calculated based on patient medical attributes, assisting clinicians through the consultation of the patient. We employ the Intraclass Correlation as the statistical analysis method to test the agreement between two variables. We specifically use this statistical test since two test variables are representing the same factor (referral Assessment Points). Furthermore, we report the ratio of triaged referral cases (triaged based on embedded triage logics) in comparison with the ratio of referrals which could not be triaged under a specific category.
- III) Average length of time for referral submission:** We evaluate the average total time to prepare a spinal condition referral and receive referral assessment results through the SCERef system. We also review a breakdown of the time spent for each step during the referral process (i.e. time spent on each referral form and the wait time for referral assessment).
- IV) Correlation between the referral assessment inaccuracy and the time spent to complete the referral forms:** We examine the correlation between total time spent to complete referral forms and the referral assessment results (Assessment Scores). For this purpose we use Spearman's ranked correlation test between referral form completion times (excluding the execution time) and the difference between automatic and manual Assessment Scores.
- V) Users' satisfaction with the SCERef system:** To evaluate users' satisfaction, we asked participants to complete a short survey. The survey comprises of a number of likert-scale questions with scores ranging from 1 (most negative) to 7 (most positive), in addition to one open-ended question to collect user opinion about the electronic system. The survey for the referral manager staff includes a different set of questions to gather referral manager's opinion about the electronic system.

## 5.3 RESULTS

### 5.3.1 Ontology Model Evaluation

For the evaluation of SCCP ontology model, we selected 5 referrals from submitted referrals by participants, and employed the ontology models resulted from execution of these referrals. In this step we tried to select referrals which cover variety of concepts. Original forms of the selected referrals can be found in Appendix D.

#### Evaluating Concept Accommodation

To evaluate ontology concept representation, we extracted concepts from submitted referral forms and matched with corresponding concepts from final instantiated ontology models resulted from ontology executions. To avoid bias during extraction of concepts due to the familiarity with ontology models, the extraction of concepts took place prior to any interactions with resulting ontology models. In other words, the resulting ontology models have not been reviewed until all available concepts from the submitted referrals have been extracted. Following this, we cross-matched the resulting concepts from each referral with the corresponding ontology model. Table 5-2 to Table 5-6 show lists of extracted referral concepts and matching ontology concepts and relations.

Table 5-2 Extracted concepts and matching ontology concepts for Referral Case 1 (#36)

Referral Concept	Corresponding Ontology Concept or Subject in a triple	Description
Patient has presenting history of pain	Pain_Finding	
Leg weakness - Poor balance - Numbness both feet: after sitting, pins & needles ~ 1hr	Pain_Finding -> description -> text value	
Pain onset: 6 months	Pain_Finding -> painOnset -> text value	'6 mo. to 1 yr.'
Pain location: lower back and lower leg	Pain_Finding -> findingSite -> Physical_Anatomical_Entity	Two separate triples: 'Lumbar/Sacral' 'Arm/ Leg Dominant'

Referral Concept	Corresponding Ontology Concept or Subject in a triple	Description
Radiation: legs	Pain_Finding -> painRadiation -> Physical_Anatomical_Entity	
Pain quality: pins and needles	Pain_Finding -> painQuality -> text	
Aggravating: Work, Walking, Rest	Pain_Finding -> painAggravatingFactor -> Intervention	Interface design do not allow to select 'Rest' as an aggravating factor
Severity Best: 6 Avr: 7 Worst: 9	Pain_Finding -> painSeverityBest (painSeverityAvr/ painSeverityWorst)	Decimal values
Previous treatment: physiotherapy, chiropractic	Past_Medical_History -> hasOutput -> Physical_Therapy	Two separate instances of Physical_Therapy
Past medical history: mild Scoliosis	Diagnostic_Imaging -> hasOutput -> Medical_Problem	
Medications: Celebrex – Lyrica – NSAIDs class	Past_Medical_History -> hasOutput -> Drug_Administration Drug_Administration -> drug_name -> Drugs Drug_Administration -> description	An instance for history of drug administration; Drug classification; Medication details.
Physical examination scores and score description: 'SLR exam positive, with pin & needles.'	Physical_Exam -> hasOutput -> PhysicalExam_Finding	One instance for each score. Scores lack a relation to add descriptions.
	Referral_Step -> triageAssessmentScore -> integer value Referral_Step -> triageCategory -> text value	Storing result of execution for this referral: Assessment points and triage category

Table 5-3 Extracted concepts and matching ontology concepts for Referral Case 2 (#38)

Referral Concept	Corresponding Ontology Concept or Subject in a triple	Description
Patient has presenting history of pain	Pain_Finding	
2 year history of sever Neu pain with numbness in left arm	Pain_Finding -> description -> text value	
Pain onset: 2 years	Pain_Finding -> painOnset -> text value	'more than 1 yr.'
Pain location: Neck and numbness in left arm	Pain_Finding -> findingSite -> Physical_Anatomical_Entity	Two separate triples: 'Cervical'

Referral Concept	Corresponding Ontology Concept or Subject in a triple	Description
		'Arm/ Leg Dominant'
Radiation: left arm	Pain_Finding -> painRadiation -> Physical_Anatomical_Entity	
Pain quality: Neuropathy	Pain_Finding -> painQuality -> text	Missing text value; will be instantiated into the model when added to the interface
Aggravating: Work	Pain_Finding -> painAggravatingFactor -> Intervention	Interface design do not allow to select 'Rest' as an aggravating factor
Relieving: rest	Pain_Finding -> painRelievingFactor -> Intervention	
Severity Best: 4 Avr: 6 Worst: 9	Pain_Finding -> painSeverityBest (painSeverityAvr/ painSeverityWorst)	Decimal values
Previous treatment: physiotherapy, acupuncture, massage	Past_Medical_History -> hasOutput -> Physical_Therapy	Three separate instances of Physical_Therapy
Medications: Lyrica 100 mg bid- Oxyneo daily	Past_Medical_History -> hasOutput -> Drug_Administration Drug_Administration -> drug_name -> Drugs Drug_Administration -> description	An instance for history of drug administration; Medication details.
Physical examination scores	Physical_Exam -> hasOutput -> PhysicalExam_Finding	One instance for each score.
	Referral_Step -> triageAssessmentScore -> integer value Referral_Step -> triageCategory -> text value	Storing result of execution for this referral: Assessment points and triage category

Table 5-4 Extracted concepts and matching ontology concepts for Referral Case 3 (#40)

Referral Concept	Corresponding Ontology Concept or Subject in a triple	Description
Patient has presenting history of pain	Pain_Finding	
Pain onset: 5 weeks	Pain_Finding -> painOnset -> text value	'Less than 6 wk.'
Pain location: Low back	Pain_Finding -> findingSite -> Physical_Anatomical_Entity	'Lumbar/Sacral'

Referral Concept	Corresponding Ontology Concept or Subject in a triple	Description
Radiation: both legs	Pain_Finding -> painRadiation -> Physical_Anatomical_Entity	
Severity Best: 2 Avr: 4 Worst: 8	Pain_Finding -> painSeverityBest (painSeverityAvr/ painSeverityWorst)	Decimal values
Presenting history: Neurogenic bladder; additional description	Presenting_Medical_History -> hasOutput -> Medical_Problem	Additional description can be added to presenting history description.
Previous treatment: physiotherapy	Past_Medical_History -> hasOutput -> Physical_Therapy	
Physical examination scores	Physical_Exam -> hasOutput -> PhysicalExam_Finding	One instance for each score.
	Referral_Step -> triageAssessmentScore -> integer value Referral_Step -> triageCategory -> text value	Storing result of execution for this referral: Assessment points and triage category

Table 5-5 Extracted concepts and matching ontology concepts for Referral Case 4 (#70)

Referral Concept	Corresponding Ontology Concept or Subject in a triple	Description
Patient has presenting history of pain	Pain_Finding	
'Severe low back pain w left side radicular symptoms'	Pain_Finding -> description -> text value	
Pain location: Low back	Pain_Finding -> findingSite -> Physical_Anatomical_Entity	'Lumbar/ Sacral'
Radiation: Down leg L	Pain_Finding -> painRadiation -> Physical_Anatomical_Entity	
Pain quality: Sharp burning	Pain_Finding -> painQuality -> text	Two separate text values
Aggravating: Movement, Sitting	Pain_Finding -> painAggravatingFactor -> Intervention	Two separate triples
Severity Best: 7 Avr: 9 Worst: 10	Pain_Finding -> painSeverityBest (painSeverityAvr/ painSeverityWorst)	Decimal values
Radiology results: Severe L4/5 Stenosis on CT	Diagnostic_Imaging -> hasOutput -> Medical_Problem	Additional description is not captured since radiology report is attached
Previous treatment: physiotherapy, massage	Past_Medical_History -> hasOutput -> Physical_Therapy	Two separate triples

Referral Concept	Corresponding Ontology Concept or Subject in a triple	Description
Medications: Percocet 4/day, Tylenol 3 20 mg	Past_Medical_History -> hasOutput -> Drug_Administration Drug_Administration -> description	An instance for history of drug administration; Medication details.
Physical examination scores	Physical_Exam -> hasOutput -> PhysicalExam_Finding	One instance for each score. Scores lack a relation to add descriptions.
	Referral_Step -> triageAssessmentScore -> integer value Referral_Step -> triageCategory -> text value	Storing result of execution for this referral: Assessment points and triage category

Table 5-6 Extracted concepts and matching ontology concepts for Referral Case 5 (#87)

Referral Concept	Corresponding Ontology Concept or Subject in a triple	Description
Patient has presenting history of pain	Pain_Finding	
Pain onset: 3 years	Pain_Finding -> painOnset -> text value	'more than 1 yr.'
Pain location: Neck and Rt. shoulder	Pain_Finding -> findingSite -> Physical_Anatomical_Entity	Two separate triples: 'Cervical' 'Arm/ Leg Dominant'
Radiation: Rt. hand	Pain_Finding -> painRadiation -> Physical_Anatomical_Entity	
Pain quality: Sharp	Pain_Finding -> painQuality -> text	
Aggravating: 'Flexion of neck'	Pain_Finding -> painAggravatingFactor -> Intervention	Not available through the interface
Relieving: 'Elevating shoulders'	Pain_Finding -> painRelievingFactor -> Intervention	Not available through the interface
Severity Best: 5 Avr: 7 Worst: 10	Pain_Finding -> painSeverityBest (painSeverityAvr/ painSeverityWorst)	Decimal values
Previous treatment: physiotherapy	Past_Medical_History -> hasOutput -> Physical_Therapy	
Physical examination scores	Physical_Exam -> hasOutput -> PhysicalExam_Finding	One instance for each score.
	Referral_Step -> triageAssessmentScore -> integer value Referral_Step -> triageCategory ->	Storing result of execution for this referral: Assessment points and



Referral Concept	Corresponding Ontology Concept or Subject in a triple	Description
	text value	triage category

This test revealed a few missing concepts and relations; First, models lack specific Intervention class instances to link as required pain aggravating factors and pain relieving factors (e.g. aggravating: rest, sitting; relieving: elevating shoulders). Second, two cases specify further descriptions for physical examination scores while ontology model does not entail any relation to add description to physical examination scores (e.g. SLR exam produces feeling of pins and needles). To resolve these shortcomings new instances can be added to the model to represent required objects for the *painAggravatingFactor* and *painRelievingFactor* properties. In addition, the *PhysicalExam\_Finding* class can be added to the subject list of the *description* property to allow further descriptions for physical examination results.

### **Evaluating Referral Ontology Model Consistency**

To test the consistency of patient data and referral workflow ontology models two steps are performed:

Following the implementation and manual instantiation of SCCPO we tested ontology consistency by running the ontology reasoner over this model and resolved any inconsistency errors. This has resulted in a consistent ontology model for the purpose of SCCPO execution and automated instantiation.

We tested consistency of 5 ontology models which are resulted from processing of 5 selected referrals and entail patient data through automatic ontology instantiation. We have found following inconsistencies by running the ontology reasoner over these models:

- 1) Uninstantiated *composedBy* property: The object property *composedBy* has not been instantiated for patients' medical records (instances of *Clinical\_Finding* and

*Medical\_Problem*) while the property is restricted by an exact cardinality (exactly 1) and a closing axiom.

- 2) Unsatisfied necessary condition for *hasRole* property: Assigned values for the datatype property *hasRole* have not been complying with the defined necessary condition for *Physician* class instances. The *hasRole* property is necessary to be defined with the value *physician\_generalPractice* for each instance of *Physician* class, while it is defined with a different value.

To resolve the inconsistency issues resulted from ontology execution, we have modified the ontology execution engine to comply with the stated restrictions. Consequently, ontology models resulted from processing of the same referrals are produced without the described consistency errors.

### 5.3.2 SCCPO Execution Engine Evaluation

We collected referral assessment results of 30 submitted referrals for the evaluation of Ontology Execution Engine accuracy. Specifically two variables are collected for this purpose: calculated total Assessment Points, and Triaging Categories.

#### **Testing Total Assessment Points:**

Results of Assessment Point calculations for 30 referrals are collected for both automatic and manual referral assessment methods. In practice these values can range between 0 to 15 [22]. Assessment Points for both manual and automatic methods are listed in Table 5-7.

In summary, nearly one quarter of these cases are scored equally by the use of both methods. In half of the cases, the automatic score is smaller than the manual score, and roughly in one quarter of cases the automatic score is larger than the matching manual score. This information is summarized in Table 5-8.

Table 5-7 List of referral Assessment Points calculated manually and automatically by SCERef. The score ranges between 0-15.

	Manual Assessment Points	Automatic Assessment Points		Manual Assessment Points	Automatic Assessment Points
Case 1	8	9	Case 16	5	7
Case 2	7	7	Case 17	4	3
Case 3	5	5	Case 18	4	0
Case 4	4	3	Case 19	5	0
Case 5	4	0	Case 20	7	7
Case 6	8	6	Case 21	4	6
Case 7	4	9	Case 22	4	1
Case 8	4	1	Case 23	8	8
Case 9	8	3	Case 24	4	3
Case 10	7	3	Case 25	4	1
Case 11	3	4	Case 26	4	4
Case 12	3	4	Case 27	4	3
Case 13	5	5	Case 28	4	9
Case 14	7	3	Case 29	5	1
Case 15	3	3	Case 30	4	5

The degree of difference between two calculation methods that is considered significant can be relatively inferred based on the categorization of these scores. Generally, resulting Assessment Scores can be categorized based on the severity of conditions they represent into three categories [22]: Mild (less than 5), Moderate (5-9), and Severe (more than 9). In this trial, we consider a degree of difference significant, when it causes the scores calculated for the same case using the two methods to be categorized in two different severity levels. For instance, the difference between scores for Case 8 is not considered significant, while it is significant for Case 9. Total of 7 cases show significant differences between two calculation methods. We believe these significant differences are mainly due to the nature of calculations in two methods, and the effect of unstructured information sources considered in manual calculations (see Section 5.4). Table 5-8 summarizes significant and insignificant score differences statistics.

Table 5-8 Referral Assessment Points data summary

Factor	Value (%)
Automatic < Manual	15 (50%)
Automatic > Manual	8 (26.66%)
Automatic = Manual	7 (23.33%)
Insignificant Score Difference	21 (70.00%)
Significant Score Difference	9 (30.00%)
Automatic Lowest Value	0
Automatic Highest Value	9
Manual Lowest Value	3
Manual Highest Value	8

The values from two scoring method are compared using a box-plot in Figure 5-2. As illustrated, automatic scores range over a wider span in contrast to manual scores. Moreover, automatic score are well spread within the span between lower and upper extremes, whereas manual scores are gathered around five values with half of scores around the median (score 4). The reason for the skewness of manual scores can partly be the effect of tacit knowledge and past experiences on scores calculation (see Section 5.4). Apart from that, interquartile ranges for both methods are located close do not significantly differ from each other.

We plot the scores using a scatter diagram to graphically illustrate any correlation between these variables. The scatter diagram in Figure 5-3 illustrates sparseness of scores around the fitness line.

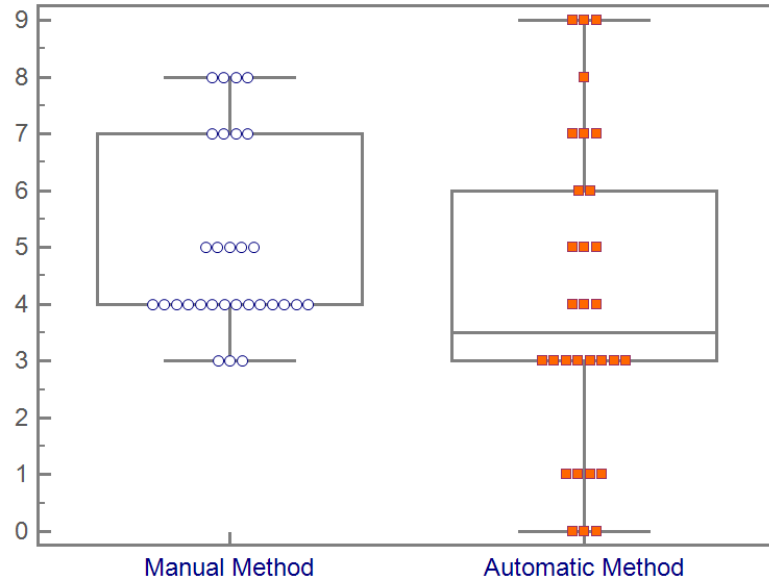


Figure 5-2 Box-plot comparing Assessment Points resulted from manual method of calculation against automatic method of calculation.

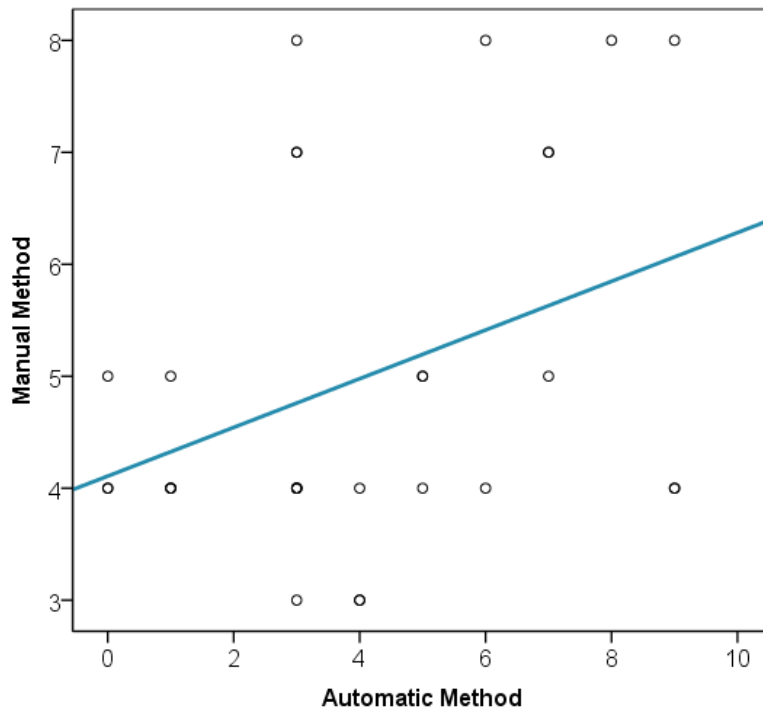


Figure 5-3 Scatter diagram presenting Assessment Points resulted from the manual method against the automatic method. The diagonal line represents the regression line for this data.

Although the diagram suggests there may be a correlation between two variables, few cases are scattered away from the fitness line. This is partly an implication of cases with significant differences (described above). Next, we statistically examine the correlation.

Through the use of the Intraclass Correlation test we would like to investigate the level of agreement between automatically calculated and manually calculated Assessment Points. For this purpose, the test is performed in *Mode 3* since all cases are assessed by two specific examiners (manual examiner and automatic examiner – not random examiners). Also, we are testing *agreement* of scores (as opposed to the *consistency* test). Table 5-9 shows the summary of results.

Table 5-9 Results of Intraclass Correlation test on automatically calculated referral Assessment Points and manually calculated Assessment Points.

Intraclass Correlation *	95% Confidence Interval		F Test <i>p</i> -value
	Lower Bound	Upper Bound	
0.304	-0.032	0.587	0.039

\* *SPSS test configuration:*  
*Model: Two-way Mixed (Mode 3); Type: Absolute Agreement*

The result of Intraclass Correlation score specifies that there is a moderate positive correlation between two methods of referral assessment with a value of 0.3, and the likely range of correlation is approximately between 0.0 and 0.6. Considering the fact that 70.0% of scores differences are insignificant, this result may suggest that the two methods of score calculation can be used interchangeably. However, due to the limited number of recruited participants, the statistical test does not provide enough power to obtain statistical justification using the *p*-value. According to sample size calculations [71], analysis of 30 referrals (our available sample size) can detect minimum correlation of 0.49, which is higher than our calculated correlation (Alpha =0.05, Power =0.80).

## Case Triaging Results:

We collected automated triaging results for 30 referrals submitted by participants. Table 5-10 shows a summary of results.

Table 5-10 Number of triaged referrals under different categories for 30 submitted referrals. The Not Assigned category specifies the cases that could not be triaged under any of other categories.

	Referral Triaging Categories			
	Axial Pain	Radicular Pain	Urgent Condition	Not Assigned
Number of Assigned Cases	5	12	10	3
Portion in Total referrals	16.66 %	40 %	33.33 %	10 %

It is found that highest number of cases are triaged as Radicular pain, followed by Urgent conditions. Axial pain includes minimum number of cases with considerable difference. In total, the Referral Execution Engine has been able to triage 90% of cases, leaving 10% of cases uncategorized. Examining the 3 uncategorized cases has revealed a gap in triaging logic that leads to unsuccessful triaging of these cases (see Section 5.4). It worth mentioning that at this point it is not possible for us to verify the ratio of correctly triaged cases since this information is not recorded during manual assessment of referrals (lack of gold standard). Therefore we focus on assessment of uncategorized cases to determine any gaps in the automated referral assessment process.

### 5.3.3 Time Requirements

To evaluate the system performance in regards to time requirements, we recorded the time taken for each step of the referral to complete; that is, the time spent by each participant to accomplish referral steps for each referral case.

For this purpose, we have collected time durations for 4 referral forms (presenting history, past history, physical examination, and radiology), and the automated referral processing. The time duration for each referral form is calculated from the moment participant views the form until the moment he leaves that form. Similarly, automated referral processing duration is calculated from when referral processing starts until it ends. The referral processing duration comprise of different processes including ontology model execution, output report preparation, and all database transactions. The granularity of all collected times is millisecond, however during the statistical analysis we consider minute as the time unit. Table 5-11 lists time durations for 30 referral cases.

Table 5-11 Recorded time durations by the SCERef software for each referral step during the evaluation of the system using 30 referral cases. All durations are in minutes.

	<b>Presenting History</b>	<b>Past History</b>	<b>Physical Examination</b>	<b>Radiology</b>	<b>Automated Referral Processing</b>	<b>Total Time (minutes)</b>
<i>Case 1</i>	9.37	1.96	2.26	0.76	0.72	15.1
<i>Case 2</i>	0.67	0.32	0.94	0.03	0.56	2.5
<i>Case 3</i>	1.50	0.17	1.58	0.31	0.27	3.8
<i>Case 4</i>	8.41	3.56	4.65	0.84	0.50	18.0
<i>Case 5</i>	1.16	0.36	1.68	0.16	0.58	3.9
<i>Case 6</i>	1.14	0.21	0.49	0.23	0.55	2.6
<i>Case 7</i>	1.33	0.27	0.16	0.09	0.54	2.4
<i>Case 8</i>	1.54	0.30	0.10	0.08	0.53	2.6
<i>Case 9</i>	10.72	0.75	4.41	0.24	0.79	16.9
<i>Case 10</i>	7.10	0.26	3.75	0.04	0.62	11.8
<i>Case 11</i>	4.05	0.42	5.42	0.12	0.75	10.8
<i>Case 12</i>	3.02	0.84	0.80	0.08	0.71	5.5
<i>Case 13</i>	3.27	0.28	1.95	0.03	0.65	6.2
<i>Case 14</i>	3.90	0.92	1.60	2.07	0.36	8.8
<i>Case 15</i>	0.57	0.11	0.25	0.04	0.67	1.6
<i>Case 16</i>	15.12	1.04	1.76	0.08	0.62	18.6
<i>Case 17</i>	3.98	0.33	1.89	0.99	0.65	7.8
<i>Case 18</i>	3.81	0.11	2.05	0.12	0.75	6.8



	<b>Presenting History</b>	<b>Past History</b>	<b>Physical Examination</b>	<b>Radiology</b>	<b>Automated Referral Processing</b>	<b>Total Time (minutes)</b>
<i>Case 19</i>	5.27	0.98	0.60	0.39	0.54	7.8
<i>Case 20</i>	1.91	0.52	0.99	6.29	0.52	10.2
<i>Case 21</i>	3.54	0.18	0.61	0.02	0.51	4.9
<i>Case 22</i>	4.68	0.14	1.95	0.02	0.55	7.3
<i>Case 23</i>	6.57	10.43	0.58	0.01	0.82	18.4
<i>Case 24</i>	1.23	0.16	0.37	0.00	0.59	2.4
<i>Case 25</i>	2.48	3.22	2.51	0.02	0.50	8.7
<i>Case 26</i>	3.77	1.74	2.18	0.00	0.50	8.2
<i>Case 27</i>	2.39	1.95	0.77	0.00	0.51	5.6
<i>Case 28</i>	1.68	0.68	0.45	0.00	0.53	3.3
<i>Case 29</i>	7.46	1.07	5.53	1.54	0.53	16.1
<i>Case 30</i>	16.49	1.96	2.60	1.49	0.54	23.1

The summary statistics in Table 5-12 lists mean and standard deviation for time durations in different referral steps. It is shown that Presenting History step has the maximum mean (4.6 minutes) with highest variation, while Radiology has the lowest mean (0.54 minutes). It worth mentioning that the Automated Referral Processing step also has a low mean (0.58 minutes) with a small variation ( $\pm 0.12$ ). The total referral time has a mean of 8.72 minutes with standard deviation of  $\pm 5.96$ .

Table 5-12 Summary statistics of recorded time durations for each referral step during SCERef evaluation. All durations are reported in minutes.

	<b>Minimum - Maximum</b>	<b>Mean</b>	<b>Standard Deviation</b>	<b>95% Confidence Interval</b>
<b>Presenting History</b>	0.57 – 16.49	4.60	4.04	$\pm 1.45$ (3.15-6.05)
<b>Past History</b>	0.11 – 10.43	1.17	1.96	$\pm 0.7$ (0.47-1.87)
<b>Physical Examination</b>	0.10 – 5.53	1.83	1.54	$\pm 0.55$ (1.28-2.38)
<b>Radiology</b>	0.00 – 6.29	0.54	1.21	$\pm 0.43$ (0.11-0.97)
<b>Automated Referral Processing</b>	0.27 – 0.82	0.58	0.12	$\pm 0.04$ (0.54-0.62)
<b>Total Time</b>	1.6 – 23.1	8.72	5.96	$\pm 2.13$ (6.59-10.85)

The confidence interval of  $\pm 2.13$  for mean total referral time states that in the majority of cases, the mean referral time by the use of this system is less than 11 minutes. However, no statistical justification can be used to test the mean referral time in our context (see Section 5.4).

### 5.3.4 Association between Referral Time and Score Difference

We calculate the correlation between referral form completion time (excluding referral processing time) and the difference between manual and automatic Assessment Scores. Table 5-13 lists referral times and score differences for submitted cases.

Table 5-13 The Assessment Score difference (|manual score – automatic score |) and referral form completion time (total referral time – processing time) for each submitted case.

	Score Difference (Error)	Referral Form Preparation Time		Score Difference (Error)	Automatic Assessment Points
Case 1	1	14.38	Case 16	2	7.15
Case 2	0	1.94	Case 17	1	6.05
Case 3	0	3.53	Case 18	4	7.26
Case 4	1	17.5	Case 19	5	9.68
Case 5	4	3.32	Case 20	0	4.39
Case 6	2	2.05	Case 21	2	6.75
Case 7	5	1.86	Case 22	3	17.58
Case 8	3	2.07	Case 23	0	1.81
Case 9	5	16.11	Case 24	1	8.2
Case 10	4	11.18	Case 25	3	7.7
Case 11	1	10.05	Case 26	0	5.09
Case 12	1	4.79	Case 27	1	2.77
Case 13	0	5.55	Case 28	5	15.57
Case 14	4	8.44	Case 29	4	22.56
Case 15	0	0.93	Case 30	1	7.15

The result of Spearman's rank correlation test on this data shows no association between time and score difference variables. Therefore we cannot conclude that spending more time on referral submissions results in smaller score differences or referrals prepared in shorter durations are associated with larger score differences. Table 5-14 summarizes the result of Spearman's rank correlation test.

Table 5-14 Result of Spearman's rank correlation test on Assessment Score difference and referral form completion time

<i>Spearman's coefficient of rank correlation (rho)</i>	0.0195
<i>Significance level</i>	P = 0.9184
<i>95% Confidence Interval for rho</i>	-0.343 to 0.377

### 5.3.5 Users' Satisfaction

At the end of the study participants were asked to complete a questionnaire in regards to system design, information quality and knowledge accessibility. Table 5-15 and Table 5-16 show the result of scored questionnaires.

Table 5-15 Result of Likert-scale participants questionnaire regarding system efficiency and interface design. Average scores are calculated for 5 participants. Scores are in the range of 1 – 7.

<b>Question</b>	<b>Average Score</b>
Q1. Text on the forms and reports 1: Hard to read – 7: Easy to read	4
Q2. Tables and figures 1: Heard to understand – 7: Easy to understand	5
Q3. Screen layouts and the sequence of the forms 1: Confusing – 7: Easy to read	6
Q4. System messages 1: Inappropriate – 7: Appropriate	6

Question	Average Score
Q5. Responsiveness of the system interface 1: Slow – 7: Fast	5
Q6. Reliability of the system 1: Unreliable – 7: Reliable	5
Q7. Speed of the referral request processing 1: Slow – 7: Fast	5
Q8. How the use of e-referral system improves submitting referrals for spine related conditions? 1: Makes the task harder – 2: Makes the task easier	6
Q8. Referral report completeness 1: Incomplete – 7: Complete	5
Q9. Referral report accuracy 1: Inaccurate – 7: Accurate	6
Q10. The recommended guideline applicability 1: Inapplicable – 7: Applicable	6
Q11. Considering the method of accessing and the duration it takes to receive the recommended guideline, how do you rate the accessibility of the care knowledge, compared to other methods (e.g. searching online, verbal consultation)? 1: Less accessible – 7: More accessible	6

The survey results show acceptable average scores for interface design (Q1-Q3) and system performance (Q5-Q7). Moreover, participants rated the referral information quality, knowledge accessibility, and the overall referral process with considerably good scores (Q8-Q11). In this survey, using one open-ended question we asked participants to describe any problems they have had with the system or discuss their comments. To summarize the descriptive answers, from 3 answers that were received 4 comments was concerned about technical issues such as system glitches, system crashes, and difficulties with account sign in. In addition to that, one participant suggested to clearly documenting consultants identification during verbal consultations in referral forms for the accountability purpose.

Table 5-16 Result of Likert-scale survey questionnaire specific to referral manager staff. Scores are listed for 1 participant. Scores are in the range of 1 – 7.

Question	Score
Q1. Medical information completeness for the purpose of referral assessment 1: Incomplete – 7: Complete	7
Q2. Included medical information accuracy 1: Inaccurate – 7: Accurate	7
Q3. Effect of the e-referral system on referral assessment task with regards to the task complexity 1: Increased workload – 7: Reduced workload	6
Q4. Effect of the e-referral system on referral assessment task with regards to the task workload 1: Inappropriate – 7: Appropriate	6

From referral manager’s point of view, the SCERef system can considerably improve referral information completeness and accuracy. The scores also show that the use of SCERef for spinal condition referrals can decrease the referral assessment task complexity and workload. Using one open-ended question, we asked for referral manager’s opinion regarding any considerations that can improve the referral information quality further. The answer reflects some concerns about the extra workload that the physical examination form can cause for referring physicians:

“I think the only issue will be with the physical exam. Most physicians do not want to complete it .... The spine referrals completed on the spine form that we use currently, usually do not have that part filled in. The option to not complete the physical exam is helpful.”

Despite this extra workload caused by the extensive physical examination form, giving the option to submit an incomplete physical examination form can negatively affect the automated Assessment Score calculation. However customizing the physical examination

form based on referral data can partly solve this issue by decreasing referral preparation workload (see Section 6.3).

## **5.4 DISCUSSION**

Our evaluation of SCERef referral processing results by the use of statistical analysis leads us to a number of facts in regards to this system.

The result of referral Assessment Point calculation shows that the automatic method results equally with the manual method in nearly a quarter of cases. Although this is not a high portion, statistical test reveals there is a correlation between results of two methods. Therefore to be able to use these two correlated methods interchangeably we need to increase accuracy of the automatic method.

To improve the accuracy of score calculation, it is important to drive referring physicians to insert more information in structured fields rather than the free-text. As an example marking radiology diagnostic results in the referral form, as opposed to only uploading a text report, can considerably impact score calculations. One factor affecting this evaluation has been illegible and unstructured referrals that could not be easily transferred to structured referral fields by participants. In these cases medical information can be inferred from textual descriptions by the referral manager which results in more accurate manual scoring.

Moreover, we believe the automatic method and manual method perform referral assessments based on two knowledge sources with different natures. The automatic score calculation method is based on logics designed by domain experts and considers detailed patient medical information. On the other hand, the manual calculation method is based on the referral manager's tacit knowledge, which considers patients' medical information from multiple sources (e.g. radiology report, referral side notes, etc.) and is driven by her inference. Referral manager's inference is also highly affected by her experience with previous cases. Consequently, scores in this method are more resulted from human

inference rather than detailed arithmetic calculations. The manually calculated scores being clustered around few values can be an implication of what has been discussed (Figure 5-2). Therefore we argue that using manually calculated assessment scores as the gold-standard for evaluation of the automatic referral assessment method may lead to underestimation of the accuracy of this system.

The result of this evaluation shows that the system has been unsuccessful to triage a small portion of cases under correct categories. Deeper analysis of these cases revealed a gap in Radicular pain and Axial pain decision logics regarding the pain location attributes. In fact, specific selections for pain location can lead to uncategorizable referrals based on the current logic. To close this gap, we plan further discussions with domain specialists. Based on the changes in decision logic definitions, we apply the modifications in the application knowledgebase and re-run the uncategorized cases through the referral system to ensure successful triaging of similar cases.

We have identified a trial bias concerning how participants interpret and work with referral forms. Based on our experience, familiarity of participants with referral forms can have a considerable impact on the referral duration, and correspondence of the resulting referral with the source referral, therefore affecting the calculation of accuracy. We have observed that occasionally participants stopped on the first form (Presenting History) trying to read the referral contents or analyze contents. Therefore we believe that a considerable portion of time in all referrals is spent as a cost of content transformation from paper forms to the electronic form.

The referral submission duration using SCERef gives us a measurable factor to evaluate the system's performance. It is notable that the average time spent on the Presenting History form is considerably much higher than other referral steps. On the contrary, the Physical Examination is one of the forms which recorded an average spent time lower than initially anticipated by domain experts. One reason can be that the recorded time only reflects the time required to transfer listed scores into the physical examination form. In addition, the majority of referrals lack sufficient physical examination scores,

hence requiring less time to transferring data to the referral form. In the actual practice, performing comprehensive physical examinations (due to restrictions imposed by the electronic form) is expected to significantly increase the required time.

From the participants' point of view, although referral information quality, knowledge accessibility, and the overall referral process are enhanced, the software interface design, performance and reliability can still be improved. In this regard, the detected reasons for few system crashes are resolved. We suggest further participants surveys are required for improvements in interface design and system performance.

This evaluation also has number of limitations. First, we have calculated a mean total referral time of 8.72 minutes, we were not able to test this value against primary care physicians' preference in our context. As a matter of fact, we were not able to locate any reported referral time preference in related literature which can be generalized to the context of our study. Second, the statistical test for association of two referral methods lacks the sufficient power to statistically justify the results. To obtain acceptable results, we suggest to increase the number of participants in future studies. Third, we have analyzed the ratio of successful triaging of referrals under four categories; nevertheless it was not possible for us to evaluate the accuracy of automatic triaging, due to the absence of explicitly recorded manual triaging results. Last, it has been discussed that comparing the result of automatic referral assessment with manual assessment scores may underestimate the system assessment accuracy. We believe another evaluation design can be undertaken in which SCERef referral assessment results are compared with the automatic referral assessment results produced by other decision supporting systems. To the best of our knowledge there are no reported results of automatic triaging score calculation based on the Assessment Points scoring system offered by [22].

## **5.5 SUMMARY**

To evaluate the SCERef system, we designed a trial in which 30 paper referrals have been re-submitted using the SCERef system. Based on the results of this trial we tried to



analyze the system in terms of referral assessment accuracy, system knowledgebase consistency and comprehensiveness, system performance, and the participants experience with the system. It has been shown that SCERef has been able to successfully triage 90% of cases. Moreover, calculated assessment scores were correlated with results of manual assessment (as the gold-standard). Our analysis of executed SCCP ontology models revealed considerably consistent and comprehensive models. In addition, referral time analysis showed lower mean than 11 minutes with a significant difference. Finally, we summarized the average score of participants' surveys, reflecting improvements in referral information quality, knowledge accessibility, and the overall referral process.

## **CHAPTER 6 Discussion and Future Work**

As previously discussed in Chapter 1, through this research we are aiming to achieve the following goals and objectives:

- Computerization of the Spinal Condition Consultation Protocol (SCCP) into a knowledge model that can be used to enable computerized spinal condition referrals assessment.
- Integrating the SCCP in referral preparation process to improve referral content quality.
- Developing a Decision Support System to improve primary care physicians' adherence to the SCCP, and facilitate the referral assessment process.

In this chapter we discuss the research achievements and our future directions.

### **6.1 ACHIEVEMENTS**

The following describes main achievements of this research:

#### **1) Specialized Spinal Condition Consultation Protocol Ontology (SCCPO):**

We have modeled and transformed the Spinal Condition Consultation Protocol (SCCP) into a knowledge base schema using semantic web technologies (OWL ontology). The resulting SCCP Ontology is able to implement detailed spinal pain attributes, symptoms and related medical conditions. SCCPO uses the OWL language to implement a semantically rich knowledge model. The use of ontologies can enhance reusability and maintenance of this model. SCCPO also offers the following key features:

##### **i. Specialized Knowledge Modeling for Representation of Spinal Referral Attributes:**

Our resulting SCCP Ontology entails significantly improved expressivity in regards to spinal referral attributes, compared to our base ontology (ACS Ontology). These attributes include triaging scores, triaging categories, and participants in each referral using semantic relations. Detailed accommodation of these attributes acts as a foundation to enable effective automated referral assessment (see Table 3-3).

**ii. Integrated Clinical Patient Record Model within SCCPO:**

SCCPO implements an integrated Clinical Patient Record that makes it possible to model and persist historical patient clinical records such as symptoms, medical problems, and examination results (see Figure 3-12). Inclusion of a semantic model of Clinical Patient Record enables the referral assessment engine to coherently incorporate historical patient information in the automated assessment process.

**2) Standardized Spinal Referral Forms:**

It is known that integration of referral protocols in the referral process for form standardization can significantly improve the referral information quality and reduce the number of inappropriate referrals [16], [23], [29], [38]. We have integrated the SCCP in the referral process by developing standardized spinal referral forms. The standardized spinal referral forms are designed by taking into account decision logics and assessment scores calculation requirements. The final referral form incorporates domain expert feedbacks through several review sessions. Consequently, we have created a standardized synoptic report template that ensures collecting of sufficient clinical and non-clinical information for the purpose of timely referral assessment and seamless inter-provider communication.

**3) Improved Referral Information and Communication Quality:**

We developed an electronic means of communication for the purpose of spinal referrals to connect providers by the use of standardized electronic forms. The use of electronic communication has the potential of improving inter-provider communication effectiveness [6], [23]. The decision support services offered by this system also considerably enhances timeliness of receiving the result of referral evaluation (see below). Moreover, the use of standardized spinal referral forms and data verifications improve the quality of information in terms of validity and sufficiency, which is a key requirement to offer effective decision support services.

#### **4) Decision Support Services**

In the context of e-referrals few studies have addressed the utilization of decision support services (Table 2-1). In this research we provide decision supporting during the spinal condition referral process through two main approaches: i) automatically assess and triage spinal referrals, and ii) support referring physicians to perform informed therapies and examinations by providing relevant spinal condition management guidelines.

A number of characteristics distinguish this research from other works in this area: 1) We employ an automatic assessment engine specialized for spinal condition referrals. To the best of our knowledge none of the automatic referral assessment engines are specialized in assessment of spinal conditions based on spinal referral protocols. 2) This system offers knowledge-based automated referral processing that incorporates a formalized SCCP model in contrast with previous knowledge-based referral systems which employ more generic knowledgebases and referral auto-approval methods [28], [36].

## **6.2 LIMITATIONS**

We were able to identify the following limitations considering the characteristics of this research:

### 6.2.1 Limitations Pertaining to the Knowledgebase

Despite the fact that the current knowledge model entails enough representation power to implement the current referral logics of SCCP, the SCCPO lacks advanced representation characteristics which can enable implementation of more complex decision rules. As an example, physical body anatomical entities in the ontology currently do not semantically define some anatomical characteristics such as anatomical side which can facilitate the formalization of protocol logics similar to: “If Patient has radiating lower limb pain, And numbness in the same distribution”.

Another limitation of our knowledgebase is the implementation of SCCP logics using an inflexible approach. After the extraction of SCCP logics, we have hardcoded the formalized logics using the utilized programming language. This provides us with a number of advantages such as ease of development and troubleshooting. This approach however imposes complications during knowledgebase maintenance and applying SCCP updates, since formalized logics lacks a sufficient level of modularity.

### 6.2.2 Limitations Pertaining to the E-Referral System

One of the limitations of this system which has been pointed out by domain experts is the high amount of detailed mandatory data that referral forms ask referring physicians to insert. This concern has been frequently raised that the extra amount of effort and time required to fill out the forms can keep the primary care physicians from accepting the new system. Considering the fact that this level of data collection is crucial for accurate referral assessment and case triaging, we argue that further restriction of data collection can negatively affect the results. However, we suggest reducing this effort by implementing methods such as dynamic adaptation of referral forms (see Section 6.3).

Another limitation of this e-referral system is that it does not integrate the result of referral assessment within an automated scheduling mechanism. Although an integrated scheduling system has the potential of reducing referral management efforts and

decreasing no-show rates [31], our intent was to avoid implementing a scheduling system to reduce the manipulation of current referral workflow.

### 6.2.3 Limitations pertaining to System Evaluation

The first limitation of our evaluation is low number of participants in the study. This lead to limited number of survey results which prevented us from justifying the statistical analysis of the results. Also, since participants of our study excluded the initial group of referring physicians who have created our selection of referrals, the participants lack sufficient familiarity with the study referrals, and occasionally with the domain, which could result in re-submission errors and additional time spent. Additionally, different level of familiarity with, and diverse interpretation of the referral forms can be a source of trial bias during our evaluation.

As previously discussed, another limitation of this study is the method by which our gold-standard calculation has been conducted during the referral assessment engine accuracy testing. We believe this approach does not impose enough similarity between the two mechanisms of score calculation in our test and gold-standard methods, which may lead to underestimation of the accuracy of our system (see 5.4). Considering other approaches may improve the evaluation process, such as comparison with other automatic referral assessment systems, or manual referral assessment based on SCCP logics.

## 6.3 FUTURE DIRECTIONS

### 6.3.1 Knowledgebase Improvement

In our efforts of further developing the SCCPO, we intend to increase the expressivity of this knowledge model. SCCPO currently entail high-level classes which implement patient clinical records. Further improvement of SCCPO semantic network enables the implementation of more complex logics for the purpose of decision supporting (see Section 6.2.1 for an example).

We believe part of domain expert's tacit knowledge can be utilized to improve SCERef and decision support services. Therefore, one of our future intentions is to formalize relevant domain expert's tacit knowledge to enable features such as dynamic referral form adaptation, conditional data validation and diagnostic intervention suggestions. We also suggest the computerization of the medication guideline which is an extension to the current SCCP. This guideline can make it possible to provide condition based medication recommendations according to the pain severity (mild, moderate, or sever).

Finally, we implement a mapping between our knowledgebase concepts and a medical terminology such as SNOMED CT. In addition to improved interoperability, this enables the SCERef for advanced features such as extraction of medical concepts from plain text that can be automatically mapped to medical terminologies embedded in the SCCPO.

### 6.3.2 E-Referral Improvement

In our future direction our aim is to decrease referral preparation times. Based on domain experts' concerns regarding the excessive workload required for form completion, especially physical examination results, we believe part of this effort can be decreased by dynamic adaptation of required data fields based on patients' conditions. This offers great benefits in the case of physical examination results, in which parts of inapplicable data fields can be filtered out for different patients. For instance, specification of pain location and quality can be a determinant for the type of physical examination and body areas that it should be administered. Some interconnections however require implementation of more complex logics which can be derived from formalization of domain experts' tacit knowledge.

Due to the limited scope of this project, we have not considered the integration with other clinical information systems. Currently SCERef creates and use a separate patient medical record database. Our future direction includes investigation and implementation

of possible data flow interactions with the hospital EHR. This holds the potential of improving referral information data quality and comprehensiveness, as well as considerable reduction of referral preparation times due to utilization of referral form data pre-population.

We also intend to investigate the implementation of case specific SCCP based notifications. Within this context, the use of time triggered (e.g. scheduled review of therapies) or event triggered notifications (e.g. auto-submission of appointment information) can be implemented using SCCPO notification related concepts. This can in turn increase physicians' adherence to the consultation protocol.

Finally, implementation of the hospital management interface has been postponed as a future work due to the scope of this project. We would develop a hospital referral management interface which in addition to providing the access to archived referrals data, it assists the clinic staff with referral administration tasks.

## **6.4 CONCLUSION**

Through this research, we focused on supporting clinicians in the spinal referral process by implementation of knowledge-based decision support services hosted by a specialized electronic referral system (SCERef). SCERef aims to provide referring primary care physicians with condition specific consultation protocols. This system also utilizes an automatic referral assessment service which instantly provides results of referral assessment to the Neurosurgery department staff and clinicians.

SCERef employs the computerized Spinal Condition Consultation Protocol (SCCP) to provide decision support services. For this purpose, SCCP is formalized into a knowledgebase using Semantic Web technologies. The use of ontologies for this purpose provides us with sufficient expressivity to computerize SCCP. This also can offer knowledge model modularity, reusability, and better maintenance. Based on our experience, the use of consultation protocol in forms of a semantically rich knowledge



model to drive the referral assessment engine can technically facilitate the automated referral assessment process.

We aimed at integrating the SCCP in the referral preparation process by developing SCCP derived structured referral forms. This design drives the referring physicians to perform necessary investigations prior to referrals which in turn improves referral data quality [29]. As a result, referral data with sufficient quality is available in a timely manner for the purpose of automate referral assessment.

Finally, we believe SCERef can enhance the spinal referral process by establishing effective and timely inter-provider communication. At the secondary care level, this system provides facilitation in the referral management process. At the primary care level, SCERef assists the referring physicians to follow the consultation protocol, and serves as an education resource by providing condition management recommendations.

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**APPENDIX A Halifax Infirmiry Neurosurgery  
Department Simple Back Pain Consultation Protocol**

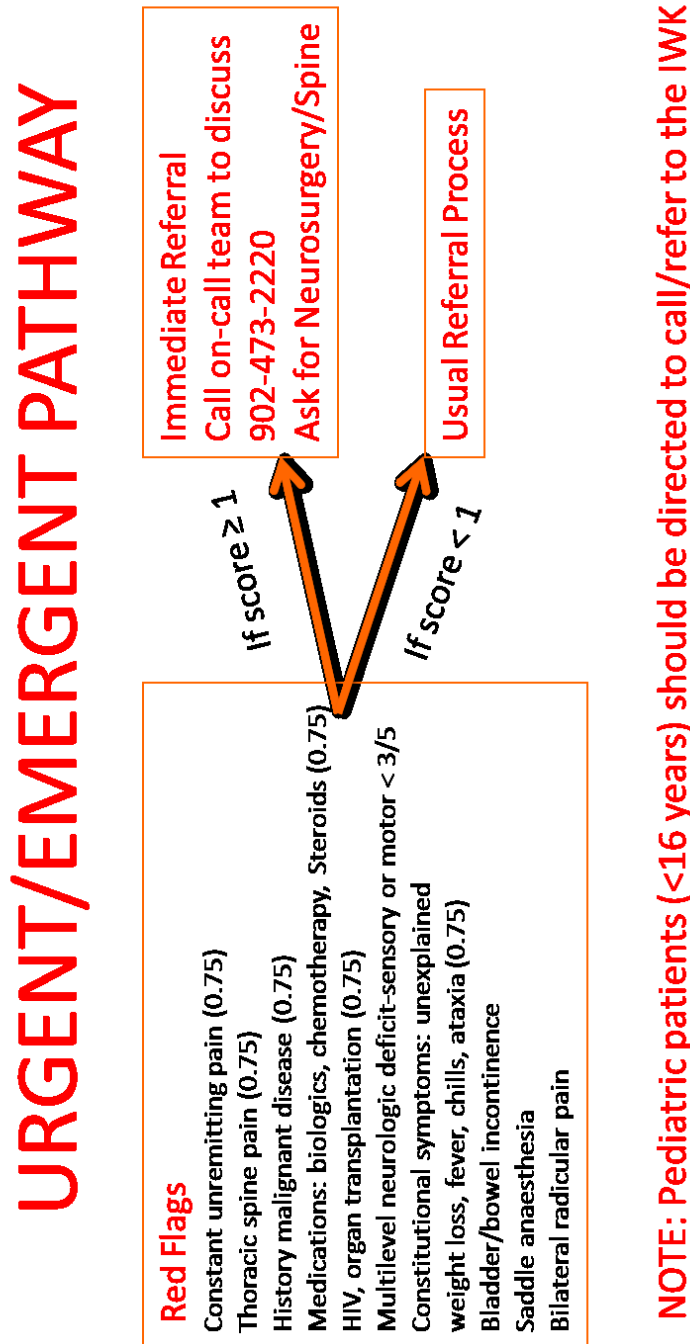


Figure B-1 Spinal Condition Consultation Protocol, Urgent condition pathway. In case score is less than 1, pathway is continued in Figure B-2.  
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# Radicular Pain (cervical/lumbar)

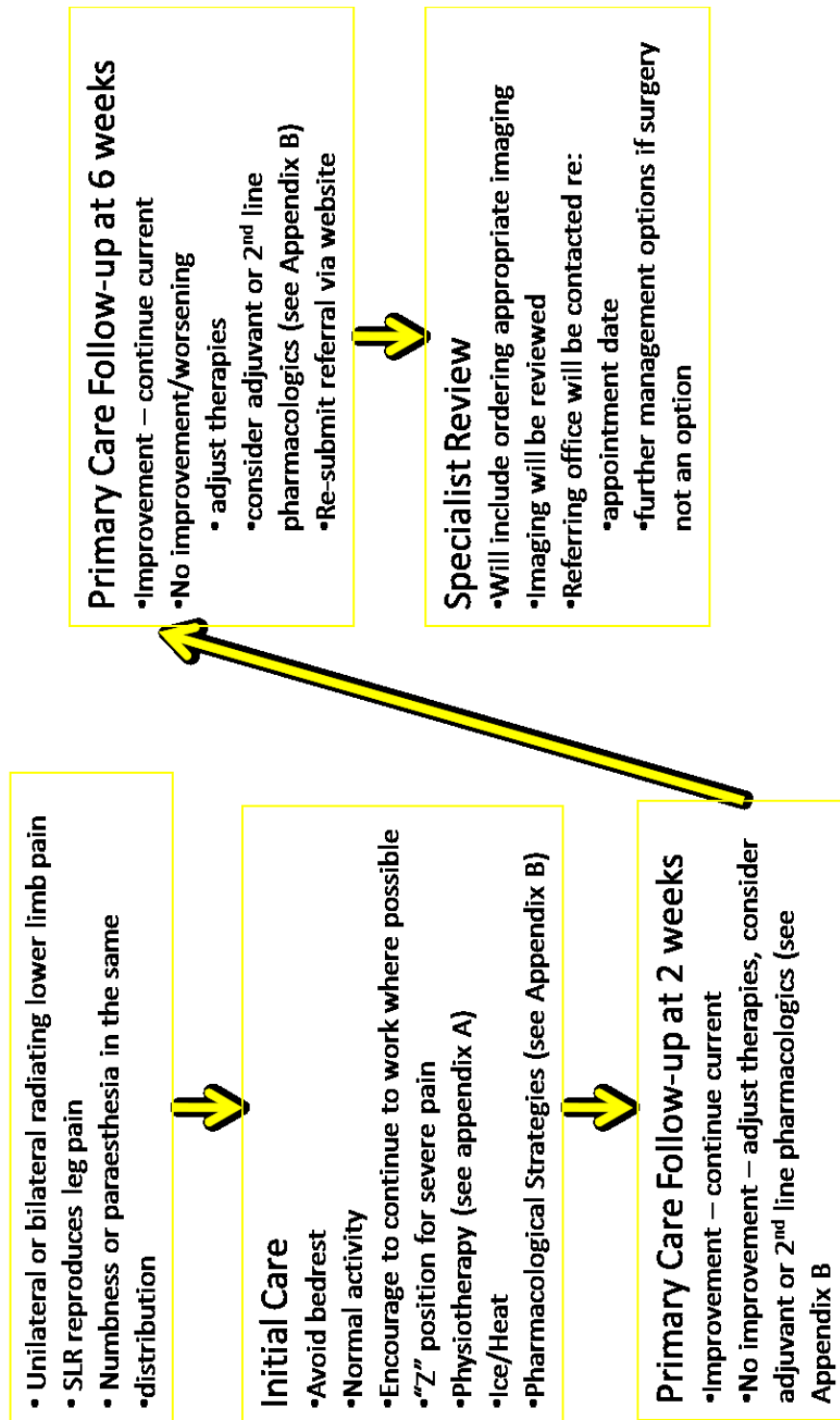


Figure B-2 Spinal Condition Consultation Protocol, Radicular pain condition pathway. In case answer to initial decision step is negative, pathway is continued in Figure B-3.

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# Axial (neck/low back) Pain

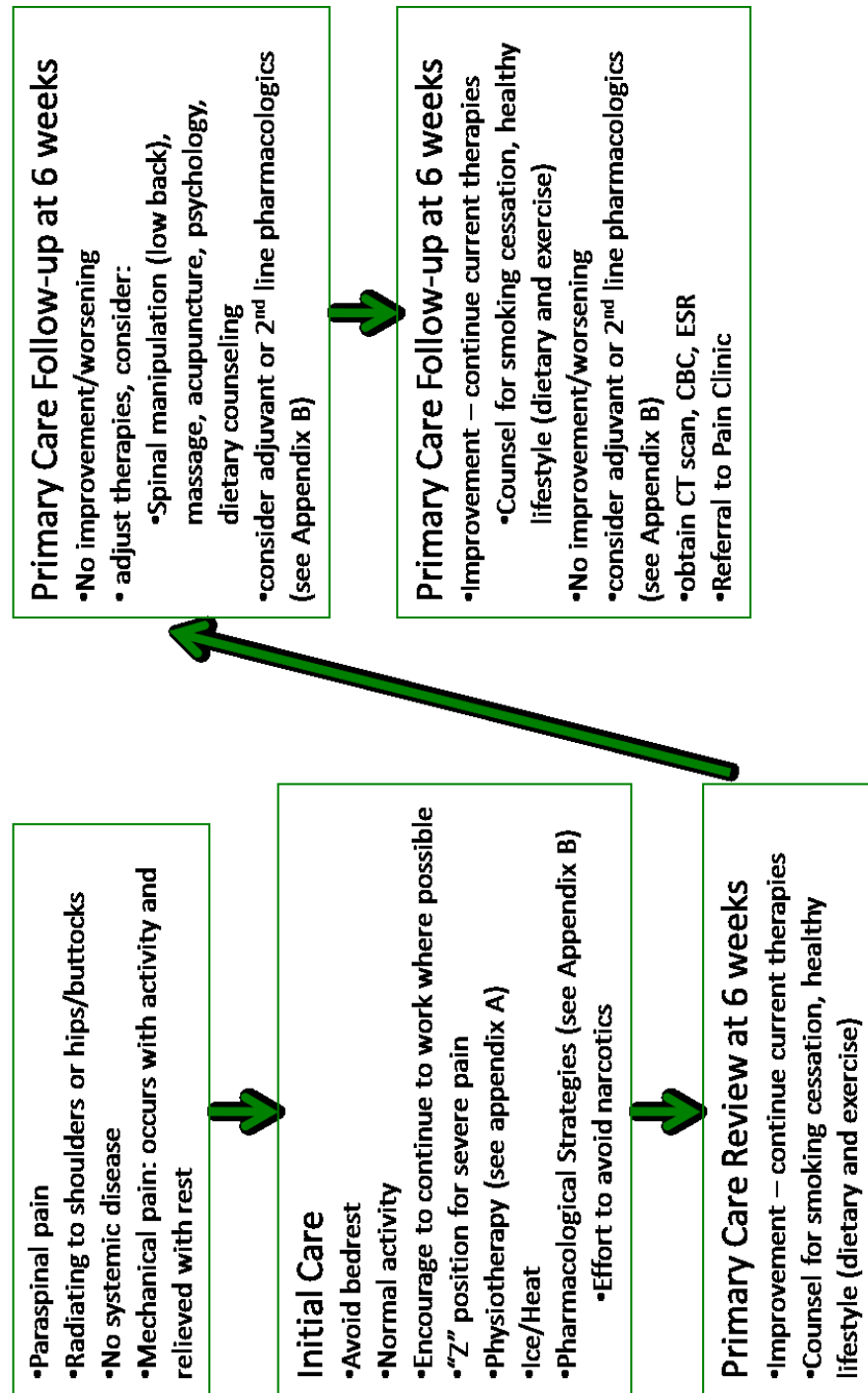


Figure B-3 Spinal Condition Consultation Protocol, Axial pain condition pathway. In case answer to the initial decision step is negative, the pathway ends. Copyright by Dalhousie Neurosurgery Spine Program. Used by permission.

## APPENDIX B    Halifax Infirmary Neurosurgery Department Referral Forms

**Association of Dalhousie Neurosurgeons – Spine Referral Form**  
Please FAX to: (902) 425-4789

Date:											
Patient Name:											
Address:											
Telephone:											
D.o.B.:											
MSI #:											
Referring Physician:											
Office Phone:					Office Fax:						
<b>History of Presenting Illness:</b>											
Pain: Onset/Timecourse:											
Location:											
Quality:											
Radiation:											
Aggravating Factors:											
Relieving Factors:											
Severity: /10(best)			/10(average)				/10(worst)				
Previous Treatment:					Past Medical History:						
<input type="checkbox"/> physiotherapy <input type="checkbox"/> chiropractic					<input type="checkbox"/> related trauma <input type="checkbox"/> infection/inflammatory						
<input type="checkbox"/> acupuncture <input type="checkbox"/> massage					<input type="checkbox"/> cancer – specify _____.						
<input type="checkbox"/> surgery (specify):					<input type="checkbox"/> congenital spine abnormality						
Medications:					Neurogenic Bowel <input type="checkbox"/> Y <input type="checkbox"/> N						
					Neurogenic Bladder <input type="checkbox"/> Y <input type="checkbox"/> N						
<b>*** PLEASE ATTACH AVAILABLE IMAGING REPORTS ***</b>											
<b>Physical Exam: please provide exam appropriate to referral (i.e. cervical or lumbar)</b>											
<b>Blank sections considered "Normal"</b>											
Motor Exam (MRC 1-5; Normal=5)	R	L	Deep Tendon Reflexes (Normal=2)	R	L	Sensory Exam (0=absent, 1=abnormal, 2=normal)	R	L	Mechanical Signs (+/-)	R	L
Shoulder Abduct (C5)			Biceps	/4	/4	C5			Spurling		
Elbow Flex (C5,6)			Brachioradialis	/4	/4	C6			Straight Leg Raise		
Wrist Ext (C6)			Triceps	/4	/4	C7					
Elbow Ext (C7)			Knee Jerk	/4	/4	C8					
Finger Flex (C8)			Ankle Jerk	/4	/4	T1					
Finger Abduct (T1)			Clonus (Y/N)			L2					
Hip Flex (L2)			Babinski (up/down)			L3					
Knee ext (L3)			Rectal Tone (Normal/ Reduced)			L4					
Dorsiflex (L4)				L5							
Extensor Hallucis Longus (L5)				S1							
Plantar flex (S1)				Peri-anal							

Figure A-1 Spinal condition referral form.  
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## Neurosurgery Spine Referral Form

Date of Referral \_\_\_\_\_

**Patient Information**

Last name \_\_\_\_\_ First name \_\_\_\_\_ Middle Initial \_\_\_\_\_  
 DOB \_\_\_\_\_ Age \_\_\_\_\_ Sex \_\_\_\_\_ Health Card Number \_\_\_\_\_  
 Home address \_\_\_\_\_

**Referring Information**

Physician name \_\_\_\_\_  
 Address \_\_\_\_\_

Radiology Performed	Date performed (mm/yy)	Location
MRI _____	_____	_____
CT _____	_____	_____
Myelogram _____	_____	_____
X-ray _____	_____	_____
Other _____	_____	_____
No imaging _____	_____	_____

**Clinical Information**

Involved spine area: Cervical \_\_\_\_\_ Thoracic \_\_\_\_\_ Lumbar/Sacral \_\_\_\_\_  
 Symptom duration:  <2 weeks  2-6 weeks  6-12 weeks  
 3-9 months  9-18 months  >18 months

Circle points that apply for the following assessments:

<p><u>Clinical</u></p> <ul style="list-style-type: none"> <li>Midline Pain (Neck or Back)-1</li> <li>Numbness Perianal <i>AND</i> both Legs-5</li> <li>Neurogenic Claudication-2</li> <li>Pain/Numbness Arm or Leg-3</li> <li>Focal Myotomal Weakness Arm or Leg-4</li> <li>Myelopathy or Spasticity-5</li> <li>None of the above-0</li> <li>Referral from neurologist/neurosurgeon-3</li> <li>Referral from other subspecialist-2</li> </ul>	<p><u>Pathology</u></p> <ul style="list-style-type: none"> <li>Neoplastic Malignant-5</li> <li>Neoplastic Benign-3</li> <li>Infection-4</li> <li>Degenerative/Arthritic-1</li> <li>Congenital-3</li> <li>Remote or low impact trauma-1</li> <li>High impact trauma-4</li> <li>None of the above-0</li> </ul>	<p><u>Radiological</u></p> <ul style="list-style-type: none"> <li>Spondylolisthesis-3</li> <li>Signal, Syrinx, Cavitation-5</li> <li>Severe Canal Stenosis-3</li> <li>Root Compression-1</li> <li>Mild/Moderate Canal Stenosis-1</li> <li>Instability-5</li> <li>Foraminal Narrowing/Stenosis-1</li> <li>Deformity-3</li> <li>Spinal Cord Compression-5</li> <li>None of the above-0</li> </ul>
↓	↓	↓
Total <u>Clinical</u> Points <input type="text"/>	Total <u>Pathology</u> Points <input type="text"/>	Total <u>Radiological</u> Points <input type="text"/>
Overall Assessment Points: <input type="text"/>		

Wait time  
 1 point for every month waiting since referral date } Total Wait Time Points:

Total Score:  
 (overall assessment points + total wait time points)

Figure A-2 Spinal condition referral summary form.  
 Copyright by Dalhousie Neurosurgery Spine Program. Used by permission.

# APPENDIX C Spinal Condition E-Referral System Interface Screenshots

## Halifax Infirmary Elective Spine Referral System

**Your Information** Patient Demographics Clinical History I Clinical History II Physical Examination Radiology Results Submit

### Physician Information

Welcome to CDHA Spine Referral service. Through this wizard you will be able to complete required information for a spine related problem consultation request. [A brief guide](#)

Please enter your identification information using the form below, or sign in using your account information. After signing in, you will be able to access the services available to you.

**Form includes invalid entries**

Name*	Given	<input type="text" value="Johnson"/>	Surname	<input type="text" value="James"/>
Address	Street	<input type="text" value="Main"/>	City	<input type="text" value="Dartmouth"/>
	Postal Code*	<input type="text" value="Z0Z-0Z0"/>		
Phone Number*	<input type="text" value="902-999-999"/>		Fax Number*	<input type="text" value="902-999-9999"/>
	<small>Follow valid phone number patterns, with or without separators. For instance: (XXX)XXX-XXXX</small>			
Email Address*	<input type="text" value="jamesid@email.com"/>		Password*	<input type="password" value="••••••"/>
			Re-Enter Pass*	<input type="password" value="••••••"/>

< >

< Referral Sign In System Guide Contact Us Study Survey

Figure E-1 A Screenshot of referring the physicians identity form. This screen is showing a system notification for invalid phone number and the system guide. A brief introduction at the top of the page provides an insight on how the e-referral system can be used.

Your Information		Patient Demographics		Clinical History I		Clinical History II		Physical Examination		Radiology Results		Submit	
<b>Patient Demographics</b>						Please complete the demographics information of your patient.							
Name*	Given	<input type="text" value="Patient"/>		Surname	<input type="text" value="Patientlast"/>								
Address*	Street	<input type="text" value="South"/>		City	<input type="text" value="Dartmouth"/>								
	Postal Code	<input type="text" value="Z1Z-1Z1"/>											
Primary Phone Number*	<input type="text" value="(999) 999-9999"/>		Alternative Phone Number	<input type="text"/>									
Email Address	<input type="text"/>												
Health Card Number*	<input type="text" value="9999999999"/>		Primary Payer	<input type="text" value="NS Gov (MSI)"/>									
Date of Birth*	<input type="text" value="1"/>	<input type="text" value="January"/>	<input type="text" value="1980"/>	Gender	<input checked="" type="radio"/> Male <input type="radio"/> Female								
<input type="button" value="←"/> <input type="button" value="→"/>													
<a href="#">&lt; Referral</a>		<a href="#">Sign In</a>		<a href="#">System Guide</a>		<a href="#">Contact Us</a>		<a href="#">Study Survey</a>					

Figure E-2 A Screenshot of the patient demographics form.

[Your Information](#) | [Patient Demographics](#) | **Clinical History I** | [Clinical History II](#) | [Physical Examination](#) | [Radiology Results](#) | [Submit](#)

### History of Presenting Illness

Please complete the following form with the appropriate information about the patient condition and past history.  
*Please be as complete as possible as the information received determines triage ranking.*

#### Patient Pain Description

Onset/Timecourse\*

Location\*:  Cervical  Thoracic  Lumbar/Sacral

The Pain is:  Back Dominant  Arm/ Leg Dominant  None

There is Pain/ Numbness in Arm or Leg  
 Patient has Pain in Neck or Back (Midline Pain)

The Pain is Unremitting (i.e. never stops, not even for short periods)

Radiation\*

Pain Quality\*

Aggravating Factors\*

Relieving Factors\*

Severity\*  0  2  5

Description of the Problem

#### Patient is also Experiencing

Neurogenic Bowel\*  Yes  No     
 Neurogenic Bladder\*  Yes  No     
 Neurogenic Claudication\*  Yes  No

Unexpected Weight Loss       Fever/ Chills

[<](#) [>](#)

[< Referral](#)      [Sign In](#)      [System Guide](#)      [Contact Us](#)      [Study Survey](#)

Figure E-3 A Screenshot of the presenting medical history form. The form is filled up with signs and symptoms of a sample spinal condition.

[Your Information](#)
[Patient Demographics](#)
[Clinical History I](#)
**[Clinical History II](#)**
[Physical Examination](#)
[Radiology Results](#)
[Submit](#)

### Past History

The following form requests information regarding the patient's past history of disease and medication.  
*Please be as complete as possible as the information received determines triage ranking.*

#### Spinal Treatment

Physiotherapy
  Chiropractic
  Massage
  Acupuncture  
 Surgery
 Specify:

#### Past Medical History

Infection/ Inflammatory
  Congenital Spine Abnormality
  Organ Transplantation
  HIV/ AIDS  
 Degenerative Spine
  Low impact/ Remote Trauma
  High Impact Trauma  
 Benign Spine Tumor
  Malignant Spine Tumor
  Cancer
 Specify:

#### Medication

Please specify if the patient is on the following type of medications:

Narcotics
  NSAIDs
  Muscle Relaxants  
 Biologics
  Steroids
  Chemotherapy

Provide the detail for the patient medications:

Medication details ...

Or Upload a Medication History Sheet [Choose a File](#)

[< Referral](#)
[Sign In](#)
[System Guide](#)
[Contact Us](#)
[Study Survey](#)

Figure E-4 A Screenshot of the past medical history form.

Your Information Patient Demographics Clinical History I Clinical History II **Physical Examination** Radiology Results Submit

### Physical Examination

The following interactive form will help you complete the physical examination information. Please select the type of examination, and by selecting each body region add the relative score to the given data field.  
*Note: Default entries are Normal.*

Save Show All Fields

Unchecked Values are Normal

C5,6- Elbow Flex Left 2 Right 5

Figure E-5 A Screenshot of the physical examinations results form. Four different physical exam score pages are accessible from the menu on the right side of the page. The body map is interactive by the use of round buttons; a red button represents an unsaved exam score, a gray button is an area with saved normal score, and a green button is an area with saved abnormal score.



Your Information Patient Demographics Clinical History I Clinical History II Physical Examination **Radiology Results** Submit

### Radiology Results

Please complete this questionnaire according to the radiology imaging, and attach any available radiology reports.

#### Radiology Tests Reports

**Plain X-Ray**  Yes  No  Pending [Report.pdf](#) [Done](#)

**CT Scan**  Yes  No  Pending

**MRI Scan**  Yes  No  Pending

#### Radiology Reports Results

Based on the reports, there are findings of (check all that apply):

Spondylolisthesis  Signal Change/ Myelomalacia  Syrinx/ Spinal Cord Cyst/ Cavitation

Severe Canal Stenosis  Mild Canal Stenosis  Moderate Canal Stenosis

Root Compression  Foraminal Narrowing/ Stenosis/ Compression  Instability

Deformity/ Scoliosis  Spinal Cord Compression

< >

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Figure E-6 A Screenshot of the radiology results form. Radiology reports can be uploaded when a radiology exam is marked as Yes.

Your Information	Patient Demographics	Clinical History I	Clinical History II	Physical Examination	Radiology Results	Submit
------------------	----------------------	--------------------	---------------------	----------------------	-------------------	--------

**Submit Your Request** *Please review the summary of the provided information.*

**\* Your Information**

Name	<b>Johnson James</b>	Address	<b>Main</b>	Phone	<b>(999) 999-9999</b>
Email	<b>jamesid@email.com</b>		<b>Dartmouth, Z0Z-0Z0</b>	Fax	<b>(902) 999-9999</b>

**\* Patient's Demographics**

Name	<b>Patient Patientlast</b>	Gender	<b>Male</b>	Birth Date	<b>1 January 1980</b>
Phone	<b>(999) 999-9999</b>	Alt. Phone	-	Email	-
Health Card	<b>9999999999</b>	Address	<b>South</b>		
	<b>NS Gov (MSI)</b>		<b>Dartmouth, Z1Z-1Z1</b>		

**\* Presenting Illness History**

Pain Onset	<b>Less than 6 wk.</b>	Pain Location	<b>- Cervical Pain - Midline Pain - Back Dominant Pain</b>	Pain Radiation	<b>- Into Leg (L)</b>
Aggravating	<b>- Lifting - Physical Activity</b>	Relieving	<b>- Heat - Rest</b>	Pain Quality	<b>- Ache</b>
Severity	<b>Best: 0 Avg: 2</b>	Worst: 5		Other	-

**\* Past History**

Treatment	<b>- Acupuncture - Chiropractic - Physiotherapy</b>	Medical History	<b>- Infection/ Inflammatory</b>	Medication	<b>- Muscle Relaxants</b>
-----------	---	-----------------	----------------------------------	------------	---------------------------

**\* Physical Examination**

Abnormal Exam Results **- Motor C5 ShldrAbduct, Left: 2**

**\* Radiology**

Plain X-Ray	<b>Yes</b>	CT Scan	<b>Pending</b>	MRI Scan	<b>No</b>
Result Findings	<b>- Instability</b>				

**Additional Documents**

Are there additional documents you would like to upload? [Add a File](#)

**Letter Submission**

The information provided is verified and accurate

**Submit Referral**

< >

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Figure E-7 A Screenshot of the submit form. The form lists a summary of the input data. Additional attachments can be added on this page.

Your Information | Patient Demographics | Clinical History I | Clinical History II | Physical Examination | Radiology Results | **Submit**

### Submit Your Request

*Please review the summary of the provided information.*

**\* Your Information**

Name	<b>Johnson James</b>	Address	<b>Main</b>	Phone	<b>(999) 999-9999</b>
Email	<b>jamesid@email.com</b>		<b>Dartmouth, Z0Z-0Z0</b>	Fax	<b>(902) 999-9999</b>

**\* Patient's Demographics**

Name	<b>Patient Patientlast</b>	Gender	<b>Male</b>	Birth Date	<b>1 January 1980</b>
Phone	<b>(999) 999-9999</b>	Alt. Phone	<b>-</b>	Email	<b>-</b>
Health Card	<b>9999999999</b>	Address	<b>South</b>		
	<b>NS Gov (MSI)</b>		<b>Dartmouth, Z1Z-1Z1</b>		

**\* Presenting Illness History**

Pain Onset	<b>Less than 6 wk.</b>	Pain Location	<b>- Cervical Pain - Midline Pain</b>	Pain Radiation	<b>- Into Leg (L)</b>
------------	------------------------	---------------	---	----------------	-----------------------

Aggravating - Lift  
- Ph  
Severity Best

**\* Past History**

Treatment - Ac  
- Ch  
- Physiotherapy

**\* Physical Examination**

Abnormal Exam Results - Motor C5 ShldrAbduct, Left: 2

**\* Radiology**

Plain X-Ray	<b>Yes</b>	CT Scan	<b>Pending</b>	MRI Scan	<b>No</b>
Result Findings	<b>- Instability</b>				

**Please wait while the referral is being submitted and processed;**  
You will receive the results shortly.




Figure E-8 The e-referral system asks the referring physician to wait for results of the automatic referral assessment.

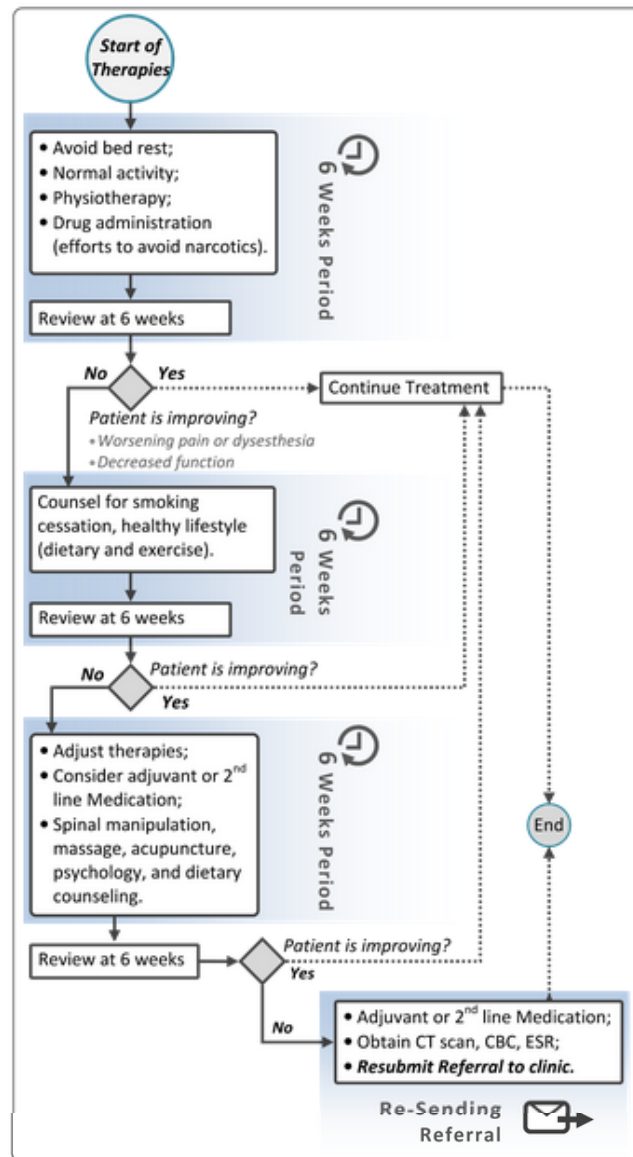
## Referral Request Assessment Result

Your referral request is successfully received and assessed. You will receive a fax containing specialist visit information in 2-3 days.

It is strongly recommended to follow the attached guideline during the patient therapies. Completion of these interventions are required when visiting the specialist.

You can download a complete report by clicking the button at the bottom of this page. The complete report contains a summary of the information, the attached guideline, as well as your system account credentials.

## Recommended Clinical Guideline



[Download the Complete Report ↓](#)

[Go back to Home U](#)

Figure E-9 A Screenshot showing the result of automatic referral assessment. The recommended condition management guideline diagram can be viewed on this page. The full report can be downloaded using the button at the bottom.

## Halifax Infirmery Elective Spine Referral System

Please Sign-In using your account information:

**Have you been on this system before?**  
If you have successfully submitted a referral before, you received an account name and a password through the referral report.

Your Account Name

Your Password  [Sign In](#)

In case you have lost your account credentials, please contact the administrator at: e h s a n @cs.dal.ca to retrieve your information.



Figure E-10 A Screenshot of the user account sign-in form.

**Your Information** Patient Demographics Clinical History I Clinical History II Physical Examination Radiology Results Submit

### Physician Information

Welcome to CDHA Spine Referral service. Through this wizard you will be able to complete required information for a spine related problem consultation request. [▼ A brief guide](#)

Please enter your identification information using the form below, or sign in using your account information. After signing in, you will be able to access the services available to you.

Name\* Given Johnson Surname James

Address Street Main City Dartmouth

Postal Code\* Z0Z-0Z0

Phone Number\* (999) 999-9999 Fax Number\* (902) 999-9999

Email Address\* jamesid@email.com Password\* Password\* Re-Enter Pass\*

[Update Information](#)

**Your Previous Patients**  
You can load a patient information from this list.

Patient Name	Patient ID	Latest Referral
Patient <a href="#">Resend</a>	9999999999	05/11/2013

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Figure E-11 A Screenshot of referring the physicians identity form, following a successful authentication of a referring physician (user is signed-in). A list of previously referred patients is appeared at the bottom of the page.

## APPENDIX D SCCPO Evaluation Selection of Referrals

Anonymous Referral ID: 36																			
<b>History of Presenting Illness:</b>																			
<i>Leg weakness Poor balance numbness both feet</i>																			
Pain: Onset/Timecourse: <i>May</i>																			
Location: <i>Lower back and lower leg</i>																			
Quality:																			
Radiation: <i>Legs</i>																			
Aggravating Factors: <i>Work Walking</i>																			
Relieving Factors: <i>After Sitting Pins &amp; needles -&gt; lasts ~ 1hr</i>																			
Severity:                      8 /10(best)                                      7 /10(average)                                      9 /10(worst)																			
Previous Treatment:						Past Medical History:													
<input checked="" type="checkbox"/> physiotherapy <input checked="" type="checkbox"/> chiropractic <input type="checkbox"/> acupuncture <input type="checkbox"/> massage <input type="checkbox"/> surgery (specify):						<input type="checkbox"/> Related trauma <input type="checkbox"/> Infection/Inflammatory <input type="checkbox"/> Cancer –specify __No_____													
Medications:						<input type="checkbox"/> Congenital spine abnormality <i>mild Sciolosis</i>													
						Bowel dysfunction <input type="checkbox"/> Y <input checked="" type="checkbox"/> N Bladder dysfunction <input type="checkbox"/> Y <input checked="" type="checkbox"/> N													
<b>*** PLEASE ATTACH AVAILABLE IMAGING REPORTS ***</b>																			
<b>Physical Exam: please provide exam appropriate to referral (i.e. cervical or lumbar)</b>																			
<b>Blank sections considered "Normal"</b>																			
Motor Exam (MRC 1-5; Normal=5)	R		L		Deep Tendon Reflexes (Normal=2)	R		L		Sensory Exam (0=absent, 1=abnormal, 2=normal)	R		L		Mechanical Signs (+/-)	R		L	
Shoulder Abduct (C5)	5	5	Biceps	2/4	2/4	C5	2	2	Spurling										
Elbow Flex (C5,6)	5	5	Brachioradialis	2/4	2/4	C6	2	2	Straight Leg Raise										
Wrist Ext (C6)	5	5	Triceps	2/4	2/4	C7	2	2	<div style="text-align: center;"> <b>SENSORY</b>  <small>KEY SENSORY POINTS</small>  </div>										
Elbow Ext (C7)	5	5	Knee Jerk	2/4	2/4	C8	2	2											
Finger Flex (C8)	5	5	Ankle Jerk	3/4	3/4	T1	2	2											
Finger Abduct (T1)	5	5	Clonus (Y/N)	N	N	L2	2	2											
Hip Flex (L2)	5	5	Babinski (up/down)	↓	↓	L3	1	1											
Knee ext (L3)	5	5	Rectoal Tone (Normal/ Reduced)	N	N	L4	1	1											
Dorsiflex (L4)	5	5				L5	1	1											
EHL (L5)	5	5				S1	1	1											
Plantar flex (S1)	5	5				Peri-anal													

**History of Presenting Illness:**

*3 years history of sever Neck pain with Numbness left arm*

Pain: Onset/Timecourse:

Location: *Neck + Numbness left arm*

Quality: *Neuropathy*

Radiation: *Left arm*

Aggravating Factors: *Works as a Nurse – worse with heat*

Relieving Factors: *Rest*

Severity:                4 /10(best)                                6 /10(average)                                9 /10(worst)

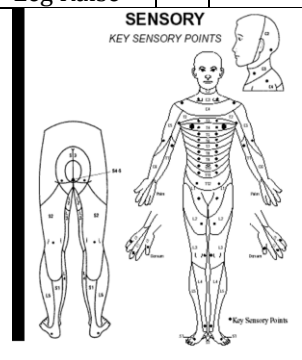
Previous Treatment: <input checked="" type="checkbox"/> physiotherapy <input type="checkbox"/> chiropractic <input checked="" type="checkbox"/> acupuncture <input checked="" type="checkbox"/> massage <input type="checkbox"/> surgery (specify):	Past Medical History: <input type="checkbox"/> Related trauma <input type="checkbox"/> Infection/Inflammatory <input type="checkbox"/> Cancer –specify _No_____ <input type="checkbox"/> Congenital spine abnormality
--	--

Medications: Lyrica 100 mg bid – OxyNeo daily	Bowel dysfunction <input type="checkbox"/> Y <input checked="" type="checkbox"/> N Bladder dysfunction <input type="checkbox"/> Y <input checked="" type="checkbox"/> N
--	--

**\*\*\* PLEASE ATTACH AVAILABLE IMAGING REPORTS \*\*\***

**Physical Exam: please provide exam appropriate to referral (i.e. cervical or lumbar)  
Blank sections considered “Normal”**

Motor Exam (MRC 1-5; Normal=5)	R	L	Deep Tendon Reflexes (Normal=2)	R	L	Sensory Exam (0=absent, 1=abnormal, 2=normal)	R	L	Mechanical Signs (+/-)	R	L	
Shoulder Abduct (C5)	5	4	Biceps	4	3	C5	N	1	Spurling			
Elbow Flex (C5,6)	5	5	Brachioradialis	2	3	C6	N	1	Straight Leg Raise			
Wrist Ext (C6)	5	5	Triceps		3	C7	N	1				
Elbow Ext (C7)	5	5	Knee Jerk	N	N	C8						
Finger Flex (C8)	5	5	Ankle Jerk	N	N	T1						
Finger Abduct (T1)	5	5	Clonus (Y/N)	N	N	L2						
Hip Flex (L2)	5	5	Babinski (up/down)	N	N	L3						
Knee ext (L3)	5	5	Rectoal Tone (Normal/Reduced)	N	N	L4						
Dorsiflex (L4)	5	5				L5						
EHL (L5)	5	5				S1						
Plantar flex (S1)	5	5				Peri-anal						





Anonymous Referral ID: 40

**History of Presenting Illness:**

*5 weeks low back pain*

Pain: Onset/Timecourse: *5 weeks*

Location: *Low back*

Quality:

Radiation: *Occasional/ both legs*

Aggravating Factors:

Relieving Factors:

Severity:            *2 /10(best)*                            *4 /10(average)*                            *8 /10(worst)*

Previous Treatment: <input checked="" type="checkbox"/> physiotherapy <input type="checkbox"/> chiropractic <input type="checkbox"/> acupuncture <input type="checkbox"/> massage <input type="checkbox"/> surgery (specify):	Past Medical History: <input type="checkbox"/> Related trauma <input type="checkbox"/> Infection/Inflammatory <input type="checkbox"/> Cancer –specify <u>  No  </u> <input type="checkbox"/> Congenital spine abnormality
--	---

Medications:	Bowel dysfunction <input type="checkbox"/> Y <input type="checkbox"/> N Bladder dysfunction <input checked="" type="checkbox"/> Y <input type="checkbox"/> N <i>occasional</i>
--------------	---

**\*\*\* PLEASE ATTACH AVAILABLE IMAGING REPORTS \*\*\***

**Physical Exam: please provide exam appropriate to referral (i.e. cervical or lumbar)**  
**Blank sections considered "Normal"**

Motor Exam (MRC 1-5; Normal=5)	R	L	Deep Tendon Reflexes (Normal=2)	R	L	Sensory Exam (0=absent, 1=abnormal, 2=normal)	R	L	Mechanical Signs (+/-)	R	L
Shoulder Abduct (C5)			Biceps	/4	/4	C5			Spurling		
Elbow Flex (C5,6)			Brachioradialis	/4	/4	C6			Straight Leg Raise	✓	✓
Wrist Ext (C6)			Triceps	/4	/4	C7					
Elbow Ext (C7)			Knee Jerk	4/4	4/4	C8					
Finger Flex (C8)			Ankle Jerk	4/4	0/4	T1	✓	✓			
Finger Abduct (T1)			Clonus (Y/N)	N	N	L2	✓	✓			
Hip Flex (L2)	✓	✓	Babinski (up/down)	✓	✓	L3	✓	✓			
Knee ext (L3)	✓	✓	Rectoal Tone (Normal/Reduced)	✓	✓	L4	✓	✓			
Dorsiflex (L4)	✓	✓				L5	✓	✓			
EHL (L5)	✓	✓				S1	✓	✓			
Plantar flex (S1)	✓	✓				Peri-anal					

**History of Presenting Illness:**

*Sever low back pain with Left side radicular symptom*

*Sever L4/5 Stenosis on CT*

Pain: Onset/Timecourse:

Location:

Quality: *Sharp Burning*

Radiation: *Down leg*

Aggravating Factors: *Movement Sitting*

Relieving Factors: *After Sitting Pins & needles -> lasts ~ 1hr*

Severity: 7 /10(best) 9 /10(average) 10 /10(worst)

Previous Treatment: <input checked="" type="checkbox"/> physiotherapy <input type="checkbox"/> chiropractic <input type="checkbox"/> acupuncture <input checked="" type="checkbox"/> massage <input type="checkbox"/> surgery (specify):	Past Medical History: <input type="checkbox"/> Related trauma <input type="checkbox"/> Infection/Inflammatory <input type="checkbox"/> Cancer –specify <u>No</u> _____ <input type="checkbox"/> Congenital spine abnormality
---	---

Medications: <i>Percocet 4/day – tyl 3</i>	Bowel dysfunction <input type="checkbox"/> Y <input checked="" type="checkbox"/> N Bladder dysfunction <input type="checkbox"/> Y <input checked="" type="checkbox"/> N
---	--

**\*\*\* PLEASE ATTACH AVAILABLE IMAGING REPORTS \*\*\***

**Physical Exam: please provide exam appropriate to referral (i.e. cervical or lumbar)**  
**Blank sections considered "Normal"**

Motor Exam (MRC 1-5; Normal=5)	R		L		Deep Tendon Reflexes (Normal=2)	R		L		Sensory Exam (0=absent, 1=abnormal, 2=normal)	R		L		Mechanical Signs (+/-)	R		L	
Shoulder Abduct (C5)	5	5			Biceps	4/4	4/4			C5	2	2			Spurling	N	N		
Elbow Flex (C5,6)	5	5			Brachioradialis	4/4	4/4			C6	2	2			Straight Leg Raise	N	N		
Wrist Ext (C6)	5	5			Triceps	4/4	4/4			C7	2	2							
Elbow Ext (C7)	5	5			Knee Jerk	4/4	3/4			C8	2	2							
Finger Flex (C8)	5	5			Ankle Jerk	4/4	3/4			T1	2	2							
Finger Abduct (T1)	5	5			Clonus (Y/N)					L2	2	2							
Hip Flex (L2)	5	5			Babinski (up/down)	N	N			L3	2	2							
Knee ext (L3)	5	5			Rectoal Tone (Normal/ Reduced)					L4	2	1							
Dorsiflex (L4)	5	5				L5	2	1											
EHL (L5)	5	5				S1	2	1											
Plantar flex (S1)	5	5				Peri-anal													

**History of Presenting Illness:**

*Increasing pain in Neck and Rt. Shoulder with radiation to Rt. Hand*

*Decreased sensation in tip of fingers*

Pain: Onset/Timecourse: *3 years and now increasing*

Location: *Neck and Rt. Shoulder. Radiation to Rt. hand*

Quality: *Sharp*

Radiation: *Rt. Hand*

Aggravating Factors: *Flexion of Neck*

Relieving Factors: *Elevating Shoulders*

Severity: 2 /10(best) 4 /10(average) 8 /10(worst)

Previous Treatment: *Recently started*

- physiotherapy     chiropractic
- acupuncture     massage
- surgery (specify):

Past Medical History: *Dislocated Rt. Shoulder in the past*

- Related trauma     Infection/Inflammatory
- Cancer –specify \_No\_\_\_\_\_
- Congenital spine abnormality

Medications:

Bowel dysfunction     Y     N

Bladder dysfunction     Y     N *occasional*

**\*\*\* PLEASE ATTACH AVAILABLE IMAGING REPORTS \*\*\***

**Physical Exam: please provide exam appropriate to referral (i.e. cervical or lumbar)  
Blank sections considered "Normal"**

Motor Exam (MRC 1-5; Normal=5)	R		L		Deep Tendon Reflexes (Normal=2)	R		L		Sensory Exam (0=absent, 1=abnormal, 2=normal)	R		L		Mechanical Signs (+/-)	R		L	
Shoulder Abduct (C5)					Biceps	/4	/4			C5					Spurling				
Elbow Flex (C5,6)					Brachioradialis	/4	/4			C6	1				Straight Leg Raise				
Wrist Ext (C6)					Triceps	/4	/4			C7	1								
Elbow Ext (C7)					Knee Jerk	/4	/4			C8									
Finger Flex (C8)					Ankle Jerk	/4	/4			T1									
Finger Abduct (T1)					Clonus (Y/N)					L2									
Hip Flex (L2)					Babinski (up/down)					L3									
Knee ext (L3)					Rectoal Tone (Normal/Reduced)					L4									
Dorsiflex (L4)						L5													
EHL (L5)						S1													
Plantar flex (S1)						Peri-anal													