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MET3-AE System to Support Management of Pediatric Asthma Exacerbation in the Emergency Department

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Abstract

A decision making process behind the management of pediatric patients with asthma exacerbations in the Emergency Department includes three stages: data collection, diagnosis formulation and treatment planning. These stages are associated with activities involving different types of clinical knowledge: factual, conceptual and procedural. Effective decision support should span over the entire decision making process and facilitate the use of diversified clinical knowledge. In this paper we present MET3-AE – a point of care decision support system that satisfies this requirement. The system helps emergency physician collect data, evaluate exacerbation severity, plan corresponding treatment and retrieve clinical evidence associated with a given treatment plan. It was developed using ontology-driven and multi-agent methodologies and implemented with open source software. The system is accessible on tablet and desktop computers and smartphones, and it interacts with other hospital information systems. It was successfully verified in a simulated clinical setting and now it is undergoing testing in a teaching hospital.

Keywords:

Decision support systems, Clinical, Pediatrics, Asthma, Patient management, Emergency care.

Introduction

Asthma exacerbations are one of the most common medical conditions for children that are brought to the Emergency Department (ED). These visits, and subsequent hospitalizations required by many of these patients, account for nearly 65% of all direct costs of asthma care. Children with asthma, compared to other non-asthmatic patients use more prescriptions and require more ambulatory care and ED visits.

A decision making process associated with the management of pediatric asthma exacerbation in the ED is presented in Figure 1. It reflects a hypothetico-deductive model of clinical decision making [1] with three main stages: data collection, diagnosis formulation and treatment planning. Activities associated with specific stages are diversified and require different types of clinical knowledge (indicated in Figure 1).

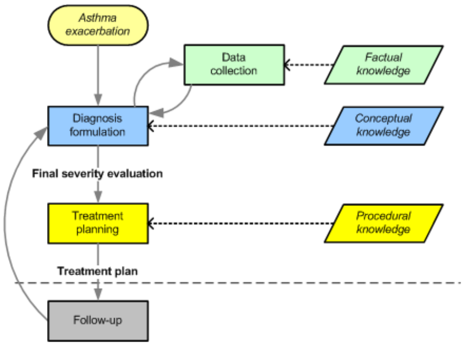

Figure 1 - Decision making process for the management of pediatric asthma exacerbations

The management process starts with the emergency physician (EP) formulating a diagnosis by assessing the severity of exacerbation. This initial evaluation is revised in an iterative way when more patient data is being collected until a final severity evaluation is established. Establishing the severity of exacerbation involves *conceptual knowledge* that is acquired during formal training and life-long learning. The collection of patient data requires the knowledge of what to collect and how to collect it efficiently and accurately. Use of this *factual knowledge* can be supported through a variety of structured data collection tools.

An established asthma severity level drives the development of a treatment plan for the patient. Knowledge required for developing a treatment plan (*procedural knowledge*) is associated with the notion of evidence-based medicine, i.e., making clinical decisions on the basis of the best available evidence. Existing research shows numerous benefits of supplementing a treatment plan with underlying clinical evidence [2].

The goal of effective decision support is to help with all stages of the entire decision making process presented in Figure 1. Moreover, according to [3] such decision support needs to be available in a computerized form and easily accessible at the point of care. All this should contribute to more efficient management of a patient during an encounter. The clinical decision support system (CDSS) described in this paper, called MET3-AE, meets these requirements. It helps collecting and accessing data, evaluating the severity of exacerbation and developing appropriate treatment plans relatively early (at around 2 hours after nursing triage), and it links each treatment plan with evidence – systematic reviews of clinical trials – extracted from The Cochrane Library[1]. Moreover, the system runs on various computing platforms including mobile devices and it can be used directly at the point of care during an encounter.

The paper is organized as follows. In the next section we describe detailed requirements for the MET3-AE system. Then, we discuss the architecture of the system and its implementation. It is followed by an example that illustrates how the system supports diagnostic and treatment decisions. In the subsequent section we describe testing of MET3-AE in a simulated setting. Finally, we conclude with a discussion.

Requirements for the MET3-AE System

In order to meet the goal of effective decision support, MET3-AE has to satisfy two main requirements that are derived from research described in [4-6]:

1. Provision of comprehensive support for the entire decision making process,
2. Availability at the point of care during a patient-physician encounter.

The first requirement translates into satisfying information needs of the EP and assisting the EP with the use of different types of clinical knowledge linked to the specific stages of the decision making process.

Satisfying information needs maps into the ability to access patient information regardless of where it is stored. This requires MET3-AE to interact with other hospital information systems (HISs), especially with an electronic patient record (EPR), in order to exchange and share patient data.

Supporting the use of clinical knowledge requires encoding of its different types in form of different abstract models and associating these models with functions that facilitate their use – they are listed in Table 1.

Linking the stages of the decision making process with abstract models and related functions constitutes the main idea behind the MET3-AE design:

- Supporting the data collection implies prompting the EP to consider specific clinical attributes and providing means for structured data entry. This calls for the data model defining the clinical attributes and the user interface model defining the structured data entry components, both codifying the factual knowledge.
- Supporting the diagnosis formulation implies the ability to arrive at an assessment for the exacerbation severity. This calls for a diagnostic model codifying the conceptual knowledge.
- Supporting the treatment planning implies the ability to recommend treatment plans and to provide underlying evidence. This in turn requires having the treatment and evidence models encoding the corresponding procedural knowledge and allowing for retrieval of clinical evidence.

Table 1 - Models and functions supporting the decision making process

Process stage	Abstract model	Function
Data collection	Data model User interface model	Structured collection of patient data
Diagnosis formulation	Diagnostic model	Suggestion of possible diagnosis
Treatment planning	Treatment model Evidence model	Suggestion of treatment plans Provision of clinical evidence

The second requirement for effective clinical decision support translates into MET3-AE ability to run on different computing platforms, thus satisfying the “multi-device architecture” postulate [7]. More precisely, MET3-AE has to be accessible on a tablet computer, desktop computer or smartphone so the EP can use it when and where necessary.

The set of requirements discussed here does not cover issues of security and privacy. However, when implementing the system we used a policy-based encryption to ensure appropriate level of access control and data security.

Implementing the MET3-AE System

Architecture

Comprehensive clinical decision support calls for a distributed architecture that facilitates multiple relatively independent function. These functions should be modeled as independent entities that provide or request services [8]. Such architecture may be implemented following service-oriented or multi-agent principles. In MET3-AE persistence of the entities is crucial, as they need to exist all times to monitor HIS or to respond to user requests. Such persistent existence is normally accomplished in a multi-agent system (MAS).

The MET3-AE architecture presented in Figure 2 was developed using multi-agent methodologies enhanced with ontology-driven design for better maintainability and extensibility. It builds on our earlier research, specifically on the multi-agent

[1] http:///www.thecochranelibrary.com

design process (described in [9]) and on the ontology-driven design for CDSS (introduced in [10]).

MET3-AE includes the following agents:

- *Encounter assistant* that provides a graphical user interface to the EP and interacts with other agents based on the user actions,
- *Model manager* that manages abstract models stored in the *model repository*,
- *Data manager* that manages patient data stored locally in the *data repository*,
- *Diagnosis suggester* that suggest a possible asthma severity level on the basis of patient data and using the abstract diagnostic model,
- *Treatment suggester* that suggests a treatment plan on the basis of the patient data and using the abstract treatment model,
- *Evidence provider* that provides clinical evidence from the *evidence repository* on the basis of the patient data and using the abstract evidence model,
- *HIS synchronizer* that receives and passes the messages between MET3-AE and HISs via the HL7 *interface engine*.

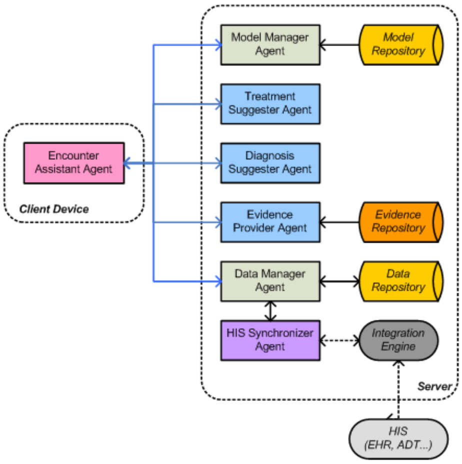

Figure 2 - Architecture of MET3-AE

The encounter assistant agent, acting as the EP's gateway to the system, runs on a "client" device (tablet computer, desktop computer or smartphone), while the remaining agents and repositories reside on a dedicated server.

The MET3-AE system was implemented in two phases discussed in the next subsections. The first phase involved creating the technological infrastructure according to the architecture presented in Figure 2, and the second phase involved implementing all abstract models listed in Table 1.

Technological infrastructure

The MET3-AE agents were programmed using JADE (Java Agent DEvelopment Framework) that provides middleware to manage agents and controls communications between them.

The repositories with abstract models (the model repository) and with patient data (the data repository) were created with Protégé. The evidence repository with systematic reviews from The Cochrane Library was implemented as a MySQL database enhanced with the Apache Lucene text search engine.

We also used Mirth Connect to enable communication between the MET3-AE and HIS. Specifically, we integrated with the ADT (admission-discharge-transfer) system through the HIS synchronizer agent using HL7 messaging.

Abstract Models

The data model for MET3-AE specifies clinical attributes that are routinely considered when managing asthmatic patients. These attributes were defined in cooperation with EPs – they come from the emergency assessment record and the asthma clinical pathway and they describe basic patients' demographics, history of asthma and the current exacerbation episode. The user interface model manages structured collection of values of the attributes from the data model. It was constructed following user- and task-centered design principles [11].

The diagnostic model employs a decision tree to predict asthma severity (research leading to its development and empirical validation is described in [12]). It was developed from a retrospective chart study using data mining techniques. Prior to building the model, collected data was preprocessed by normalizing age-dependent clinical attributes and by removing questionable patient records – we used Pediatric Respiratory Assessment Measure (PRAM) to identify these records.

The treatment model consists of decision rules that assign appropriate treatment given the asthma severity level. These rules were extracted from a pediatric asthma clinical guideline published by the Canadian Association of Emergency Physicians[2].

The evidence model defines terms used for indexing systematic reviews and introduces mappings between attributes from the data model and the indexing terms. These terms were identified using the UMLS Metathesaurus and located in the systematic reviews from The Cochrane Library with the help of the MetaMap Transfer (MMTx) system [13].

An Example of MET3-AE Operations

To provide a better understanding of how MET3-AE works we provide in Figure 3 a scenario of a clinical case in the ED. The scenario focuses on two stages of the decision making process – diagnosis formulation and treatment planning (due to limited space the data collection stage has been skipped). Corresponding agent interactions are presented in Figure 4 and 5.

[2] http://www.caep.org

At the diagnosis formulation stage (Figure 4) Dr. Brown asks for a diagnostic suggestion (1). The encounter assistant agent sends a request (augmented with available patient data) to the diagnosis suggester agent (2), which in turn sends a request to the model manager agent for the diagnostic model for asthma (3). The model manager retrieves the model from the model repository (4) and sends it back (5). Then the diagnosis suggester agent applies the diagnostic model to Peter's data and returns elaborated diagnostic suggestion to the encounter assistant agent (6), which finally reports it to Dr. Brown (7).

Peter Smith, a 2-year old boy with asthma exacerbation, has been brought by his parents to the ED in a pediatric hospital. Following nursing triage, Dr. Jane Brown takes care of Peter's management. After the first round of standard treatments according to hospital's asthma pathway, Dr. Brown continues Peter's assessment and is using MET3-AE running on her tablet computer to record patient data and to get decision support. Her initial hypothesis is that Peter suffers from severe asthma exacerbation. She consults MET3-AE for diagnostic advice and in return receives a suggestion pointing towards moderate asthma exacerbation. Dr. Brown decides to continue with observing the patient and monitoring oxygen saturation level. After short period of observation she assesses Peter again and diagnoses him as having moderate exacerbation (confirmed by MET3-AE). According to asthma practice guideline embedded in the MET3-AE, administration of systemic corticosteroids is a recommended treatment. Dr. Brown asks the system for the evidence regarding such treatment for a young boy and MET3-AE responds with a ranked list of abstracted systematic reviews. After consulting the summaries, Dr. Brown prescribes systemic corticosteroids and proceeds to discharge Peter to care of a family physician.

Figure 3- A scenario of a clinical case

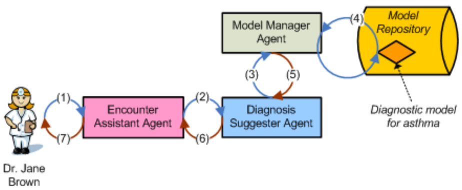

Figure 4- Agent interactions during diagnosis formulation

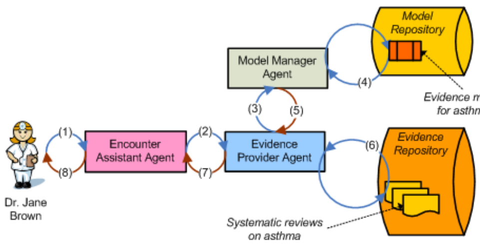

Figure 5- Agent interactions during treatment planning

At the treatment planning stage (Figure 5) Dr. Brown asks for a treatment suggestion and for evidence supporting suggested treatment. Agent interactions for providing treatment suggestions are very similar to the interactions described above, therefore they are not repeated. After MET3 has provided treatment suggestions, Dr. Brown asks for evidence supporting the use of systemic steroids (1). In response the encounter assistant agent sends a request to the evidence provider agent (2). This request includes all Peter's data, as well as the initially suggested treatment. The evidence provider agent sends a request to the model manager agent for the evidence model for asthma (3). The model manager retrieves the proper model from the model repository (4) and sends it back (5). Then, the evidence provider agent applies the model to the patient data and obtains a set of indexing terms that can be used to query the evidence repository for relevant systematic reviews (6). Retrieved reviews are ranked according to their relevance and passed back to the encounter assistant agent (7) that finally presents them to Dr. Brown (8).

Testing MET3-AE Operations in a Simulated Clinical Setting

MET3-AE is currently undergoing a clinical testing in the ED at the Children's Hospital of Eastern Ontario (CHEO) in Ottawa, Canada. The test involves a team of EPs, nurses and residents, who use MET3-AE on a tablet computer (Motion Computing C5). The test aims at evaluating and comparing predictions of EPs with those of the diagnostic model of MET3-AE and PRAM. The secondary goal of the test is to verify computing technology acceptance by EPs.

Prior to starting hospital testing we evaluated MET3-AE integration with a HIS and assessed how the system was handling typical information load. Based on published data we simulated a typical day in the ED at CHEO assuming 120 visits over a period of 12 hours (a relatively heavy workload). Amongst these visits there were 40 patients with asthma exacerbation that needed to be processed by MET3-AE. We simulated 10 concurrent sessions of patient management (i.e., up to 10 patients had to be handled by the system at the same time) covering all functionalities of the MET3-AE. All load tests were successful and system responded with no delays and no operational problems.

We also verified accuracy of advice (suggested diagnosis and evidence documents) produced by the diagnosis suggester and evidence provider agents. The performance of diagnosis suggester agent was tested on 120 unseen retrospective patient records giving sensitivity and specificity of 0.84 and 0.71 respectively. The evidence provider agent was tested using 15 prospective patient records and systematic reviews were retrieved with precision and recall of 0.89 and 0.81 respectively.

Discussion

Management of pediatric asthma exacerbations in the ED involves a complex multi-stage decision making process, where activities associated with specific stages are diversified and require different types of clinical knowledge. An effective CDSS should provide comprehensive support for all stages and be available the point of care. In this paper we demonstrated that such a CDSS can be designed following the ontology-driven and multi-agent methodologies. We also presented MET3-AE – a proof-of-concept CDSS that provides a comprehensive decision support for data collection, diagnosis formulation, treatment planning and evidence retrieval.

MET3-AE belongs to the latest generation of CDSSs [8] that depending on desired functionality are designed according to service-oriented principles and implemented as web services (for example the SEBASTIAN system [14]), or designed and implemented as MASs. However, even those implemented as MASs do not combine all functionalities required to support all stages of a decision making process and do not offer as comprehensive support as MET3-AE. For example, the PalliaSys system [15] facilitates collecting palliative patient data and alarms physicians about abnormal values and the K4Care platform [16] facilitates execution of personalized treatment guidelines.

To the best of our knowledge, MET3-AE is the first CDSS that supports the entire decision making process associated with management of asthma pediatric asthma exacerbations. The system is accessible on multiple computing platforms directly at the point of care. It supports the HL7 standard to interact and exchange data with HIS. Finally, MET3-AE was implemented using open source software to limit the cost of proprietary solutions and long-term limitations that come with their use, thus this should be seen as is additional advantage.

We successfully tested the MET3-AE operations in a simulated ED setting under realistic load conditions, and now system is being tested in a teaching hospital.

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