Published in S. Tsumoto, R. Slowinski, J. Komorowski, J. Grzymala-Busse (eds): Rough Sets and Current Trends in Computing. Proceedings of the 4th International Conference, RSCTC 2004, Uppsala, Sweden, June 2004. LNAI 3066. Springer-Verlag, Berlin, Heidelberg, New York, 2004, 805-814. (c) Springer Verlag

Rough Set Methodology in Clinical Practice: Controlled Hospital Trial of the MET System

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Abstract. Acute abdominal pain in childhood is a common but diagnostically challenging problem facing Emergency Department personnel. Experienced physicians use a combination of key clinical attributes to assess and triage a child, but residents and inexperienced physicians may lack this ability. In order to assist them, we used knowledge discovery techniques based on rough set theory to develop a clinical decision model to support the triage. The model was implemented as a module for the Mobile Emergency Triage system – a clinical decision support system for the rapid emergency triage of children with acute pain. The abdominal pain module underwent a clinical trial in the Emergency Department of a teaching hospital. The trial allowed us to compare in a prospective manner the accuracy of the system to the triage performance of the physicians and the residents. The preliminary results are very encouraging and they demonstrate validity of developing computer-based support tools for a clinical triage.

Keywords: Rough set theory; Emergency triage; Clinical trial; Clinical decision support systems; Handheld computers

1 Introduction

Acute abdominal pain in children is a common but diagnostically challenging problem facing Emergency Department (ED) personnel. There are many possible causes for the pain. Some patients have serious illnesses requiring urgent treatment, and possibly surgery. Most patients, however, have non-serious causes, or the pain resolves before a cause is determined.

Experienced physicians use a combination of key historical information and physical findings to assess and triage children. These attributes frequently occur in recognizable patterns, allowing the physician to make the correct assessment quickly and efficiently. Medical residents and other inexperienced physicians may lack the acumen to know what information to collect or recognize the patterns. This may lead to delays in definitive care for those who are unwell, while expensive, time-consuming tests and observation might be carried unnecessarily.

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In order to assist the inexperienced ED physicians and residents we used knowledge discovery techniques based on rough set theory to develop a clinical decision model that uses easily determined attributes to support the triage by distinguishing between three disposition categories: *discharge*, *observation/further investigation*, and *consult*. The clinical decision model was implemented as a module in the Mobile Emergency Triage (MET) system – a modular clinical decision support system aimed at supporting the emergency triage of children with acute pain. The system is intended to be used by the ED clinicians to help them in evaluating patients and making triage decisions.

The MET abdominal pain module underwent a clinical trial in the ED of the Children's Hospital of Eastern Ontario (CHEO).[1] When the complete analysis of trial data is finished, its results will allow us to compare thoroughly the triage accuracy of the system with the performance of the clinicians.

The paper is organized as follows – we start by describing the process of triaging a child in ED. Then we explain the development of the clinical decision model and describe the MET system. Further, we give details on the clinical trial and present preliminary results obtained after the first 3 months. We finish with conclusions.

2 Triage of Abdominal Pain

Medical personnel in the ED makes triage decisions in order to assess whether a patient requires urgent attention from a specialist, or some other course of action needs to be taken. Based upon information from the patient's complaint, history, physical examination, and the results of laboratory tests clinicians make decisions about the severity of the patient's presenting condition, and the management process that follows.

The process of triaging non-trauma cases in the ED is illustrated in Figure 1. It involves two assessment phases, which answer the following questions: how quickly does a patient need to receive medical attention, and what type of management is necessary.

The first phase, called prioritization, is done by a triage nurse who evaluates severity of patient's clinical condition and assigns her an appropriate priority level that determines waiting time in the ED. Patients with high priority are immediately seen by physicians, while the other may wait for longer period of time.

The second phase – disposition involves physicians who on a basis of examinations and laboratory tests triage a patient. In the teaching hospital, patients are also often assessed by residents and then reviewed by staff physicians. Disposition leads to one of the following recommendations: *discharge*, *observation/further investigation* (*observation* in short), and *consult*.

Focus of the research described here is on supporting the disposition phase only that is further referred to as triage.

[1] CHEO is a teaching hospital that is a part of the University of Ottawa.

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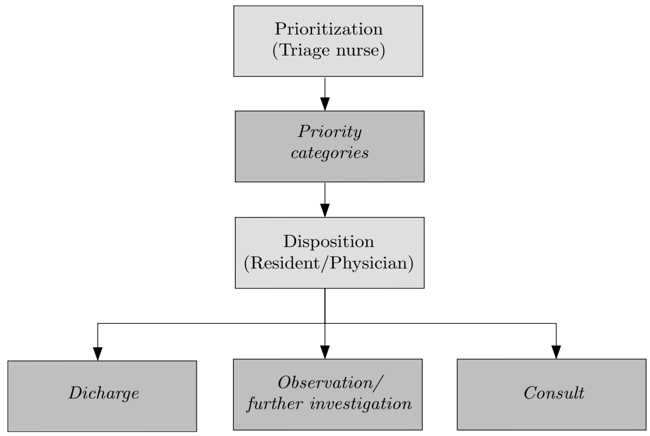

Fig. 1. Prioritization and disposition as a part of the triage

3 Development of the Clinical Decision Model

There are several possible ways of represent clinical reasoning – decision rules being one of them. The decision rules constitute a convenient way of representing clinical knowledge as they are intuitive and easy to interpret by the domain experts. They also offer a comprehensive representation of regularities and patterns present in data. Moreover, they are accepted and used in medical practice [1].

The development of the clinical decision model started with a retrospective chart study to collect clinical data that could be used to induce decision rules. Charts of 623 patients with presenting abdominal pain complaint, seen during the 1996 – 2002 period in the ED of CHEO were evaluated. The chart of each patient was reviewed with special reference to most common clinical symptoms and signs evaluated in the ED (see Table 1). The final discharge diagnosis (not the ED disposition) was used in order to ensure accuracy of the clinical outcomes that were used for developing and evaluating the clinical decision model. As our goal was to develop a triage algorithm as opposed to the diagnostic tool, we used discharge diagnosis to assign each patient to appropriate triage category that corresponds to a disposition decision in ED (e.g., if the discharge diagnosis was appendicitis, then the triage category was *consult* because such a patient needs to be seen by pediatric surgeon).

The data set created from the charts was studied for regularities using knowledge discovery techniques based on rough set theory [2]. As the clinical data were incomplete (for some attributes, such as rebound tenderness or WBC, the number of missing values was close to 25% of cases) we used extended rough set approach that deals with incomplete data without need to modify the origi-

Table 1. Attributes and their domains

Attribute	Domain[2]
Age	0–5 years, $\geq$ 5 years
Sex	male, female
Duration of pain	$\leq$ 24 hours, 1–7 days, $>$ 7 days
Site of pain	RLQ, lower abdomen, other
Type of pain	continuous, intermittent
Shifting of pain	yes, no
Previous visit	yes, no
Vomiting	yes, no
Site of tenderness	RLQ, lower abdomen, other
Rebound tenderness	yes, no
Localized guarding	yes, no
Temperature	$<$ 37 C, 37–39 C, $\geq$ 39 C
WBC (white blood cells)	$\leq$ 4, 4–12, $\geq$ 12

nal information [3]. This extended approach replaces indiscernibility by a new relation – cumulative indiscernibility.[3]

The data set was analyzed using ROSE software [4]. We started with checking all attributes given by medical experts and then attempted to reduce this set, however this did not produce satisfactory results (number of the attributes in a reduct diminished from 13 to 12). Considering our earlier experience with the analysis of the smaller abdominal pain data set [5] when it was possible to generated good classification rules using a reduced set of attributes (9 out of 12), we decided to expand evaluation of the attributes. We used an approach based on a fuzzy measure[4] to assess information value of attributes [6]. Specifically, we used Shapley value [7] that interprets the quality of rough approximations of the triage in terms of the fuzzy measure. This permits to estimate how well an attribute explains relationships in data. Shapley values for all single attributes are presented in Figure 2 (the greater the value, the more information an attribute carries).

To identify a minimal set of attributes for which accurate decision rules could be created, we iteratively tested subsets of them in an order determined by their Shapley values – starting from the top 4 ones (the minimal subset resulting in the non-zero quality of the approximation of the triage) and ending with all 13

[2] Domains of real-valued attributes (age, duration of pain, temperature and WBC) were discretized according to medical practice.

[3] The relation assumes two objects are indiscernible if their values for considered attributes are equal or at least one is missing (in other words, it is assumed a missing value is equal to any specified one).

[4] Fuzzy measure is a set function that satisfies the property of monotonicity [6]. Quality of the approximation of the triage fulfills this property and thus can be considered a fuzzy measure.

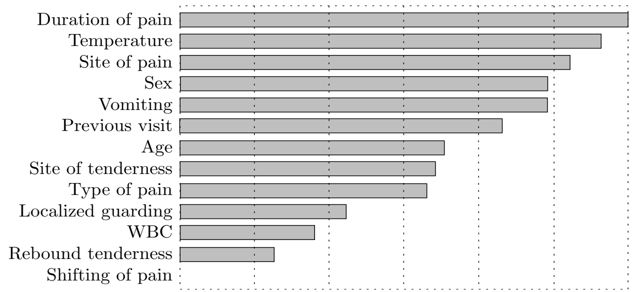

Fig. 2. Attributes and their Shapley values

attributes. For each subset we assessed classification capabilities of corresponding decision rules (in terms of their classification accuracy) using cross-validation tests [8]. Results of the tests suggested that rules based on all 13 attributes offered the highest accuracy. This contradiction of our earlier findings [5] can be explained by the fact that the initial analysis was conducted on a much smaller set of patients (175 records) divided into two categories – *consult* and *discharge*. Clearly, more specific classification requires that all attributes are considered.

A clinical decision model for triage of abdominal pain patients that was ultimately created consists of 172 rules induced from the complete set of attributes, sample ones are presented in Table 2.

4 The MET System

The MET system [9] currently has two clinical modules - scrotal pain and abdominal pain, and research is under way to develop a hip pain module. The clinical decision model described in the previous section forms the core of the abdominal pain module. The system's design, illustrated in Figure 3, follows the principles of extended client-server architecture [10] with the client running on a mobile device – a handheld computer. Mobility of the system is imposed by the specificity of the clinical setting (no room for a desktop workstation in ED and no time to leave triage area for consulting the system) and it significantly improves the usability of the system by offering support directly at a point of care [11].

The desired functionality of the MET is accomplished through a clear division of tasks and functions to be executed on the server and on the client side. The server performs two functions: it provides integration with a hospital information system (IS) using HL7 protocol,[5] and it communicates with mobile clients using local and remote (wireless) connections. The mobile client is used for entering clinical data and triaging a patient.

[5] HL7 (Health Level 7) is the standard protocol for exchanging information between medical applications [12].

Table 2. Sample decision rules

Triage	Conditions
discharge	site of pain is in lower abdomen, and vomiting occurred, and there was a previous visit
observe	age is under 5 years, sex is female, and there was a previous visit, and localized guarding is found
consult	sex is male, and pain is constant, and temperature is above 39 C, and site of pain is in RLQ

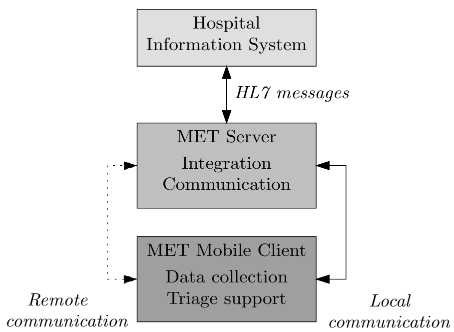

Fig. 3. MET architecture

As soon as a patient is admitted to the ED and recorded in the hospital IS, it transmits to the MET server a record containing patient's demographic information and the presenting complaint. If the complaint is supported by any of the modules, the server transfers a patient record to the client. Then the client is used to collect values of clinical attributes and to generate triage recommendation.

One of the unique features of the MET client is its adaptability to the type of captured clinical information [13]. For example, the results of the physical examination of the abdomen are entered, using pictograms (see Figure 4), while the temperature is entered using a numeric keypad to minimize the amount of data typed-in manually (see Figure 5). For most of the clinical symptoms and signs, the system allows for a free entry of any additional comments about the patient's condition. There is reported evidence that such structured data collection usually contributes to the improved triage and diagnosis of a patient [14].

The triage function on a client can be invoked at any time, and it uses the patient's most current data to provide a triage recommendation. Depending on the information currently available, the distance-based classifier [15] embedded in the MET system invokes the most suitable part of the clinical decision model, that is, a subset of rules providing the best overall match. The system gives a triage recommendation by prioritizing the outcome that according to the model represents the strongest triage recommendation. Even if the model does not have rules exactly matching the available data, the system will consult the most closely matching rules.

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Fig. 4. Data capture using the pictogram

Fig. 5. Data capture using the numeric keypad

When collection of information about the patient's condition is completed, all the information gathered to date is transferred to the MET server, thus updating the patient's record, and when the triage phase is finished, the completed record is moved back to the hospital IS.

5 Design of the Clinical Trial

The purpose of clinical trial is to verify and compare triage performance of the ED personnel (physicians and residents are considered as two separate groups) and the MET system. It is one of the first clinical trails involving clinical support system that was conducted during normal operation of the ED and involved all residents and staff physicians (together over 50 people). The design, following the recommendations appropriate for any clinical trial in the ED, and information flow captured by the trial is presented in Figure 6. Upon arrival to the ED, patient is admitted and assessed in the usual fashion. When a patient is registered, the main presenting complaint is recorded. If it is abdominal pain, then a patient record created by the hospital IS is flagged accordingly, thus enabling the MET server to filter these patients who should be potentially included in the trial.

A physician or a resident starts the primary disposition phase by asking for a consent to participate in the trial (a physician who performs the primary disposition is denoted as the primary observer). Positive answer triggers check if the patient is eligible for the trial. The patient can be included if she is between 1 and 17 years of age and abdominal pain lasts up to 10 days. Exclusion criteria encompass abdominal pain as the result of trauma, pain caused by an acute disease or a chronic illness, and direct referral to surgery. If the patient is eligible, values of the clinical attributes are entered into the MET client as the examination progresses. Regardless of the eligibility, paper documentation (an ED chart) is filled and completed.

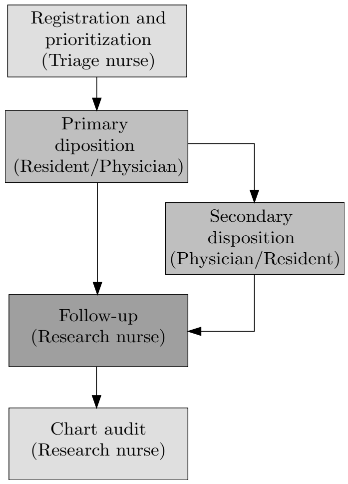

Fig. 6. Design and information flow of the clinical trial

When the physician makes a disposition decision, it is entered into the system indicating the end of the triage and locking the patient's data. The MET client runs the triage function to create a triage recommendation, but this recommendation is not accessible to the user. Keeping the triage recommendation blinded from the physician addresses one of the main ethical concerns raised before starting the trial, namely that use of MET at this stage does not affect the way a patient is managed in the ED.

When possible, another physician (denoted as the secondary observer) repeats the triage process collecting clinical data through independent examination of the patient and entering triage decision. The information is handled in the same manner as during the primary observation, however the secondary observer is not able to view the patient data collected by the primary one. As the patient's condition change with time, the secondary observer is considered to be valid only if patient is seen within 1 hour from completing the primary observation. The purpose of such a setup (typical for regular clinical trials) is to assess inter-observers accordance in evaluating the patients.

Each eligible patient who a had triage decision is followed-up at 7 − 14 days after her visit in the ED. For patients admitted to hospital, the hospital chart is retrieved to assist in determining the patient's final diagnosis. All categorization decisions are reviewed by the physicians for accuracy and, where necessary, to resolve ambiguities. All decisions are made without the knowledge of the triage recommendation generated by MET.

6 Preliminary Results

The clinical trial was designed to last for 6 months. During the first 3 months (August − September, 2003) 898 patients with abdominal pain visited the ED in CHEO, 420 were asked to participate in the trial and 400 agreed. 328 patients were eligible and were included in the study. For 230 included patients the follow-up and the chart audit phases have been already completed, thus the final categorization for these patients is established and verified. 178 verified patients were examined by physicians and 150 – by residents (98 patients were seen by both).

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The accuracy of triage decisions is presented in Table 3. We focused on the records of patients seen and evaluated by the ED physicians, as they were fully verified, thus could be used for a reliable comparison. For those records MET gave better overall accuracy and the accuracy for *discharge* and *consult* categories, but it had difficulties with triaging the patients requiring *observation* – the majority of them were incorrectly triaged as *discharge*. This prompts for revising the classification strategy embedded in the system, as such mistakes should be minimized.

Table 3. Accuracy of disposition for ED physicians and MET

	Overall	Discharge	Observation	Consult
Physicians	64.6%	64.8%	63.0%	65.2%
MET	66.3%	75.8%	18.5%	69.6%

7 Conclusions

Knowledge discovery techniques based on rough set theory and its extensions allowed us to mine incomplete clinical data, to estimate the information content of attributes and to express patterns found in data in form of decision rules. The rules constitute the clinical decision model to support the triage of children with abdominal pain which was implemented in the MET system.

The system underwent the clinical trial in the ED of CHEO. Preliminary results show that the system offers the triage accuracy comparable to the one achieved by the ED physicians. Preliminary analysis of the results also shows that quality of data is very important for providing an acceptable level of support. While MET mimics physicians' reasoning and works well on data collected by the ED physicians, at the same time it is less accurate when used on data collected by the residents who are less accurate in correctly evaluating patient's symptoms and sign and also are more prone to give "spot diagnosis" that does not have solid justification in the collected information. This observation underlines the synergy between the physicians and MET and clearly shows the system is not a competitor for humans, but a sophisticated tools that requires experienced users to operate properly.

The overall evaluation of the system by participating physicians and residents is favorable with both groups emphasizing the usefulness of the MET system by providing structured and easy-to-use information-gathering facilities and its available directly at a point of care.

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8 Acknowledgments

The research reported in this paper was supported by the grants from the Natural Sciences and Engineering Research Council of Canada and the Polish Committee for Scientific Research. Authors would like to thank Rhonda Correll, Nataliya Millman, Mathieu Chiasson and Bernard Plouffe for their work on the MET system development and organization and management of the clinical trial.

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