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MET System: A New Approach to m-Health in Emergency Triage

Wojtek Michalowski, Roman Słowiński, Szymon Wilk**

School of Management, University of Ottawa, Canada and *Institute of Computing Science, Poznan University of Technology, Poland.

ABSTRACT

Objective: To design and implement a system that supports emergency triage of various types of acute pain at the point of care through the use of handheld computers.

Design: Developmental process and evaluation in a non-randomised clinical trial.

Setting: The system known as Mobile Emergency Triage (MET) was used and evaluated by physicians in the Emergency Department (ED) of a pediatric teaching hospital in Canada.

Methods: MET is designed following the extended client-server architecture where a client takes over some functions of the server when a connection is not available. The MET server interacts with the hospital information system to retrieve information about patients admitted to the ED. It also stores current patients' demographic and clinical data to be exchanged with mobile clients. The MET mobile client, running on a handheld computer, is used for collecting clinical data and supporting triage decisions. MET was clinically evaluated in a pediatric teaching hospital where it was used to support triage of patients with abdominal pain. The objectives of the trial were to validate the usefulness of the system in clinical practice, and to compare its triage accuracy with that achieved by physicians. The trial lasted for 7 months, and involved over 100 ED physicians and 574 patients.

Results: Physicians found the system easy to use and were satisfied with its design allowing direct use at the bedside and its clear, intuitive interface. Patients found the MET system acceptable as it did not introduce additional tests or examinations and did not lengthen the time spent in the ED. The accuracy of the system was comparable to the accuracy of physicians (65.4% vs. 70.2%), and for the patients requiring specialist consultation (most critical group), MET and physicians demonstrated the same performance.

Conclusion: Due to implementation on handheld computers and working in weak-connectivity conditions, the MET system is very well suited for use in the ED and fits seamlessly into the regular clinical workflow. The system facilitates patient-centred service and timely, high quality patient management. It provides recommendations using a limited amount of clinical data, normally available at the point of care. Furthermore, it offers the possibility for structured evaluation of these data by an attending physician. The clinical trial of the system proved its usefulness in clinical practice. Moreover, performance of the MET system was very close to that of experienced ED physicians, supporting our hypothesis that it is possible to build a clinical support system that effectively triages patients using a limited amount of information.

Correspondence and reprint requests: Szymon Wilk, Institute of Computing Science, Poznan University of Technology, Poland. E-mail:szymon.wilk@cs.put.poznan.pl.

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INTRODUCTION

The integration of healthcare with wireless, tele- and mobile technologies has the potential to provide a powerful solution to the intense need for instant, up-to-date patient information. In addition to providing ready access to comprehensive patient information these technologies also enable care to be cost-effective and evidence-based, resulting in improved patient outcomes at the point of care[1,2]. Consequently they are applied in clinical decision support systems (CDSS) which are defined as "*computer based tools using explicit knowledge to generate patient specific advice or interpretation*"[3]. To be effectively adopted and widely accepted in clinical practice, CDSS have to satisfy several requirements – in particular they must facilitate clinical reasoning and be integrated with the clinical workflow [4]. The latter requires CDSS to interact with hospital information systems, or electronic patient record systems (EPRS)[5], and to be available at an appropriate point in the clinical management process to provide support[6]. Systems that do not satisfy these requirements are unlikely to be accepted in routine use by clinicians[7].

One potential use of CDSS is in aiding triage of patients presenting to the Emergency Department (ED). This is the first stage in management and is aimed at providing a decision on the priority of treatment and the type of care that the patient will receive. Although CDSS applications have been successfully used for triage in specific medical conditions[8], designing and implementing a CDSS for use in the ED is a challenge. The nature of emergency workflow requires clinicians to constantly move from patient to patient and work under time and pressure constraints. The provision of a computer hosting a CDSS in each examination room is not usually feasible due to a lack of space in the examination room. Placement of a computer outside the examination room is not readily acceptable to clinicians as it disrupts their workflow pattern and is perceived as causing unnecessary delays. For these reasons and others it has been difficult to deploy CDSS in the ED[9].

A potential solution to the above problems can be provided by the use of mobile computing devices[10] and wireless networking[11]. Their use in clinical practice has led to the concept of mobile health or *m-health*[12]. Perceived benefits of m-health systems include portability and availability directly at the point of care. There is a large number of medical applications for m-health and the best known are drug information databases, simple medical calculators and patient tracking systems[13]. However, until now there have been only a few clinical decision support applications[14,15].

To deal with the specificity of workflow in the emergency department, we designed and developed the Mobile Emergency Triage (MET) system[16]. This is an m-health application which is implemented on handheld computers and supports triage of various types of acute pain. Clinical knowledge is explicitly coded in the form of decision rules which are consulted for presenting possible triage

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decisions. The decision rules are not obtained from medical experts but are inferred from a record of previous experience, using a data mining technique based on the concept of rough sets[17–19]. Result of such a consultation is a triage recommendation with associated strengths reflecting the uncertainty inherent in clinical reasoning. The system has a modular and open architecture with separate modules for various types of acute pain, so it can be easily extended to handle new types of presentations. MET offers triage support any time and anywhere, irrespective of the stage in the process of patient management. It is integrated with the EPRS to extract data collected during registration and to allow users to transfer results of examinations conducted in the ED back to the hospital information system. It consequently can be considered as an extension of the EPRS and the electronic patient chart.

Before detailing the MET system, its role in the triage process, and how it integrates with the information infrastructure in a hospital, the clinical workflow for triage of acute pain will be described. Finally, the results of a clinical trial designed to test the MET system will be presented.

CLINICAL WORKFLOW FOR TRIAGE OF ACUTE PAIN

The clinical workflow for triaging non-trauma cases of acute pain in the ED involves two assessment phases (see Figure 1). The first phase, called prioritisation, is done by a triage nurse who evaluates the presenting complaint and the severity of the patient's clinical condition and assigns him/her an appropriate priority

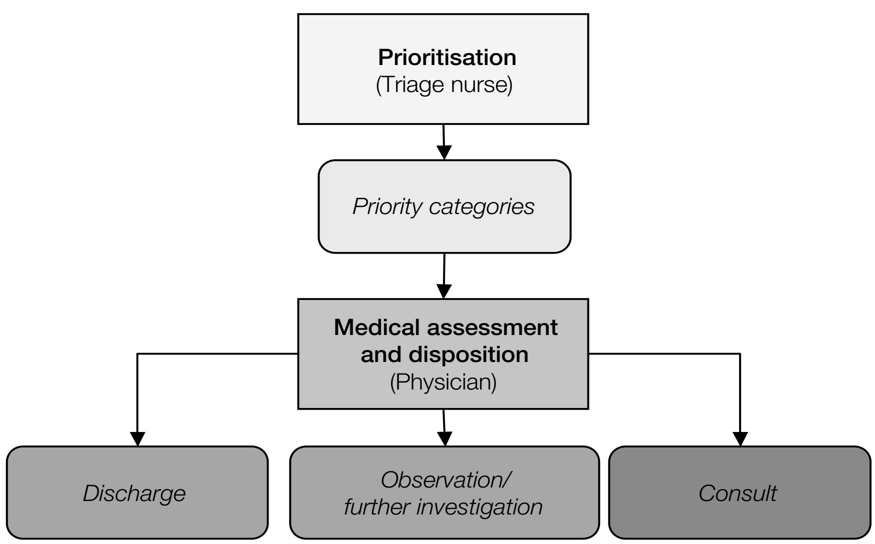

Figure 1. *The clinical workflow for triage of acute pain in the Emergency Department*

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level that determines waiting time in the ED. Patients with a high priority are seen immediately by a physician, whereas patients with a low priority inevitably have to wait for a longer period of time before they are seen.

The second phase is termed 'medical assessment and disposition'. Assessment involves taking a history, performing a physical examination and ordering appropriate investigations. On the basis of these processes a diagnosis is made leading to one of the following disposition decisions (triage recommendations):

- Discharge
- Observation/Further investigation
- Consultation

Discharge applies to patients with non-serious pathology that require only reassurance, advice or outpatient medication. The patient is able to leave the ED department once the physician has completed his/her assessment. For *observation/further investigation* the patient is kept in the ED to enable further re-evaluation including the ordering of investigations that may be useful in confirming or refuting pathology requiring further treatment. *Consultation* applies to patients who have pathology that requires assessment or treatment by a specialist (for example, a general surgeon in case of abdominal pain, or a urologist for scrotal pain).

The MET system facilitates rapid emergency triage and supports the disposition phase, (for simplicity, henceforth in the text the disposition phase will be referred to as 'triage'), and is intended to be used by ED physicians to help them in evaluating patients and making accurate disposition decisions. Such support should result in timely patient management, avoidance of unnecessary tests, and prompt final management. These are all factors that ultimately contribute to higher quality of care and improved patient-centred services[20].

There are many possible roles that m-health applications like MET can play in facilitating the workflow[21]. We consider MET to be a *debiaser*, i.e, a system that helps to correct biases or errors during or after completing a task. MET does not try to replace or to influence a physician during examination. It is only consulted after the physician has completed his assessment. When used in this manner the system does not require any significant changes in workflow organisation. When used by a less experienced medical resident, the system also fulfils the role of *influencer* by enforcing structured data collection. This gives the reassurance that decisions are made on complete and relevant information.

METHODS

The MET system has been designed according to the principles of the extended client-server architecture[22] where a client takes over some functions of the server when a connection is not available. This architecture is particularly suited for weak-connectivity conditions with occasional connections between clients and a

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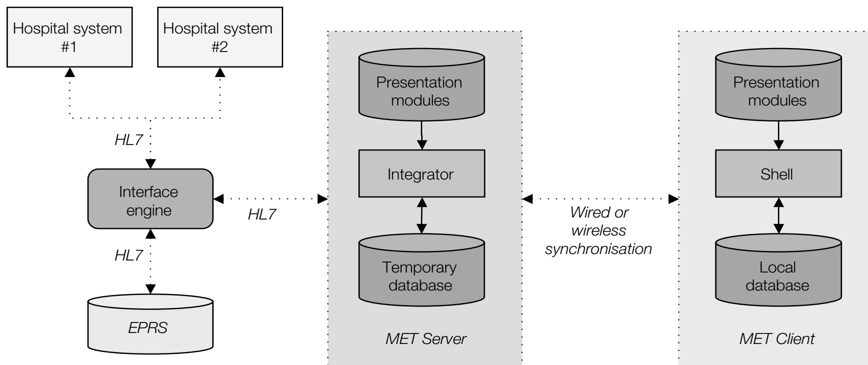

Figure 2. *The MET system and the information infrastructure*

EPRS = Electronic Patient Record System, HL7 = Health Level 7, MET = Mobile Emergency Triage.

server. MET can be easily introduced in any ED environment without a wireless network. However, its availability significantly enhances the versatility of the system.

The basic MET system architecture and its position within the information infrastructure are shown in Figure 2. The MET server integrates via an integrator with the EPRS using HL7 (Health Level 7) protocols[23]. HL7 is a standard for exchanging information between medical applications. It allows the use of various network protocols and the integration of diversified systems. The MET server also communicates with the MET clients to exchange patient data and to send necessary presentation modules that support triage of specific pain presentations. The MET client works on a handheld computer. Using the shell, it requests and receives modules from the server, executes the modules transferred from the server and synchronises patients' records with the server. Physicians use the client to collect clinical data and to support triage decisions (without the need to be connected to the server).

In order to make the MET client operate in weak connectivity conditions, the requested presentation modules and the local database with data received from the server and collected during medical assessment are stored on the client side. Weak connectivity and integration with the EPRS also impose the use of the temporal database on the server side. The database plays the role of a buffer that stores information before it can be transferred to clients or back to the EPRS, thus minimising the number of interactions with the EPRS as there is no need to query the EPRS whenever clinical data are to be sent to the client.

When a new patient is registered in the EPRS, an admission message is generated by the EPRS. The interface engine passes the message to all registered hospital systems, including the MET server. The server (namely the integrator) decodes it and stores received data (demographic information and the description of a

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complaint) in the temporal database where it awaits for the next synchronisation with any of the clients. When data in the server's temporal database are updated, the server sends messages with observation reports to the EPRS, thus keeping the data stored there and in the MET system consistent. To minimise the number of interactions with the EPRS, the server sends messages when the assessment of a patient is finished by the physician.

The server and the client synchronise using wired or wireless connections. The process consists of two phases. During the first phase a patient's record is synchronised so that up-to-date information is stored on the client and on the server side. First the client sends the record from its local database to the server, which in turn updates the temporal database with the most recent values. Then the server sends the data to the client and the client updates the contents of the local database. During the second phase the server sends requested presentation modules to the client. First, it sends those modules that are required to handle patients transferred in the first phase and that are not available on the client side. Then the server sends the modules explicitly requested by the client (for example, it is possible that the initial description of pain given during the prioritisation phase is not accurate and another module, not available on the client side, is necessary to triage a patient).

Each presentation module contains information necessary for handling a specific presentation of pain. At present there are modules for abdominal pain[16], and scrotal pain, whilst a module for hip pain is being developed. The decision to separate support functionality of the system into modules was based on the design of knowledge-based decision support systems with domain models separated from generic solvers[24]. Such separation increases reusability and flexibility of created systems, and in addition follows basic research in medical informatics. Domain models are the means by which health applications are conceptualised in a machine-understandable form, and generic solvers represent fundamental algorithms for processing clinical data and knowledge[24].

The presentation module includes a data model with a detailed specification of clinical attributes, and a decision model for triaging this specific presentation. The decision model is composed of decision rules created by data mining and knowledge discovery methods from past data collected and transcribed during a retrospective study. Specifically, we have employed rough set theory[17–19] to analyse clinical data. The usefulness of the rough set theory comes from its capabilities to process both symbolic and numeric data, and to deal with inconsistent and incomplete information[19].

When the physician starts triaging a patient using the MET client, the shell identifies the type of presentation (from the description of a complaint recorded in a patient's record) and retrieves an appropriate presentation module. Then it uses the data model to customise the interface, runs the interface and interacts with the physician. When the physician decides to enter or modify values of

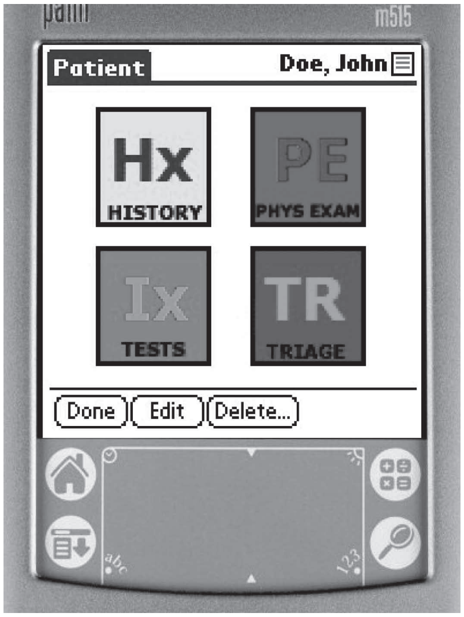

Figure 3. *Navigation*

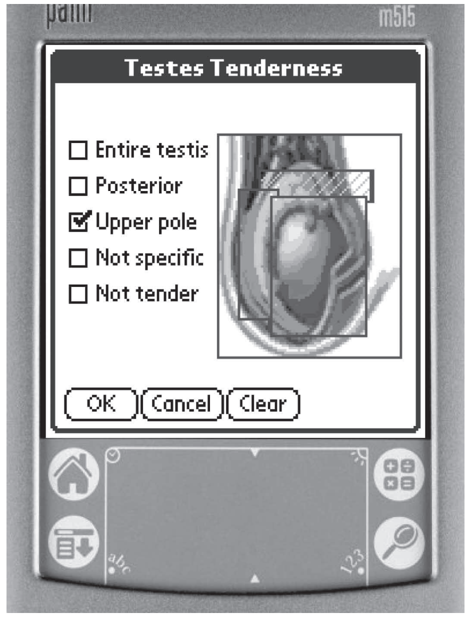

Figure 4. *List with a pictogram*

Figure 5. *Numeric keypad*

Figure 6. *Triage recommendations*

clinical attributes, the shell offers an appropriate editing tool, and when the physician invokes support function, it consults the decision model and runs an embedded solver to produce recommendations.

Triaging a patient in the ED should not be obstructed by unnecessary cognitive burden associated with using the m-health application. The interaction between the physician and the system has to be quick and easy, allowing a physician to continue his or her typical management without any interruption[25]. Moreover, the interface should be organised in a way that is easy to understand by physicians and should rely on familiar terms, notions, symbols and domain-specific metaphors (e.g. pictograms of body parts).

The MET client supports ED workflow by offering easy navigation between activities as shown in Figure 3. This allows a physician to call the triage function at any time, regardless of the amount of available data. To accommodate time and workflow constraints, the data entry mechanism is simple and the need for typed information is minimised. Whenever possible, the physician selects a proper value from a list of possible choices, sometimes combined with pictograms (Figure 4), and if a numerical value has to be entered, the numeric keypad is presented (Figure 5).

In order to better support physicians in making triage decisions, the triage function gives all possible triage outcomes together with the associated strength for each recommendation (Figure 6). The recommendation that acquires the highest strength is indicated as the suggested one.

CLINICAL TESTING

To evaluate the MET system in clinical practice, a trial utilising the system's abdominal pain module was conducted at the Children's Hospital of Eastern Ontario (CHEO) in Ottawa, Canada. The ability of the system to fit in with the ED workflow was assessed as well as evaluation of its performance.

The general design of the trial is presented in Figure 7. The trial was run on a 24 hour, 7 days a week basis. After a patient was registered and prioritised, the system checked to see if the presenting complaint was abdominal pain. Patients without abdominal pain were automatically excluded from the trial by the MET server. Those with abdominal pain were checked for eligibility against a set of inclusion and exclusion criteria. Inclusion criteria were age between 1 and 17 years, abdominal pain as the presenting complaint and duration of pain of 10 days or less. There were several exclusion criteria and these included abdominal pain following trauma, previous abdominal surgery, and known chronic illnesses causing abdominal pain e.g Crohn's. For patients eligible to participate in the trial consent was sought, usually from the child's parents. For patients who agreed to participate in the trial, the physician used MET to collect the 11 items of clinical data shown in Table 1 and to record their triage prediction. In all cases, documentation of the patient's visit

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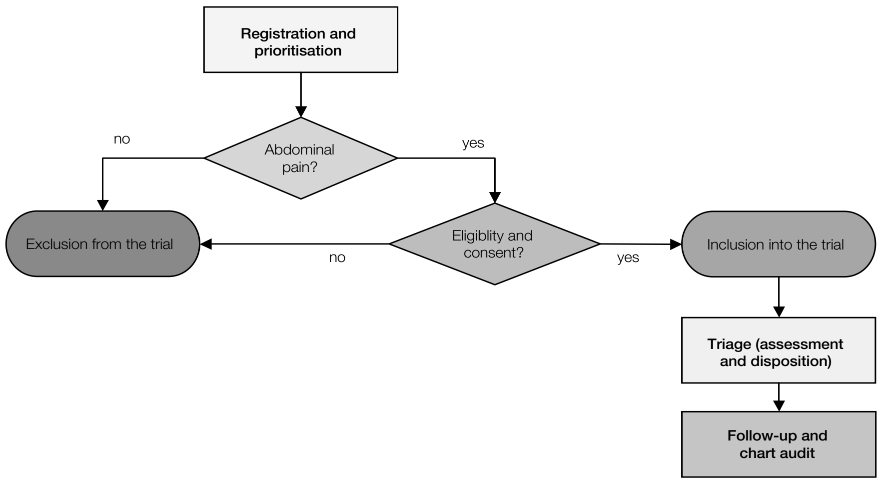

Figure 7. *Design of the trial*

was also completed on the paper ED chart. A number of eligible patients were not approached to participate in the trial for a variety of reasons. These included physicians not realising that the patient was eligible to participate in the trial and temporary problems with the hardware and network.

As part of the trial design, the functionality of the system was limited. Consequently the results from the triage function were *not* displayed to the ED staff. The system was, therefore, in effect used only as an electronic patient chart and not as a decision support system. Physicians, however, had to provide their triage decisions and these and those of the MET system were compared and verified against the actual patient outcomes.

Table 1. *Data collected by physicians for the trial*

Clinical Attribute	Possible values
Duration of pain	Numerical value (hours/days)
Localised guarding	Yes, No
Previous visit	Yes, No
Rebound tenderness	Yes, No
Shifting of pain	Yes, No
Site of pain	RLQ, Lower abdomen, Other
Site of tenderness	RLQ, Lower abdomen, Other
Temperature	Numerical value
Nature of pain	Intermittent, Constant
Vomiting	Yes, No
WBC	Numerical value

RLQ =Right lower quadrant (of abdomen), WBC= White Blood Cell Count. For temperature and WBC, actual values were entered. These were then categorised by the system according to guidelines established in clinical practice.

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The follow-up and chart audit were conducted 10–14 days after the patient's visit in the ED to determine the patient's final outcome. This included a telephone call to all patients to check if other medical interventions had been required after visiting the ED. The hospital chart was also reviewed for the results of any further visits, tests or consultations. The actual triage recommendation established during this stage was used for calculating and comparing the accuracy of the ED physicians and MET.

RESULTS

The trial started in July 2003 and lasted for 7 months. During that time 2,255 patients with abdominal pain visited the ED, of which 1,098 were eligible to participate. 632 of them were approached to participate in the study and 594 gave consent. Complete data including follow-up verification was obtained for 574 patients.

The MET system was used by over 100 consultant and resident physicians none of whom had been involved in the development of the system. These physicians had a diverse range of prior experience with handheld computers, ranging from complete novices to advanced users experienced with medical applications. All users participated in short orientation sessions and were able to operate MET on a handheld computer without any difficulties. They were satisfied with the clear and intuitive interface. The vast majority (94%) of the patients and their parents agreed to participate in the trial as the use of MET did not introduce additional examinations or invasive tests, and did not lengthen time spent in the ED.

Of the 574 patients, 117 were evaluated solely by residents. Because one of the aims of the study was to compare the MET system with experienced physicians, the data from these 117 patients were not used in evaluating the accuracy of the system in triaging patients. Data from the remaining 457 patients demonstrated that the overall accuracy of the MET system was comparable to those of consultant physicians (see Table 2). The system offered performance comparable to experienced physicians for patients who could be discharged ('discharge' category), and who required specialist consultation ('consult' category). However, its accuracy was much lower for patients needing observation ('observation' category). This situation might be attributed to the heterogeneous nature of this category, as it includes patients with a wide variety of clinical problems, making it very difficult to establish a common pattern. Though the utility of a tool with only 65% accuracy may be questioned, we maintain that the performance of the MET system is satisfactory, considering that its performance mirrors that of experienced physicians at the very early stage of assessment and management, and the fact that it is not to be used as an oracle, but only as a helper that assists the physician in triaging the patient. Also the calculations of accuracy considered only the recommendation that acquired the highest strength against the final triage

Table 2. *Triage accuracy*

	Physicians	MET
Overall	70.2%	65.4%
Discharge	71.3%	75.3%
Observation	63.9%	19.7%
Consultation	70.8%	70.8%

recommendation. Physicians using the system would receive a set of the three recommendations with associated strength factors, and this information would allow them to consider those recommendations in totality.

DISCUSSION

The management of patients with acute pain in the ED requires evaluation based on history, physical findings and laboratory and radiological investigations. On the basis of such an assessment, the patient is triaged and an appropriate management plan is formulated. Any clinical decision support system needs to have the ability to follow this process by having information-gathering capabilities, and the ability to give a triage recommendation any time and anywhere at the point of care. MET allows for structured data capture, storage and bi-directional transmission with the EPRS, and provides triage support any time and anywhere, independent of the stage in the management process. The system can be consulted for a triage decision without all the fields being completed. In this study, for example the WBC was frequently not performed and the site of tenderness was not entered for about 10% of patients. The system also runs on a handheld computer which many physicians are familiar with, and requires no special networking setup. Consequently it can be easily introduced and used in the ED environment.

Although, as reported in the literature, structured data capture leads to improved diagnostic efficiency and accuracy[26–28], the MET system goes further by offering triage support with rule-based decision models. These models capture the basic reasoning of experienced physicians, for example, in the management of specific pain presentation. They also provide, if necessary, an explanatory function, and attempt to support triage using minimal available information. Systems that utilise such models can ultimately help provide timely and efficient patient management, and, in effect, contribute to the provision of a high-quality patient-centred service[20].

The clinical trial of the system validated its usability in the ED setting. It also demonstrated that it is possible to support ED triage using a clinical decision support system that relies on a very limited amount of information. As a next step, we plan to organise a multi-centre trial where physicians will use MET with direct access to the triage function.

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