ISABEL: a novel Internet-delivered clinical decision support system

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Abstract
The development, and the results of clinical evaluation of ISABEL, an Internet-delivered integrated clinical decision-support system developed over the past 3 years, is described. Utilising a novel technique, pattern-recognition software from Autonomy™ is used to search standard medical text. The system consists of an innovative differential diagnosis tool to provide a list of potential diagnoses for a patient’s clinical features. Further clinical corroboration for each of these diagnostic suggestions is provided by the associated text description, relevant images annotated by experts, national guidelines for management, and pertinent clinical experiences. Initial evaluation of ISABEL showed that in around 85% of the cases tested, ISABEL presented the final diagnosis in the list of differential diagnoses. In an assessment of impact on clinical decisions made by doctors, both in a simulated setting and in real life, ISABEL reminded the user to consider a significant diagnosis in 1 out of every 8 cases.

Introduction
Biomedical knowledge has grown exponentially in the past few years, resulting in severe information overload for clinicians¹; it is estimated that this problem will double every 20 years². It is clear though that information related to newer medical tests and treatments is constantly evolving, whereas traditional knowledge pertaining to clinical diagnosis has changed relatively little. This suggests that all domains of medical
knowledge have not been equally affected by this rapid growth. Recent
techniques that attempt to summarize latest treatment
recommendations to comply with medical evidence are now available,
and are popular with clinicians3,4. Systems that might assist in routine
clinical diagnosis remain scarce. We know that medical information
relevant to making clinical diagnoses is constantly needed, and that
this information need is fulfilled mainly by consulting textbooks5.

We also know that errors related to misdiagnoses, or missed
diagnoses, constitute a significant proportion of the preventable burden
of medical error6. Medical error is reportedly common, yet there are
no reliable estimates of the incidence of medical error within the
National Health Service (NHS). Previous studies in the USA and
Australia have estimated adverse events to occur in between 4 and
16% of all hospital admissions7,8; a recent study from the UK reported9
an estimate of medical error in the UK. In this latter study, 10.8% of
all inpatients suffered an adverse event in hospital, either related to
diagnostic evaluation, operative procedure, ward management, or drug
prescription. Some patients suffered more than one adverse medical
event. Underlying reasons that predispose the occurrence of medical
error are often systemic, not related to individuals. As the authors of
the British study conclude, these reasons may include dependence on
diagnoses made by inexperienced clinicians, poor medical records, poor
communication and inadequate consultant input10.

Diagnostic errors were recorded in a fifth of the cases. These errors
may be due to errors of omission – failure to consider all clinically
relevant diagnoses during initial workup. Additional contributors to
diagnostic error may include incorrect formulation of the clinical
problem, as well as difficulty in extracting relevant information from
textbooks quickly, whether paper-based or electronic. The current
structure of healthcare delivery in the NHS may also contribute to
the occurrence of medical error. The current ‘inverted knowledge
pyramid’ of clinical care, junior doctors with relatively little knowledge
and experience at the bottom and experienced, knowledgeable
consultants at the top, may be one main reason11. Unfortunately, the
critically patient is initially assessed by a junior doctor at the frontline,
deprived of specialist advice out of working hours and unarmed with
clinical experience. Financially as well as in practice, it seems clear
that inverting this knowledge pyramid is difficult to achieve without
incorporating the use of techniques to manage knowledge and deliver
it in usable form to the clinicians at the bedside.

One reason why computerized diagnostic aids are scarce may be
related to the difficulty of converting traditional medical knowledge
into computer-readable form. Expert systems developed for internal
medicine, such as DXplain, QMR and ILIAD, were developed over many
years, involving the input of multiple experts to provide semi-
probabilistic relationships between thousands of clinical features and hundreds of diseases. These tools were also developed to assist the clinician primarily during the rare entity of a diagnostic dilemma (clinical dead-end), by acting as oracles. As a result of this design, they often required the user to expend a considerable amount of time interrogating the system. To regularly use such a stand-alone system in practice, a clinician had to be highly motivated. This may be one reason why diagnostic decision support as a concept has not captured clinicians’ interest.

**Aims**

To develop an easy to develop and user-friendly, integrated clinical decision-support system meant to be used for point-of-care decision-support in hospital, and to evaluate the clinical performance and impact of this system.

**Methods**

**Underlying knowledge base**

Standard electronic medical text was used to populate a pre-designed diagnostic tree comprising around 3500 diagnoses. Text pertaining to each diagnosis within the tree was copied into the ISABEL database, without any modifications, by one research nurse. Thus, unformatted text relating to the same disease, from different sources, was collated under one disease label. Where new disease labels were necessary to accommodate text from a new source, they were created within the same overall diagnostic tree model. Since there was no modification of the text involved, this entire process took less than 4 months for one researcher.

**Inference engine**

Commercially available software was used as the inference engine (Autonomy™, Autonomy Corporation, Cambridge, UK, www.autonomy.com). This software utilizes Bayesian inference and Shannon’s principles of information theory to generate pattern-matching algorithms to enable sophisticated concept extraction from documents. By collating text related to one specific diagnosis under a single diagnostic label within the diagnostic tree, it was possible for the software to generate a unique signature of key concepts for each diagnosis, by using its concept extraction techniques. This signature was constantly modified with the addition of text from each additional source used to populate the ISABEL database.

**Search methodology**

In response to a set of key clinical features for a patient (concepts),
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ISABEL utilized Autonomy™ to search the underlying database of text, and return all documents (diagnostic labels) whose concept signature matched that generated from the clinical features.

System architecture and delivery platform
In order to maximize the use of the system, and eliminate inequalities of regional distribution, the intention was to deliver ISABEL on the World Wide Web to all medical practitioners, after a short registration process. To this end, a website was created by DynamicWeb, UK using Javascript. The Autonomy Dynamic Reasoning Engine™ (DRE) was hosted on a dedicated ISABEL server, as was the database comprising the diagnostic tree, which could be construed as being the equivalent of multiple documents of text in html. At the front end, a free text box, into which the user could enter the clinical features of a patient, was created on a dedicated diagnostic tool webpage on the ISABEL website. On searching the database with these features, a list of all matching diagnostic labels (diseases) was returned. The maximum and minimum number of the diagnoses displayed on the results page could be varied by the developers of the system.

Figures 1 & 2 show how a set of clinical features entered in free text into the search box produce a set of diagnostic labels (with the preceding text: have you considered?) for the user’s attention.

**Figure 1: Differential diagnosis tool**

![Differential diagnosis tool](image-url)
Figure 2: Differential diagnosis tool output, ranked in order of textual match

<table>
<thead>
<tr>
<th>Infectious Diseases</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meningitis and Encephalitis</td>
<td>91</td>
</tr>
<tr>
<td>Meningococcal Encephalitis</td>
<td>88</td>
</tr>
<tr>
<td>Rocky Mountain Spotted Fever (Rickettsia rickettsii)</td>
<td>65</td>
</tr>
<tr>
<td>Malaria</td>
<td>65</td>
</tr>
<tr>
<td>Dengue Fever / Dengue Haemorrhagic Fever</td>
<td>65</td>
</tr>
<tr>
<td>Rocky Mountain Spotted Fever (Borreliosis)</td>
<td>64</td>
</tr>
<tr>
<td>Mumps Tophus (Rickettsia Tophi)</td>
<td>63</td>
</tr>
<tr>
<td>Rat-bite Fever</td>
<td>62</td>
</tr>
<tr>
<td>Crimean-Congo Haemorrhagic Fever</td>
<td>62</td>
</tr>
<tr>
<td>Anaplasma Lataplasico</td>
<td>60</td>
</tr>
<tr>
<td>Ehrlichiosis</td>
<td>76</td>
</tr>
<tr>
<td>Varicella Pox (Small)</td>
<td>77</td>
</tr>
<tr>
<td>Meningococcal Disease / Neisseria Meningitidis</td>
<td>73</td>
</tr>
</tbody>
</table>

Search again:

Patient is child (1-12 years) with the following clinical features:

Figure 3: Guideline page

Algorithm for the management of MENINGOCOCCAL DISEASE

- Recognition
- Call consultant in A&E, Paediatrics, Anesthesia or Intensive Care.
- Assess: Look for signs of early shock/raised ICP.
- DO NOT ATTEMPT LUMBAR PUNCTURE
- IV Cefotaxime (80 mg/kg) or Ceftriaxone (80 mg/kg)

- Signs of Early Compensated Shock?
  - YES
    - ABC and Oxygen (10 L/min), bedside glucose.
    - Insert 2 large I.V. Cannulae (or intravenous)
    - Volume Resuscitation
      - NO
      - After 40 ml/kg fluid resuscitation still signs of shock?
        - YES
        - FURTHER RESUSCITATION
          - NO
          - Transfer to Intensive Care
        - NO
        - REPEATED REVIEW
      - NO
    - Management of raised ICP
      - YES
      - Dexamethasone
        - NO
        - Close monitoring for raised ICP
          - YES
          - Repeated Review
        - NO
        - FURTHER RESUSCITATION
          - NO
          - Transfer to Intensive Care
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Guidelines
National guidelines for the management of various conditions were collected from numerous sources. These included the Advanced Paediatric Life Support group (APLS) and other specialists. The most appropriate and evidence-based guideline in use for each particular condition was chosen. This was then adapted for ease of access and uniformity on ISABEL. All guidelines were represented in the same format, as algorithms with clear decision nodes and action nodes. Hyperlinks were created for each drug name in the guideline to link to the appropriate page in the British National Formulary (BNF), with description of the dosage, interactions and side effects. Bare detail was presented to the user in a first layer, and the evidence and textual description for each node hidden in a second more complex layer for use only if chosen by the user.

Images
Clinical images from experts in various specialities were collected and digitised for use on the website. Once annotated with textual description by the experts online, each image was then linked to a diagnostic category as was previously described for the DDT. This annotation included a description as well as a management plan for each image. Images included clinical photographs, radiographs, blood pictures and other clinical pictures. These images could be searched in multiple ways – by image type, body system involved as well as by keywords.

Experience section
Clinical experience is a result of years of learning and an accumulation of clinical lessons learnt. These experiences are commonly reported as case reports in journals to alert the readers of potential pitfalls in clinical medicine. The aim of this section of ISABEL was to be able to collate and categorise lessons gathered in everyday clinical practice, as contributed by users and experts, as well as from journal reports. For users, the facility to anonymously record clinical errors and lessons was created, so that a short description of the clinical setting, the associated lesson learnt and the keywords to be assigned to the particular experience could be recorded. An editor for the section vetted the experience for utility as well as for significance. This was then assigned a category as described for the DDT. Users could search for individual experiences by keywords or by the system involved. In addition, experiences were integrated into ISABEL, as described later.

Users
ISABEL was primarily intended for junior doctors and primary care physicians, but other medical professionals could also use the system.
While the initial version of the website was restricted to paediatrics, it is being extended to adult medicine and surgery. The user group has also extended to other medical professionals including nursing staff, physiotherapists and others. Members of the general public can view only selected sections of the system. This was ensured by registration and password access, by confirming credentials using the unique identification number assigned by each professional body eg General Medical Council, United Kingdom Central Council for Nursing, Midwifery and Health Visiting (UKCC) etc.

Clinical evaluation
Validation of the DDT has been performed extensively, and reported in the peer-reviewed medical literature. The scheme followed for the evaluation process is shown.

Figure 4: Scheme of clinical evaluation process

![Scheme of clinical evaluation process](image)

Results

Usage statistics
25 GB of data was transferred in the period from July 2001-August 2003 (average/day: 32 MB). There were 9,168,147 successful page requests (average/day: 11,641); over 12,000 users registered to use the site in the specified period. Over a fifth of users accessed the system more than five times since registration. The entire National Health Service (NHS), UK was provided log-in free access via IP address recognition in mid-2002; it then proved difficult to estimate the true number of users.

Evaluation results of the DDT have been encouraging. They were reported in the Archives of Disease of Childhood in 2003. The initial system performance, using hypothetical cases and data from real cases, is summarised in the table.
Table 1: Initial performance evaluation summary

<table>
<thead>
<tr>
<th>Stage 1 validation</th>
<th>Stage 2 validation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objectives</strong></td>
<td><strong>To assess the number of cases in which the expected final diagnosis was presented in ISABEL DDT</strong></td>
</tr>
<tr>
<td><strong>Source of cases/features</strong></td>
<td><strong>Junior doctors in one paediatric centre</strong></td>
</tr>
<tr>
<td><strong>Nature of cases</strong></td>
<td><strong>Mainly hypothetical</strong></td>
</tr>
<tr>
<td><strong>Source of final diagnosis</strong></td>
<td><strong>Junior doctors’ expected diagnoses for a set of clinical features</strong></td>
</tr>
<tr>
<td><strong>Number of diagnoses in ISABEL List</strong></td>
<td><strong>10</strong></td>
</tr>
<tr>
<td><strong>Accuracy rate</strong></td>
<td><strong>87%</strong></td>
</tr>
</tbody>
</table>

*Accuracy: defined as proportion of cases in which the final/expected diagnosis was present in the DDT output list.

The results of the impact evaluation, both for the simulated experiment, as well as the clinical trial conducted at four NHS hospitals is summarised below.

<table>
<thead>
<tr>
<th>Simulated field trial</th>
<th>Real life clinical trial</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objectives</strong></td>
<td><strong>To assess the impact of ISABEL-delivered diagnostic suggestions in a simulated environment</strong></td>
</tr>
<tr>
<td><strong>Subjects</strong></td>
<td><strong>60 junior paediatricians in training at 4 NHS hospitals in the South-East of England</strong></td>
</tr>
<tr>
<td><strong>Case material</strong></td>
<td><strong>Real patients assessed by the participating junior doctors, and thought to warrant the use of ISABEL during the trial period</strong></td>
</tr>
<tr>
<td>24 simulated cases, balanced to represent different specialities and levels of difficulty</td>
<td>24 simulated cases, balanced to represent different specialities and levels of difficulty</td>
</tr>
</tbody>
</table>
Simulated field trial | Real life clinical trial
---|---
**Gold standard** | Decisions judged by an expert panel to be clinically significant Final diagnoses for patients | Decisions judged by an expert panel to be clinically significant

**Outcomes** | Number of significant diagnoses reminded by ISABEL | Number of significant diagnoses reminded by ISABEL Number of final diagnoses reminded by ISABEL

**Results** | In 1 out every 7 cases, a significant diagnosis was reminded | In 1 out every 8 cases, a significant diagnosis was reminded

**Discussion**
This project aimed to produce a clinically useful Internet-delivered decision-support system for the use of the busy clinician at the bedside. The separate components of the system integrate with each other, so that when the user is provided a differential diagnosis, textual description of that diagnosis is made available to the clinician, images are provided to support the diagnosis, guidelines are provided to aid management of the child’s condition, and finally clinical experience from a number of experts and journals is brought to the point-of-care at the appropriate point to improve the junior doctor’s clinical reasoning. Such integration is crucial to quality decision-making in a modern healthcare system and attempts to invert the knowledge pyramid.

Extension of the DDT to adult medicine as well as surgery and obstetrics is underway. The addition of various other components of the site is also ongoing. Clearly, the use of knowledge management techniques is crucial to a profession that is knowledge-intensive. Clinicians regularly use up to 2 million pieces of information to make decisions. The use of clinical decision-making support systems on the Internet is the way of the future, considering the need for universal access and the problems with geographically disparate medical care settings. ISABEL is one attempt to address this need.

**References**
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