An Expert System For The Prediction Of Outcome In Gastrointestinal Haemorrhage

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ABSTRACT

Acute Upper Gastrointestinal Bleeding (AUGIB) requires immediate, urgent attention. Accurately predicting the outcome of a patient with AUGIB allows a doctor to decide on the appropriate treatment, which range from medication and endoscopy to surgery. The 'traditional' means of predicting outcome is through mathematical and statistical models. A decision support tool, built using the case-based reasoning approach, however, has a built-in degree of flexibility and offers an intuitive attraction to its users since it utilizes past learned experiences. This paper describes such a tool, its knowledge base structure, the nearest neighbour matching and retrieval of past cases that best match the profile of a new case and the future potential of a system 'intelligently' monitoring and managing patients dynamically.

Index terms - Case-based reasoning, gastrointestinal bleeding, prediction.

I INTRODUCTION

Acute Upper Gastrointestinal Bleeding (AUGIB) accounts for a large number of all emergency admissions to a general hospital. Overall morbidity and mortality remains significant. The range of medical, endoscopic and surgical therapy available is wide and is often dependent on physician factors and availability of facilities and expertise. Therapeutic decision making is usually difficult and any error or delay may result in adverse outcomes.

Studies from specialist units have shown that management based on strict treatment protocols have resulted in improved outcomes. Moreover, many clinical and endoscopic factors have a value in predicting outcome, re-bleeding and requirement for surgery[1,2]. These allow a more rationale treatment based on a defined approach. Many systems have been described which utilise risk scoring based on mathematical and statistical models[3, 4]. However, they are inflexible, lack clinical intuition and ability to utilise new learned experiences.

The deployment of Artificial Intelligence (AI) technology in a medical domain is still largely limited. However, there is tremendous potential that someday AI technology will support the traditional statistical approach for the analysis of data from studies and clinical trials. An Expert System is able to reason and solve complex problems in a specialised domain. An AI approach known as Case Based Reasoning (CBR) is the main paradigm used in this system. CBR reasons from past cases to solve new problems and can learn by assimilation for future use[5,6]. Version 1 of the AUGIB expert system utilises CBR for the prediction of outcome in AUGIB, and version 2 is currently being developed to enhance the system further using other technologies such as rule-based reasoning. This will, in future, lead to a system which can not only dynamically monitor all patients but also provide powerful computer aided assessment and treatment.

II DOMAIN DESCRIPTION

The first step taken by a doctor in managing a patient presented with AUGIB is to assess his condition and taking necessary resuscitative measures to ensure that the patient is medically stable. Blood tests are taken promptly to assess the need for a blood transfusion. Once the patient's condition stabilises, the doctor will proceed to gather the patient's medical history and particulars (patient factors), and perform a physical examination and diagnostic endoscopy to establish the symptoms presented (disease factors). Based on the patient and disease factors, the doctor will assess the likely outcome of a patient's condition and decide on the appropriate treatment. Choices of treatment range from medication and endoscopy to surgery. Each day, as treatment is being administered, the patient's condition is monitored, and the outcome re-assessed. The management of an AUGIB patient is summarised in Figure 1.

While statistical scoring systems based on mathematical and statistical models are currently being used in the assessment of outcome, an approach using CBR may be more accurate and intuitive. This is because of the following characteristics of the AUGIB domain which makes CBR amenable to solving this problem:

- Domain is naturally case-oriented, with each patient admission treated as a case by itself.
- Similar problems have similar solutions. Patients showing the same symptoms and have similar medical histories and other characteristics may be prescribed the same treatment.
- Historical records exist. For each new case of AUGIB, there is a good chance that at least one sufficiently similar previous case exists from which a probable treatment can be applied.

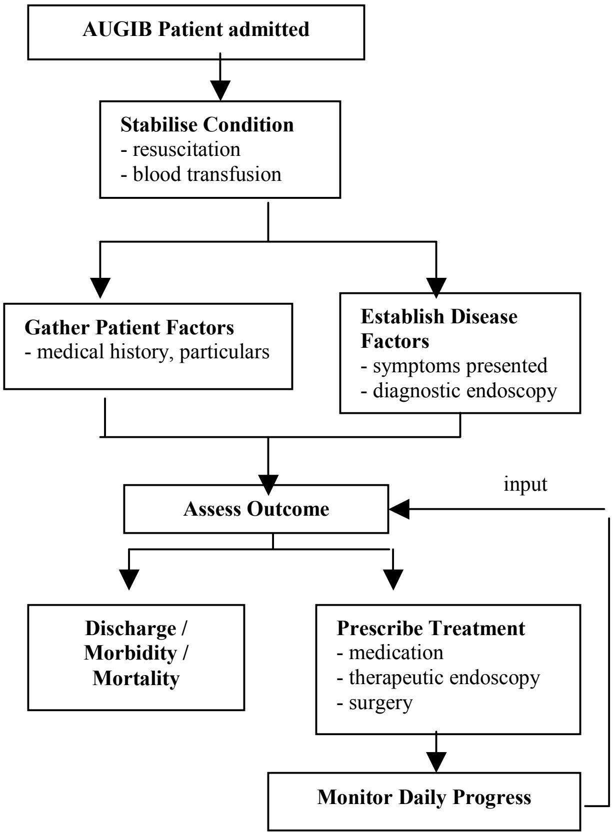

Figure 1: Management of AUGIB patient

III THE EXPERT SYSTEM

This paper describes the design and development of an expert system for the prediction of outcome of patients with AUGIB. Essentially, the system predicts patient's outcome based on past cases of AUGIB patients who share similar profiles of patient and disease factors instead of using existing statistical scoring systems. With the information collected, the system selects from the casebase of past AUGIB patients, cases with profiles that best match the profile of the patient. From the selected list of past cases, the system estimates the patient's outcome; alternatively the doctor may choose to view records of these best matching cases, and use his own judgement to predict the patient's outcome.

A. Case Representation

Currently, a case in the system is represented by 86 fields pertaining to the patient's particulars, admission details, past history/co-morbidity, disease factors, symptoms, investigations, endoscopy (OGD) pathology, daily progress and outcome. Table 1 shows a sample list of fields captured and stored by the system. The fields marked with a √ are used as match fields. Not all these fields are used to represent the problem description and solution for a case, but are nevertheless captured to make the case extensible. While risk factors extracted from statistical systems are used as the starting point (see Table 2) the doctors working on this project have identified other key factors to be used for predicting outcome. Currently there are about 200 cases in the casebase, but the process of adding new cases is on-going.

Table 1: Fields captured and represented as a case; not all the fields are listed here

Patient's particulars 1) IC No 2) Name 3) Sex √ 4) Age √ 5) Race √	Admission details 6) Ward class 7) Admission date 8) Source of admission √
Past history / co-morbidity 9) Previous GI bleed √ 10) Previous ulcer √ 11) Previous gastric surgery √ 12) NSAIDs √ 13) Aspirin √ 14) Warfarin / anticoag √ 15) Steroids √ 16) Alcohol √ 18) Liver disease / cirrhosis √ …………..26)	Disease factor 27) Duration of symptoms (no. of days) √ Symptoms 28) Haematemesis √ 29) Coffee ground emesis √ 30) Malaena hx /PR √ 31) Fresh blood on BO /PR √ 32) NG fresh blood √ ……………36)
Investigation 37) Prothrombin time / partial thromboplastin time √ 38) Platelets √	OGD pathology (3 sets, ach for the first OGD, and subsequent OGD2 & OGD3) 39) Day of OGD done 40) Esophagitis √ 41) Mallory Weiss √ …………55)
Endoscopic Stigmata of Recent Haemorrhage (if ulcer) 56) Active bleeding √ 57) Adherent clot √ 58) Visible vessel √ 59) Red spot √ 60) Blood in upper gastrointestinal track √ 61) Size of ulcer (measured in mm)	Daily progress (value as per readings recorded) 62) Haemoglobin (for each day in the ward – max. of 14 days) 63) Time (at A&E and admission; and for each day in the ward - 14 days) 64) Blood pressure (same as Time) 65) Pulse rate (same as Time)
Outcome Endoscopic therapy 66) ENDOTX (first endoscopic therapy) 67) ENDOTX2 (second endoscopic therapy) 68) ENDOTX3 (third endoscopic therapy) 69) Blood transfusion (no. of pints) 70) re-bleeding 80) unplanned repeat OGD	Outcome Surgery (values are the day that surgery is done) 81) SX (first surgery) 82) SX2 (second surgery) 83) SX3 (third surgery) 84) major morbidity / mortality 85) day of discharge (day) 86) death (day)

Table 2: Sample of a scoring system[1]

Risk Factors Associated with Stress Mucosal Bleeding in the ICU	
Ventilatory assistance > 24 hours' duration	
Shock (systolic BP < 90 mm Hg)	
Sepsis	
Myocardial infarction or congestive heart failure	
Acute renal failure (creatinine > 3 mm/ dl or BUN > 50 mm/ dl)	
CNS injury	
Steroid administration	
Coagulopathy (platelet count <50 K or PT < 30% of control value)	
Bilirubin > 5 mm/ dl	
No. of Risk factors	Incidence of Bleeding
0 – 2	11 %
3 – 6	34 %
> 7	55 %

B. System Architecture

The system is broadly divided into 3 separate modules – the system (or CBR) engine, the user interface and the casebase. The CBR engine is responsible for all processing required – search, match, compute, retrieve, add, delete, update, etc. The CBR engine is further divided into subsystems responsible for the following functions:

- Maintenance of the casebase – stores and maintains records of existing AUGIB patients, system data and online help manuals;
- Search the case base, compute similarity scores and matching degrees (MD), select best-matching cases based on MD threshold, and compute predicted outcomes;
- Retrieve past cases from case base of AUGIB patients.

The user interface and CBR engine modules were implemented making use of distributed component technology, such that both modules can be developed, tested and enhanced without requiring much modification on the other module. A set of APIs serve as the 'contact' between the two components.
For future reuse of the same engine for other applications, the CBR engine has minimal knowledge of the problem domain; only the weights are domain dependent. Thus the CBR Engine provides a generic set of primitive functions and features, both for the manipulation of data during case retrieval and matching as well as for ease in redefining the case library to suit other applications.

[1] Extracted from Gastrointestinal Bleeding by Sugawa, Schuman and Lucas

The user interface provides the standard facilities for the entry, retrieval and updating of a patient's record. For ease of data entry, checkboxes or menu selection list are predominant; monitors are provided to prompt user of erroneous data input and allow spontaneous corrections to be made. Users may view a summary of the retrieved cases, each with its respective outcomes, or the details of a retrieved case by clicking on that particular case in the summary list. The system will compute the patient's predicted outcome based on the set of retrieved cases, and displayed graphically as bar/pie charts. Doctors are able to revise the weights used in the CBR algorithm if the results presented do not agree with their own predictions. Once a patient is discharged, the system is able to confirm the completeness of the patient's records and prompts the user for its inclusion in the case base. To assist in the maintenance of the case base (such as removing obsolete cases) a statistical summary on case usage showing cases that were never retrieved is presented to allow the user to decide whether to remove these cases. Online user guidelines are available for quick references on the system usage. Some screen shots of the user interface are shown in Figure 2 below.

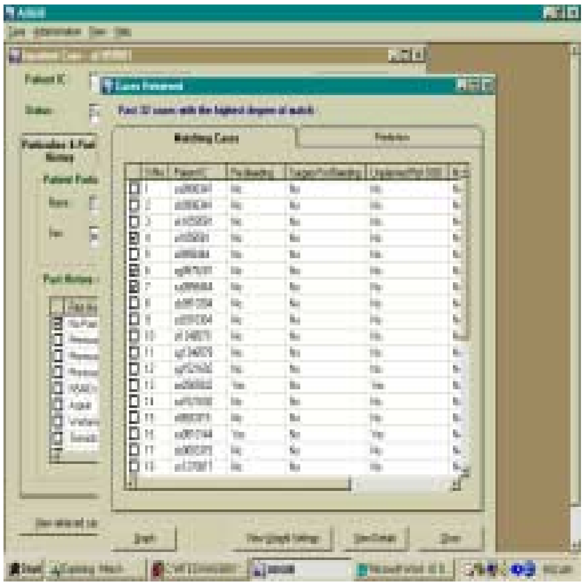

Figure 2: User Interface

C. Nearest Neighbour Matching

Eighty-six fields, which correspond to every patient and disease factors, are captured and represented as a case in the system. However, not all the fields are used for matching. Only the fields deemed useful for the prediction of outcome are used (but fields with no values are not used for matching) and weights indicating the relative importance of the fields are used to compute the similarity scores of the cases in the casebase, and the highest ranked cases retrieved. These are the cases deemed to be sufficiently similar to the input case. Final similarity score between two cases is given by computing the weighted average of the score of all fields.

For each field, depending on its type, one of the following computation methods is applied to obtain the field's similarity score:

- Match/No-match fields: For example, *Source, Race, Sex* and binary valued fields.
  These fields either match, for which the similarity score of 100 is assigned, or don't match, for which a score of 0 is given instead.

- Integer scoring: For example, *Class, Duration, Age, Investigations (PT/PTT, Platelets* and *Size if Ulcer)*
  Each field is assigned a new value based on the mean and standard deviation calculated for the field across the casebase. The similarity score is computed as:

  100 – | (assigned value for input field) – (assigned value for the same field from a case in the casebase) |

- List scoring: For example, *Symptoms, Past History, Investigations (OGD Pathology, ESRH if Ulcer)*

  The similarity measure for list fields requires groupings of the values of each list field, and assigning hierarchical weights to each list field value.
  Consider the simplest method of one-to-one match for each value of the list fields, then:

  Similarity score = 100 * (size of intersection)/(size of union)

  This method cannot correctly compute the similarity of cases when there exist some values that are as important as others. For example, if *Esophagitis* is as important as *Mallory Weiss* in terms of judgement of severity and decision of treatment to be administered, then two cases, one with only *Esophagitis* and the other with only *Mallory Weiss* will be considered quite different which is erroneous.

  This is solved by introducing the concept of groups. Size of intersection and size of union refers to groups instead of values. Thus in the example above, *Esophagitis* and *Mallory Weiss* belong to the same group, so size of intersection will be at least 1. The user has to indicate the groupings of values for each list field. With groupings, all values or groups are assumed to be of equal importance and are independent of each other. What if a certain combination of values or groups is very different in terms of treatment compared with other combinations? For example, if a test case contains values 1, 2 and 3. Matching two cases, one containing 1, 2 & 4, the other with 2, 3 & 4 returns the same similarity measure. So if a match of values 2 & 3 is much more important than a match of values 1 & 2, this method fails.

To resolve this, weights are introduced to each value or group, much like introducing weights to the fields of cases, at a micro-level. Thus the weights specified by the user is hierarchical – highest level weight to the list field itself relative to other fields in the cases plus lower level weight applicable to the individual value or group within each list field. A 'ROOT' variable is created to represent the total similarity score between two cases. The hierarchical grouping of the fields is partially shown in Figure 3.

But all the above remedies fall short of catering to field-to-field synergistic relationship. For example, cases with similar values in fields 1 & 2 may be more 'similar' than cases with similar values in fields 3 & 4, even though individually fields 1 & 2 are weighted less relative to fields 3 & 4. Specifying hierarchies of weights solves this problem. Say if two fields under the same hierarchy matches, the user specified higher-level weight is used to 'boost' or 'weaken' the similarity measure. The score for each field without sub-field, or sub-field without sub-sub-field, or a sub-sub-field is computed as follows:

Score = 100% - |Val_CaseB – Val_CaseA| / (Max_Possible_Val – 1)

Groupings can be assigned for lowest level fields that take *yes/no* as values. When this is the case, their values become the sum of the values of each of the constituent fields. Thus for a group of 3 sub-sub-fields, the Max_Possible_Val is 4 (i.e. 0, 1, 2 & 3), and the total number of sub-sub-fields within the same super-field will be changed from N to N – 2 for the purpose of computing the weighted average of the scores.

If the weight for a sub-sub-field is set, then the weight for its sub-field and field must also be set. Otherwise the weight set for the sub-sub-field will be ignored. If Groups of all sub-sub-fields are not defined (i.e. all sub-sub-fields belong to different Groups), then the weight for all sub-sub-fields under the same sub-field will be equal (i.e. weight has no effect). The score for each field with sub-fields, or sub-field with sub-sub-fields is computed by taking the weighted average of the scores of the sub-fields or sub-sub-fields. Table 3 illustrates the similarity score computation.

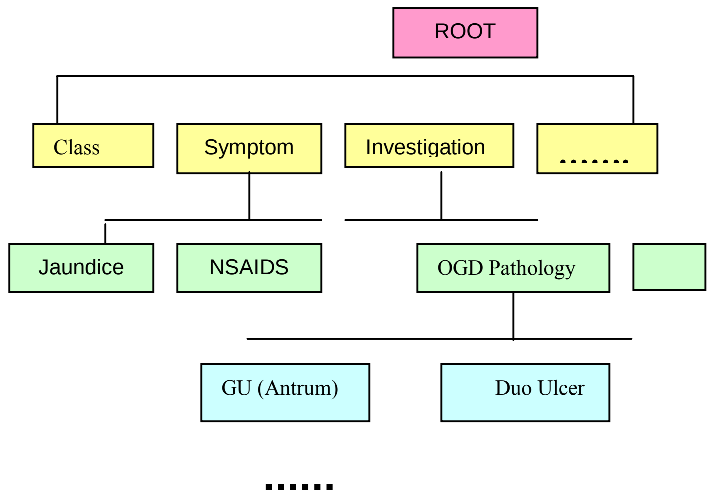

Figure 3: Hierarchical grouping of the fields

Σ/No	Field	Sub-Field	Sub-Sub-Field	Name in Code	Possible Values	Weight	Group	Case 10	Case 20	Score
1	Age			AGE	Integer in years (0 – 100)			45	71	74%
2	Duration of Symptom			DUR	Integer in days (0 – 10)			3	2	90%
3	Disease Factor / Symptom									50%
a.		Haematemesis		SYHAEM	1. Yes, 2. No		1	1	2	0%
b.		Coffee ground emesis		SYCOFF	1. Yes, 2. No		2	2	1	0%
c.		Malaena hx/PR		SYMALA	1. Yes, 2. No		3	2	1	0%
d.		Fresh blood on BO/PR		SYFRBL	1. Yes, 2. No		4	2	2	100%
e.		NG fresh blood		SYNGBL	1. Yes, 2. No		5	2	2	100%
f.		Epigastric pain		SYPAIN	1. Yes, 2. No		6	1	1	100%
4	Past History/Co-Morbidity									85%
a.		Prev GI Bleed		PHGIBL	1. Yes, 2. No		1	1	2	0%
b.		Prev Ulcer		PHULCR	1. Yes, 2. No		2	2	2	100%
c.		Prev Gastric Surgery		PHGASX	1. Yes, 2. No		3	2	2	100%
d.		NSAIDS		PHNSAI	1. Yes, 2. No		4	2	2	100%
e.		Aspirin		PHASPR	1. Yes, 2. No		5	2	2	100%
f.		Warfarin/anticoag		PHWARF	1. Yes, 2. No		6	2	2	100%
g.		Steroids		PHSTER	1. Yes, 2. No		7	2	2	100%
5	Investigations			INVESTIGATIONS						82%
a.		PT/PTT		PTPTT	0. Not done, 1. Normal, 2. Prolonged			1	1	100%
b.		Platelets		PLATE	0. Not done, 1. Normal, 2. Low			1	1	100%
c.		OGD Pathology		OGDPATH						100%
i.			Esophagitis	OESO	0. No, 1. Yes		1	0	0	100%
ii.			Mallory Weiss	OMALLW	0. No, 1. Yes		2	0	0	100%
iii.			Eso Varices	OEVAR	0. No, 1. Yes		3	0	0	100%
iv.			Gastric Varices	OGVAR	0. No, 1. Yes		4	0	0	100%
v.			Gastritis	OGAST	0. No, 1. Yes		5	0	0	100%
vi.			Gast Erosions	OGERO	0. No, 1. Yes		6	0	0	100%
d.		ESRH if Ulcer		ESRH						40%
i.			Active Bleeding	EACTV	0. No, 1. Yes		1	0	1	0%
ii.			Adherent Clot	ECLOT	0. No, 1. Yes		2	0	1	0%
iii.			Visible Vessel	EVISV	0. No, 1. Yes		3	0	0	100%
iv.			Red Spot	ERED	0. No, 1. Yes		4	0	0	100%
v.			Blood in UGIT	EBLOD	0. No, 1. Yes		5	0	1	0%
e.		Size if Ulcer		ULSZ	Integer in millimeters (0 – 50)			5	20	70%
										76.2%

Table 3 : Illustration of the similarity score computation

The final similarity score of each case is computed as follows:

1) For each weighted field, multiply the similarity score obtained from the formula above by the weight assigned.
2) Sum up the results in 1) for all weighted fields.
3) Divide the sum obtained in 2) by the total weight.

D. *Computation of predicted outcome*

The predicted outcome of the current case is computed based on the outcome of the list of most similar cases, known as nearest neighbours, which are retrieved if the overall match score is above a numeric cut-off value. This is to ensure that the system makes a reasonable good prediction based on the cases which are sufficiently similar to the new one. The predicted outcome is computed for each of the outcome type. The computation steps are as follows:

Suppose OC is one of the outcomes (e.g. re-bleeding):

OC (yes) = case that has this outcome
OC (no) = case that does not have this outcome
Total OC (yes) = ∑ (case with OC (yes) * corresponding case MD)
Total OC (no) = ∑ (case with OC (no) * corresponding case MD)

P(yes) = Proportion (OC (yes)) =
$$\frac{\text{Total OC(yes)}}{\sum \text{caseMDs}}$$

P(no) = Proportion (OC (no)) =
$$\frac{\text{Total OC(no)}}{\sum \text{caseMDs}}$$

If P(yes) > P(no) then the predicted outcome for OC is *yes* at a probability of P(yes); and vice versa for P(no).

IV. SYSTEM EVALUATION

The system has performed to expectations when tested and evaluated using 20 past cases with known outcomes. The users have also given their feedback on the usefulness and relevance of the system, as summarised in Table 4. However, for actual deployment, this prototype should be evaluated over a longer period of time with real-time cases.

V. FUTURE WORK

The prototype system is currently being evaluated by the doctors at Tan Tock Seng Hospital. Initial reaction to the system has been very positive, and now the project is currently in Phase 2 with further enhancements to improve the accuracy of the prediction, recommend individually tailored treatment protocols (in real time) which will specify the execution of tasks over time, and include detection of problems (or recovery), drug prescriptions (that will automatically check for contraindications, drug interactions, patient allergies, etc). An important enhancement would be to combine rule-based reasoning and case-based reasoning by recommending treatment protocols based on a knowledge base of rules (defined by senior doctors) and past learned experience.

It is hoped that this project would result in the development of an intelligent system to provide guidance in clinical decision-making and thus quicker responses to patients with gastrointestinal bleeding who require urgent intervention.

Evaluation criteria	**Comments**
System is easy to use.	*Agree*. Interface is user-friendly and allows rapid input of data in acute emergency cases.
System's prediction is comparable with doctors'.	*Agree*. System's predictions based on previous cases is advantageous over doctors', which at best are often gross estimates only.
The comparison with previous cases is useful.	*Agree*. The ability to retrieve data of previous (matched) cases is definitely useful and improves confidence in management.
Doctors are comfortable with system's predictions & recommendations	*No opinion*. A larger base of doctors is needed to try out the system first hand to have a feel of the system and its predictions/recommendations.
System is useful for new / inexperienced doctors.	*Agree*. It is useful as a guideline if senior doctors are not immediately available to assist in management.

Table 4: Users' comments on the system

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