A Rule-based Decision Support Application for Laboratory Investigations management.

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The appropriate management of clinical laboratory requests in specialised clinical units often requires the adherence to pre-defined protocols.

We evaluated the impact of a rule-based expert system for clinical laboratory investigations management in a pediatric liver transplantation unit of our hospital. After one year, we observed an overall reduction in laboratory resources consumption for transplanted patients (-27%) and a decrease in the percentage of "STAT" requested tests (-44%). The percentage of tests ordered in agreement with the protocols for those patients increased from 33% before the introduction of the expert system to 45% when the system was used.

The system was perceived by the clinicians as increasing the overall benefits in use of clinical resources, improving the laboratory data management, and saving time for the execution of laboratory ancillary tasks.

INTRODUCTION

Many types of interventions have been aimed at improving laboratory utilization by clinicians.[1] At one side, educational programs, including general education about testing effectiveness, cost-control education, and guidelines or protocols definitions[2,3,4,5] were described. Feedback systems on test ordering behavior[6] or on laboratory costs[7], and the effect of intelligent workstations for inpatients orders writing[8] were also evaluated. A significative reduction of unnecessary test ordering was achieved in most of those studies. However, the effects of such interventions were often temporary and disappeared after a few weeks when the incentive system was retrieved.

A rule-based expert system for laboratory investigations management was developped by the Wolfson Research Laboratories of University of Birmingham (U.K.).[9,10] A multilingual version of the system was exported in our University Hospital in Brussels. It runs since March 1994 in a Pediatric Liver Transplantation Unit.

The Liver Unit Management Protocol System (LUMPS) allows static and dynamic requesting rules to be defined for different clinical classifications of patients. The attending physician may accept or amend the system's proposals by adding or removing requests to the proposed schedule. After acceptance, request forms and tube labels are automatically printed. The laboratory results are electronically transmitted by the Laboratory Information System (LIS) to the expert system, allowing dynamic rules to be fired in reaction to previous laboratory results.

The aim of this study was to validate the usefulness of the expert system in a different clinical environment, namely the pediatric liver disease unit of our hospital, largely involved in liver transplant care.

METHODS

Protocols

The protocols used to implement the system were adapted from the Liver Unit's current hand-written protocols. They were validated by senior staff before their implementation in the expert system's rulebase. A protocol is composed of clinical classifications and related orders management rules. They are under permanent revision by the senior staff.

Classification definitions. The correct clinical classification of patients represents an essential part of the system. The clinicians defined patient classes for which precise proposal rules could be outlined. The corresponding rules were defined by the clinicians and translated into the expert system syntax. Classes can be defined to allow coexistence of two or more classes or to be mutually exclusive.

The rules defined for coexistent classes are additive: all investigations defined for the two or more classes will be proposed. Typical coexistent classes are a "Liver Transplantation" class and a "FK trial" class.

The adding to a patient's record of a class which is mutually exclusive with the preceding class for that patient induce the end of preceding classification's proposals. Mutually exclusive classes are, for instance, "Liver Transplantation" and "Discharged" or "Pre-Transplant assessment" and "Transplanted".

When classifying a patient, questions may be

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asked to allow easier subclassification and to avoid any omission of important clinical data.

Rules. Two type of rules were defined in the rulebase: static and dynamic.

The static rules allow the definition of "baseline" proposals within a precise time schedule (liver function tests to be ordered every day after transplant for two weeks, for example). They translate the hand-written protocols already in use at the ward.

Dynamic rules allows the system to react to results of previously ordered tests (if WBC rising above $20.10^3/mm^3$ for a transplant patient, perform haemocultures).

The parameters evaluated by the rules may be: current patient classification status, current and previous test(s) results, including trends analysis (five successive decreasing values of liver enzymes, for example), and previous proposals (if haemoglobin level drops below 9 g/dl, take a sample for blood compatibility only if the previous compatibility sample is more than 15 days old).

The rules are implemented in the form of IF-THEN-ELSE statements. The database maintains the proposals for each patient for the next seven days. The system reevaluates the proposals for a patient in three circumstances: every night, at each new laboratory result sent by the laboratory information system, and every time a new classification event occurs.

Security and confidentiality

The users of the system are given a user ID and a password. The system was designed so that the user accepting the proposals by printing the request forms and the tube labels is regarded as the official writer of the order. His legal identification is mentioned on the request form. A clinician responsible for the patient may also be defined for each new entry.

Laboratory data transfer

A results transfer protocol was defined between the LIS and the application. The existing protocol for results transfer between the LIS and the HIS (Hospital Information System) was used. The non LIS-connected laboratories can't transfer any test result to the system. Consequently, dynamic rules could not be defined for such laboratories.

Labels and request forms

The request forms to be printed were defined to mimic as much as possible the currently used request forms in our hospital. For all laboratories already linked to the LIS, the multi-sheet request form could be replaced by a single printed sheet. For non-connected laboratories, the multi-sheet request forms currently in use has to be maintained. For those laboratories, the system only prints a list of requested investigations to be ticked on the corresponding pre-printed hospital's request forms.

User interface

The main screen of the system is represented in figure 1. It allows the clinician to define several panels of biological parameters to be presented. Up to ten previous results for those parameters are shown on the screen. The last four columns are used to show the system's proposals and to allow the clinician to easily amend them.

No de patient ... Nom Séjour
Classement: TRHS,CICLO,POST_OP,TRH Age **4a** Sexe **M** Unité **U97** Méd **OTTE**

	12.04	13.04	14.04	15.04	16.04	17.04	18.04	19.04	20.04	21.04	0123
Hct -----	24.1	24.7	24.9		22.6	31.1	29.8		29.1		...P
Plaq -----	152	156	192		201	179	160		173		...P
Glob Bl-----	5.52	6.45	7.51		4.88	4.78	4.89		4.37		...P
Neut % -----	79.9	79.7	83.6		69.2	70.7	70.5		70.2		...P
Lymph %-----	10.1	9.5	7.2		15.8	19.2	18.7		22.9		...P
Mono % -----	4.8	5.2	4.6		4	5.6	7.3		4.1		...P
Eosi % -----	2.8	2.8	2.6		0.6	0.3	0		0.6		...P
Baso % -----	0.6	0.5	0.7		0.3	0.2	0.3		0.2		...P
LUC % -----	1.9	2.2	1.4		10	4.1	3.1		2.1		...P
Uree -----	39	45	44	53	73	91	88	84	61		RPPP
Creat -----	0.38	0.24	0.34	0.4	0.41	0.47	0.47	0.36	0.31		RPPP
Na -----	136.6	137.8	138.3	136	134.3	136.5	135	137.1	141.7		RPPP
K -----	3.45	3.56	3.33	3.38	3.95	3.86	3.55	3.04	2.83		RPPP
Cl -----	92.4			97.5	96.2	97.1	97.6	96.4			....
CO2 -----	25.8	25.4	24.5	23	22.5	22.3	14.7	26.7	27		RPPP
Ca -----	8.81	9.17		9.65	8.57	8.44	cCODE	9.03	8.79		...P
Ph -----	4.33	5.01		3.82	4.16	4.67	3.87	3.43	2.88		...P
Gluc -----			80								R..P

Figure 1 : Main results screen. The rightmost column labelled "0123" shows the current proposals state for the current day (0) and the next three days (123). A "R" on the line of a test signals that the test has already been ordered for the corresponding day (request forms already printed). A "P" means that the test is proposed by the system or already manually added by the clinician. By erasing or adding "P" for the desired test in the corresponding day column, the clinician may easily alter the proposed ordering schedule.

Clinical laboratory resources consumption evaluation

The requesting of laboratory tests was compared at two levels: number of tests requested in each discipline and for each class, and number of urgently requested investigations. Most studied investigations concern LIS-connected laboratories (mainly Chemistry, Haematology, Coagulation and Drug Monitoring). A major non LIS-connected laboratory involved in the system evaluation was the Virology laboratory. The lack of results transmission between this laboratory and the system did not allow dynamic rules to be defined.

The LUMPS software allows to extract statistical data about performed tests. The tests were classified either as "protocol-compliant" (tests proposed by the system and accepted by the clinician) or "unsollicited" (tests results received without any requesting by the system).

A baseline study was performed for patients admitted at Liver Unit between June and December 1993. A first comparison of laboratory investigations ordering during this period and after system start was performed for patients of same classification. Two types of protocols were studied: assessment protocols (pre- and post-transplant assessment) and immediate post-transplant monitoring.

Computer system

The LUMPS server is a PC 486 model running MUMPS. The server runs the rulebase engine and maintains the patients database. Results are send to the LUMPS server by the LIS. A PC at the liver unit ward, connected to the HIS network, runs a terminal emulation session to the server. A laser printer is attached to the PC for request forms and tube labels printing.

RESULTS

Laboratory resources consumption

During the six month preceding the introduction of the system, the clinicians classified the incoming patients according to the already defined classes of pre-transplant assessment, post-transplant assessment, and transplant monitoring. We extracted from the LIS databases the number and type of tests performed for those patients. After stabilization of the system, we extracted the same data for patients monitored by the system.

Table 1 shows the evolution of the requesting behavior, before and after the introduction of LUMPS.

For assessment patients (Table 1 (a)), we observed an increase of the total number of tests requested per patient after introduction of the LUMPS system (+13%). Interestingly, a disproportionately large increase (+46%) was observed in the "Other" category of tests, grouping essentially special chemistry, serology, nuclear medicine, and bacteriology. This suggests that specialized diagnostic tests were more often requested after introduction of LUMPS.

Table 1 : Evolution of the mean number of tests requested per assessment patient (a) and transplant patient (b), before and after introduction of LUMPS. The number of patients of each group (N) is represented in parenthesis.

(a) Assessment protocols - mean number of tests ordered / admitted patient

	Before (N=32)	After (N=151)	Δ %
General Chemistry	46	53	15 %
Virology	22	18	-18 %
Haematology & Coagulation	23	30	30 %
Others	13	19	46 %
Total	**106**	**120**	**13 %**

(b) Transplant protocols - mean number of tests ordered / admitted patient

	Before (N=10)	After (N=24)	Δ %
General Chemistry	368	273	-26 %
Virology	70	49	-30 %
Heamatology & Coagulation	345	268	-22 %
Others	264	178	-33 %
Total	**1047**	**768**	**-27 %**

For transplant patients (Table 1 (b)), a major decrease of the total number of tests requested was observed (-27%). The decrease is evenly spread over all disciplines. The mean number of STAT requested tests (figure 2) per patient was of 65 before LUMPS. After introduction of the system, a mean of 36 tests per patient were urgently requested, showing a 44% decrease of STAT requesting.

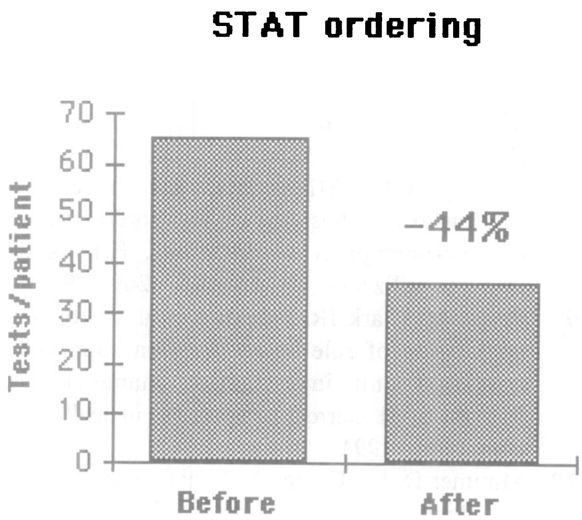

Figure 2 : Evolution of the STAT requesting behavior for transplant patients, before and after introduction of the LUMPS system.

Protocol compliance

Two major kinds of protocols were defined: assessment protocols and transplant monitoring protocols.

The percentage of tests proposed by the assessment protocols was around 78% of the total performed laboratory tests. This compliance to static protocols was easy to achieve and a stable situation was obtained after a few months of usage of the system.

For transplant monitoring protocols (more complex and dynamic rules), the overall compliance to the protocols was of 45%. The dynamic protocols are still under revision. A protocol-compliance of 33% was observed for the tests requested during the baseline evaluation period for transplant patients (based on the hand-written protocols in effect during this period).

DISCUSSION

The introduction of a rule-based expert system for laboratory investigations management at the liver unit of Queen Elizabeth Medical Centre of Birmingham triggered a 9.5% reduction in the number of clinical chemistry analyses requested per patient day for liver transplant recipients.[10] For other patients, the reduction was of 28.8%. The number of STAT requests fell by almost 50%.

In our specific setting, we observed the same trends regarding transplant recipients (-27%). The great difference observed between the "assessment" group in Brussels and the "other patients" group in Birmingham is due to a major difference between the two groups. The patients from Birmingham were a mix of pre- and post-transplant assessement patients and other liver pathologies, whereas our group consisted only of pure assessment patients. The rise in laboratory consumption in our clinic (+13%) is mostly observed in the specialized laboratory tests area (+46%). This points out that the classification procedure, with a number of precise questions to be answered at patient admission, may help to trigger more specific laboratory requesting for diagnosis purposes.

The implementation of the expert system in a pediatric liver transplantation unit proved to be beneficial. A regularisation of the laboratory workload was obtained by reducing the STAT requested tests, mainly for immediate transplant follow-up. For those patients, the introduction of the expert system triggered an increase from 33% to 45% of the protocol-compliance of the ordered tests. The parallel decrease in the total number of requested laboraory parameters (-27%) observed is a sign that the requesting behaviour of clinicians may be successfully and durably altered by appropriate clinical management tools.

An important benefit of the implementation of the system resides in a thorough review of requesting practice at the ward. The evidence of existing discrepancies between the hand-written protocols and the real requesting behavior was a surprise for the senior clinicians. The impact of such a review of clinical practice is evidenced by the important reduction of virology requesting for all patients of the study. The virology laboratory was not yet connected to the LIS at the moment of the statistical data collection. No dynamic requesting rules could thus be defined for that laboratory. The sole effect of a revision of the ordering practice, combined to definition of static rules was sufficient to consistently alter the requesting behavior of the clinicians: -18% for assessment patients and -30% for transplant monitoring. The decrease in virology ordering for assessment patients seems to be essentially due to review of clinical practice by the clinicians. For transplant patients however, the trust in the static rules seems to reduce the defensive over-ordering behavior for virology follow-up.

A reduction of the time spend by clinicians and nurses to perform laboratory ancillary tasks such as requests filling, tubes labelling, and results collecting was reported by the ward staff. This could not be supported by objective data because no time studies were performed before the implementation of the system. The possibility of viewing laboratory results and requesting laboratory parameters on the same screen was perceived by the clinicians as one of the great benefits of the system. The ability of the system to provide a preview of the proposed testing schedule for up to three days in advance on the same screen was also judged by the users to be of great importance to avoid unnecessary testing.

When reviewing a number of studies regarding the modification of laboratory ordering behavior of clinicians, a general conclusion was that the effect of the interventions was short-lived.[1] The major interest of the expert system used for this study is that it may be embedded in our Hospital Information System (HIS). The effect of the system should be permanent and his extension to other specialized units is now considered.

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