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Interfacing a Stand-Alone Diagnostic Expert System with a Hospital Information System

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Few diagnostic decision-support systems are in routine clinical use, mainly because these systems typically require time-consuming manual data entry. This research investigated the feasibility of reducing manual data entry by integrating a stand-alone diagnostic expert system with an existing comprehensive hospital information system (HIS). A knowledge-based intervocabulary mapping technique was developed to map disparate vocabularies. The results of a retrospective study indicate that transferring clinical data from the HIS to the diagnostic expert system at the beginning of a workup significantly reduces the manual data entry required for generating the correct diagnoses for patients. © 1994 Acadeamic Press, Inc.

INTRODUCTION

The practice of medicine is a knowledge-based process. With medical knowledge doubling every 8 years, it is increasingly difficult for physicians to assimilate the large body of medical information. Covell *et al.* found that 70% of the information needs of medical practitioners were not being met satisfactorily (*1*).

Despite the advances in medical knowledge, diagnostic errors in day-to-day practice may be increasing. Autopsy studies have found that the accuracy of clinical diagnoses ranged from 46.75 to 96.4% and underdiagnosis, overdiagnosis, and misses in potentially treatable diseases occurred (*2, 3*). Since treatment plans are based on diagnoses, diagnostic errors result in patient management errors. Weinberg found that patient management errors ranged from 10 to 38% and that these errors relate more to the process of making a diagnosis than inappropriate therapy (*4*). Diagnostic errors cause unnecessary or inappropriate treatments or procedures and produce serious morbidity and mortality (*5–7*).

Physicians strive to provide quality patient care by making optimal clinical

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decisions. Expert systems have been developed to help physicians interpret patient data and provide reminders, alerts, and advisory messages. With such systems, physicians might minimize the diagnostic errors that occur in daily practice and so improve the quality of patient care. Studies have demonstrated that stand-alone diagnostic decision-support systems have improved diagnostic accuracy (*8–10*). In addition, Lau *et al.* showed the benefits of using a diagnostic expert system to detect quality problems arising from diagnostic errors (*11*).

Although diagnostic expert systems are useful as decision-support tools for physicians, few diagnostic decision-support systems are in routine clinical use (*12*). Both Shiffman *et al.* (*13*) and Bergeron (*14*) concluded that diagnostic expert systems are not embraced by physicians in routine clinical practice. Perry stated that computer-assisted medical decision making tools are used mostly in education and research (*15*). The lack of efficient interfaces to a comprehensive clinical patient database is a major reason (*12, 14*). Consequently, physicians must manually enter patient-specific data into these diagnostic expert systems for consultation. Most physicians are unable or unwilling to spend the extra time required to use stand-alone decision-support tools. Shortliffe explicitly pointed out that the dislike for data entry is a reason that physicians reject the idea of decision-support systems (*16*).

To solve the data entry problem and increase the routine use of diagnostic expert systems by physicians, two basic approaches can be taken: (i) provide a user-friendly interface to simplify and speed the data entry process; (ii) make comprehensive patient databases available for the direct retrieval of patient-specific data, thus partially or completely eliminate the data entry process. This research studied the latter approach by interfacing Iliad (*17*), a diagnostic expert system in internal medicine, with HELP (Health Evaluation through Logical Processing) hospital information system (*18, 19*), which has a comprehensive patient database. The hypotheses of this research were: (i) intervocabulary mapping between Iliad and HELP would enable Iliad to obtain some patient-specific data from the clinical patient database in HELP; and (ii) providing HELP clinical data to Iliad would reduce the manual data entry requirements.

Methods

Assumptions

This retrospective study assumed that physicians might consult Iliad for patients admitted to the hospital without an established diagnosis. The design also assumed that 2 days of clinical data would be sufficient for establishing the admission diagnosis of each patient. Consequently, only clinical data acquired within the first 48 hr after admission were transferred from HELP to Iliad.

Issues

Three key issues arose in interfacing Iliad and HELP: the physical link between the two systems, the communication protocol to facilitate information exchange, and the intervocabulary mapping between Iliad and HELP. This research explored the feasibility and usefulness of interfacing a stand-alone diagnostic expert system with a hospital information system. Of the three issues raised above, only intervocabulary mapping was addressed. In addition, this study measured the effect of transferring clinical data from HELP to Iliad, which was simulated by manual data entry.

Intervocabulary Mapping between Iliad and HELP

In recent years, many investigators have attempted to develop different strategies to map different controlled vocabularies. Sherertz *et al.* employed a lexical matching technique to map structured text to MeSH (*20*). Cimino *et al.* created a semantic network and a comparison algorithm for automated translation of a subset of medical and surgical procedures between the ICD9, MeSH, CPT4, and SNOMED (*21*). Masarie *et al.* developed a frame-based system based on the interlingua approach to map the manifestations of cardiopulmonary diseases between MeSH, QMR, DXplain, and HELP (*22*).

Intervocabulary mapping between Iliad and HELP created a dilemma. None of the above mapping techniques were available and it was impractical to develop another mapping technique as part of this research. As a result, a labor-intensive manual mapping technique was used in this study.

Both Iliad and HELP use a hierarchical data dictionary to define clinical manifestations such as history, physical examination, and laboratory results. Each term in the dictionaries has a text description and a unique numeric code that identifies its relation in the hierarchy. For instance, the Iliad term "CHEM-20: creatinine is = = = mg/dL" has a numeric code of "13.2.18.0.0.0." The identical term in the Point-to-the-Text (PTXT), which is the HELP data dictionary, has a numeric code of "13.14.1.13.0.0.0" and the associated text string of "Chemical analysis: ser: quant: creatinine." Both the Iliad data dictionary and the PTXT are organized into "data classes" that represent clinical areas or departments. These data classes simplified the manual mapping process because Iliad terms in one data class were restricted to one or two corresponding data classes in the PTXT. For example, mapping of the Iliad term "CHEM-20: creatinine is = = = mg/dL" in the data class "Chemistry Lab Data" was restricted to the PTXT data class "Clinical Chemistry."

The outcome of mapping an Iliad term to the PTXT fell into three categories: "exactly matched," "partially matched," and "not-matched." For an exactly matched term, there exists a PTXT term that contains the exact concept, information, or meaning of the Iliad term. For instance, "Chemical analysis: ser: quant: creatinine" in the PTXT is exactly matched to "CHEM-20: creatinine is = = = mg/dL" in the Iliad vocabulary. For a partially matched term, there exists a PTXT term that contains only part of the concept, information, or meaning of the Iliad term. For instance, the PTXT term "glucose" is only partially matched to the term "fasting glucose" in the Iliad vocabulary. Finally, for not-matched terms, no mapping can be found.

There were few exactly matched terms because the two controlled vocabularies were developed by two different groups of researchers for different purposes. Most of the Iliad terms were only partially matched to PTXT terms. However, if there were more exactly matched, more patient data could be transferred from HELP to Iliad. Consequently, to increase the amount of data that could be transferred, a knowledge-based intervocabulary mapping technique, called MLM-mapping, was developed.

In the HELP system, medical logic modules (MLMs) represent medical knowledge. Each MLM is an independent knowledge module that has decision logic and medical knowledge for a single concept (*23, 24*). Whenever the criteria in an MLM are satisfied, the particular action specified in the MLM is executed.

Most terms in the PTXT are atomic, with each term representing a single simple concept. This atomic nature allows terms to be combined to form more complex concepts. For instance, in the radiology data class of the PTXT, the atomic terms "nodule" and "right upper lobe" can be combined to represent the concept "right upper lobe nodule."

The MLM-mapping approach took advantage of the atomic nature of PTXT terms and the MLM-knowledge representation of the HELP system. Each MLM created captures the concept of a targeted Iliad term. MLM creation required understanding the targeted Iliad term, finding the PTXT terms that can represent the same information, and combining these PTXT terms with appropriate logic. For instance, for the Iliad term "Anti streptolysin O (ASO) test is positive," the closest PTXT term is "ASO test." However, the "ASO test" is a numeric term that does not specify positive or negative. Therefore, mapping "Anti streptolysin O (ASO) test is positive" required creation of a MLM. This MLM included the PTXT term "ASO test" and the logic specifying that the ASO test is positive if its value exceeds 199. Each MLM was tested against real patient data.

Developing a Query Program

Mapped Iliad terms or newly created MLMs do not guarantee that Iliad can get the clinical data it needs from HELP. Any data to be transferred from HELP to Iliad must first exist in HELP's central patient database. Currently, HELP captures and stores only a subset of patient data.

Once the intervocabulary mapping was accomplished, a query program was developed to retrieve clinical data from HELP's central patient database. In addition, a patient file, a PTXT file, and an output file were created. The patient file contained patient numbers. The PTXT file contained the numeric codes of the exactly matched PTXT terms. It also contained a pointer to each MLM that had been developed to translate inexactly matched HELP data into Iliad terms. The output file was a text file designed to hold all the clinical data extracted from HELP.

Diseases and Patients Selection

Three disease domains were selected for this study: pulmonary, hematology, and gastrointestinal, because Iliad's knowledge base in these areas is well developed. In addition, LDS Hospital admissions to these medical services provided a sufficient number of cases for this study.

The ICD9 codes of each disease domain were identified. A program was developed to retrieve patients whose principal discharge diagnoses matched any of these ICD9 codes. This progarm reviewed all patient admissions to LDS Hospital during a 6-month period. The resulting patient numbers were entered into the patient file with a text editor. Patients who were transferred from other medical facilities were excluded because their clinical data for the first 48 hr after admission might not have been available.

Next, the query program retrieved clinical data from HELP as specified in the PTXT file. The retrieved clinical data of all qualified patients were stored in the output file. From this output file, the 50 patients with the most clinical data were selected for the retrospective study. The medical charts of these 50 patients also were retrieved from the medical records department.

Experimental Design

Creating patient cases. The HELP clinical data of the 50 patients were first entered manually into Iliad to create 50 Iliad patient cases. A physician reviewed each patient's medical chart and entered missing data into the corresponding Iliad patient case. These missing data were collected within the first 48 hr of admission, but not found in HELP's central patient database. They included the chief complaint, history, physical examination, and certain test results. The data entry process stopped when all missing data were entered or the principal discharge diagnosis or a secondary discharge diagnosis of each patient case reached 95% probability or above.

Creating test cases. Two different types (Type I and Type II) of test cases were created from each patient case. Both types of test cases were provided with the same chief complaint. In addition, Type II test cases were also provided with the clinical data from HELP. Both types of test cases had the same working hypothesis, which was the principal discharge diagnosis or a secondary discharge diagnosis from the patient's medical record.

Processing test cases in "least cost mode." An Iliad option called least cost mode simulates physician interaction with Iliad. As a test case is being processed in the least cost mode, Iliad automatically generates a list of questions based on the current available patient data. A ranking algorithm directs questioning to the most informative and least expensive items of information. Simultaneously, Iliad attempts to retrieve the answers from the patient case that was previously created. The least cost mode was used to process both types of test cases to reduce the cost of this study by eliminating the requirement of manual data entry by physicians.

At the beginning of processing each test case, the provided chief complaint (in both Type I and Type II test cases) and the HELP data (in Type II test cases only) were first used to infer the working hypothesis. If Iliad could not confirm the working hypothesis with 95% probability, it performed two tasks.

First, Iliad identified the most informative but least expensive question. Second, Iliad attempted to retrieve the answer from the patient case that was previously stored. This cycle repeated until the designated working hypothesis reached 95% probability. However, if too many questions remained unanswered, Iliad would stop the workup without being able to confirm the working hypothesis with 95% probability. At the end of each workup, whether Iliad was able to conclude the working hypothesis (complete) or unable to conclude the working hypothesis (incomplete), a summary was generated. The summary indicated all the clinical data that were used in the workup to produce the final differential diagnosis.

Data analysis. Two analyses of data were performed to study the feasibility of intervocabulary mapping between Iliad and HELP and the impact on manual data entry when HELP clinical data were provided at the beginning of a workup. First, the result of the intervocabulary mapping was tabulated into the categories of exactly matched and exactly matched with MLMs in each data class. Second, the summaries of all processed test cases were analyzed to determine the additional number of clinical data items entered by physician in Type I and Type II test cases.

Results

Intervocabulary Mapping

Table 1 shows the results of the mapping. The mapping of the Iliad and HELP vocabularies focused on clinical findings. Although history and physical examination findings are defined in the PTXT, these findings are not captured currently in the HELP system. Consequently, no attempt was made to map the corresponding data classes in Iliad. Note that the overall mapping effort concentrated on laboratory findings.

In the first phase of the manual mapping process, the number of synonyms found in the PTXT for the 2352 Iliad findings was 133 (5.6%). In the second phase, MLM-mapping increased the number of synonyms. Creating MLMs for mapping the remaining Iliad terms would have demanded tremendous human effort. Therefore, only a small subset of the remaining Iliad terms was mapped with MLMs. This subset of Iliad terms was pertinent to the three chosen disease domains. One hundred and five MLMs were created to map 105 Iliad terms. In total, 238 of 2352 Iliad findings (10.1%) were mapped. The 238 mapped terms represented only 4% of the terms in the Iliad vocabulary. It is important to realize that many more MLMs could have been created for each data class in the Iliad vocabulary. However, this does not imply that the significance of the results of this study will increase linearly.

Patient Selection, Clinical Data Retrieval, and Data Entering

The patient archive for the second half of 1991 at LDS Hospital was searched. Based on the ICD9 codes for the three chosen disease domains, 1001 patients were found. Using the 238 synonyms and MLMs, clinical data were retrieved

TABLE 1

RESULTS OF MAPPING ILIAD AND HELP VOCABULARIES

Data classes in Iliad	No. of terms in the data class	No. of exactly matched terms (%)	No. of additional exactly matched terms using MLMS (%)	Total No. of terms matched in this study (%)
Nursing data	9	0 (0)	[a]	0
Blood bank	6	3 (50)	[a]	3 (50)
Chemistry lab data	297	67 (22.5)	26 (8.8)	93 (31.3)
Immunology lab data	168	16 (9.6)	11 (6.5)	27 (16.1)
Hematology lab data	205	33 (16.1)	1 (0.5)	34 (16.6)
Microbiology lab data	362	0 (0)	[a]	0 (0)
Rheumatology lab data	8	0 (0)	[a]	0 (0)
Pathology lab data	25	0 (0)	[a]	0 (0)
Radiology	948	0 (0)	59 (6.2)	59 (6.2)
EKG and holter monitor	124	13 (10.5)	[a]	13 (10.5)
Pulmonary lab data	25	1 (4)	8 (32.0)	9 (36.0)
Cardiac catheterization	53	0 (0)	[a]	0 (0)
Nuclear medicine	12	0 (0)	[a]	0 (0)
Skin test	11	0 (0)	[a]	0 (0)
Ob/Gyn lab data	26	0 (0)	[a]	0 (0)
Ophthalmology	73	0 (0)	[a]	0 (0)
Therapeutic procedures[b]				
Diagnostic procedures[b]				
Frame titles[b]				
Medical history[b]				
Physical exam[b]				
Total	2352	133 (5.6)	105 (4.5)	238 (10.1)

[a] Terms in these data classes were not mapped with MLMs.
[b] The 3648 terms in these five data classes were excluded from the mapping.

from the HELP central patient database for each of these patients. The number of clinical data items retrieved from HELP for the patients ranged from 0 to 105. Patients without clinical data in the HELP patient database were outpatients. For each inpatient, only a subset of the 238 mapped data items were retrieved for the following reasons. First, not all clinical data were necessary for each patient's care. Second, the HELP system does not routinely capture all findings defined in the PTXT. From the 1001 patients, the 50 patients with the most retrieved clinical data were selected for the retrospective study. The number of clinical data retrieved for these 50 chosen patients ranged from 31 to 105. The HELP clinical data for each patient were entered and saved individually in Iliad. In addition, clinical data from the chart-based medical records of the patients were also entered by a physician.

Creating and Processing Test Cases

To create a test case, the patient's principle discharge diagnosis must reach 95% probability in the differential diagnosis that was generated by Iliad when the patient case was created. Two of the 50 patient cases were excluded in the retrospective study because the principle discharge diagnoses of these 2 cases did not reach this threshold. Therefore, only 96 rather than 100 Type I and

TABLE 2

ILIAD'S ABILITY TO CONCLUDE THE WORKING HYPOTHESES FOR TEST CASES WITHOUT AND WITH HELP DATA

Type I (without HELP Data)	Type II (with HELP Data)	
	Complete	Incomplete
Complete	30	1
Incomplete	5	12

Notes. Complete, Iliad able to conclude the working hypothesis; Incomplete, Iliad unable to conclude the working hypothesis.

Type II test cases were created. These 96 test cases were processed by Iliad in the least cost mode.

Table 2 shows Iliad's ability to conclude the working hypotheses for both types of test cases. As mentioned earlier, the working hypotheses were patients' principle discharge diagnoses. For 30 of the 48 patient cases, both types of test cases were able to conclude the working hypotheses with 95% probability or above (complete). For 12 patient cases, both types were unable to conclude the working hypotheses (incomplete). This suggests that some patient cases may be too difficult for Iliad. The remaining 6 patient cases had one incomplete test case. The number of incomplete Type II test cases is slightly lower than the number of incomplete Type I test cases (13 vs 17). This is because in some patient cases the clinical data from HELP allowed Iliad to focus on the working hypotheses. On the contrary, if no clinical data were provided to Iliad at the beginning of the workup, or if the given clinical data were not pertinent to the working hypothesis, Iliad tended to ask more questions. The more questions Iliad asked, the more likely the answers to these questions could not be found in the patient's file. As a result, Iliad exhausted its questions and the workup remained incomplete. This explained why there were many incomplete test cases.

Comparing Type I and Type II Test Cases

To study the effect of providing HELP clinical data at the beginning of the Iliad workups, Type I (only chief complaint was provided) and Type II (chief complaint and HELP data were provided) test cases were compared. Tables 3, 4, and 5 show this comparison in two categories. Category I is the total number of clinical data required to conclude the working hypotheses. Category II is the additional number of clinical data required to conclude the working hypotheses after the provided data were used. Only 30 of the 48 patient cases were reported in Table 3 because in 18 patient cases the workups of either Type I, Type II, or both Type I and Type II test cases were unable to conclude the working hypotheses (see Table 2). As the result, these 18 patient cases were discarded.

TABLE 3

Comparing the Results of Type I and Type II Test Cases

Patient case No.	Category I: Total No. of clinical data required		Category II: No. of additional clinical data entered by a physician	
	Type II	Type I	Type II	Type I
1	39	141	8	141
3	111	57	36	57
4	66	50	14	50
5	88	64	60	64
6	167	141	131	141
9	140	84	70	84
11	299	164	194	164
13	148	68	52	68
15	140	107	37	107
16	118	39	16	39
17	132	131	46	131
19	153	57	53	57
20	139	46	38	46
21	176	114	73	114
23	266	156	165	156
28	104	139	65	139
30	73	16	6	16
32	80	37	17	37
33	103	13	37	13
34	140	76	75	76
37	169	179	115	179
40	162	183	126	183
43	182	186	113	186
44	123	68	65	68
45	112	16	84	16
46	228	169	188	169
48	83	141	37	141
50	84	43	50	43
54	129	61	60	61
55	125	110	78	110

TABLE 4

Comparing the Means, Medians, and Ranges of Type I and Type II Test Cases in Category I

	Mean	Median	Range
Type I	95	80	13–186
Type II	136	130	39–299

TABLE 5

COMPARING THE MEANS, MEDIANS, AND RANGES OF TYPE I AND TYPE II TEST CASES IN CATEGORY II

	Mean	Median	Range
Type I	95	80	13–186
Type II	70	60	6–194

Figure 1 shows that for 24 patient cases, Type II test cases were higher than Type I test cases for Category I. The mean of the total number of clinical data processed by Iliad in Type II test cases was greater than in Type I test cases by 41 (42.8%). It is important to realize that in this study, the transfer of data from HELP to Iliad was based on availability. In other words, instead of transferring the data elements that Iliad needed to make diagnoses, all available data elements in HELP patient database were transferred to Iliad. Hence, Iliad has received more data than necessary to generate the working hypotheses.

To determine whether providing HELP data at the beginning of the workups reduced physician data entry, Type I and Type II test cases were compared in Category II. For 24 patient cases, Fig. 2 shows that Type II test cases required much less physician data entry than Type I test cases. However, the remaining 6 patient cases: 11, 23, 33, 45, 46, and 50 (see Table 3) required more physician data entry in Type II test cases than Type I test cases. This phenomenon was due to the excessive clinical data transfer, from HELP to Iliad, which generate "noise" that misled Iliad during the inference process. Overall, the mean of additional data entered by the physician in Type II test cases was fewer than in Type I test cases by 25 (26.3%). In essence, by processing the HELP clinical data at the beginning of the workups, Iliad required fewer additional clinical data to conclude the working hypotheses than when no HELP data were provided.

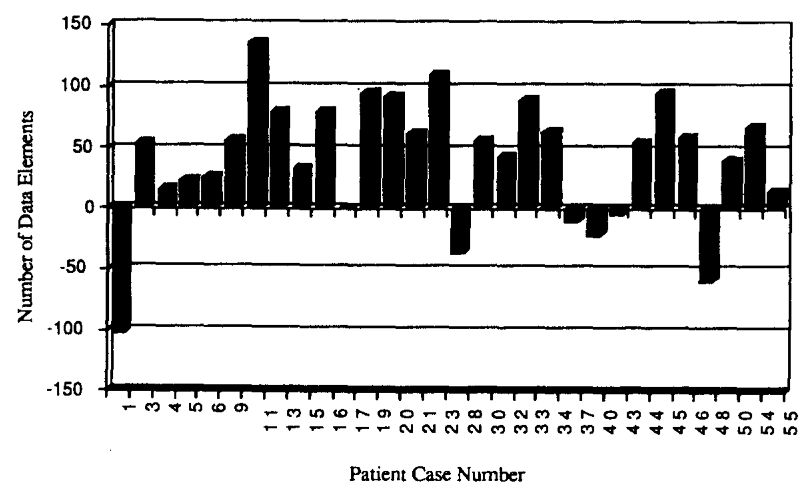

FIG. 1. Type II test case subtract Type I test case in Category I for all 30 patient cases.

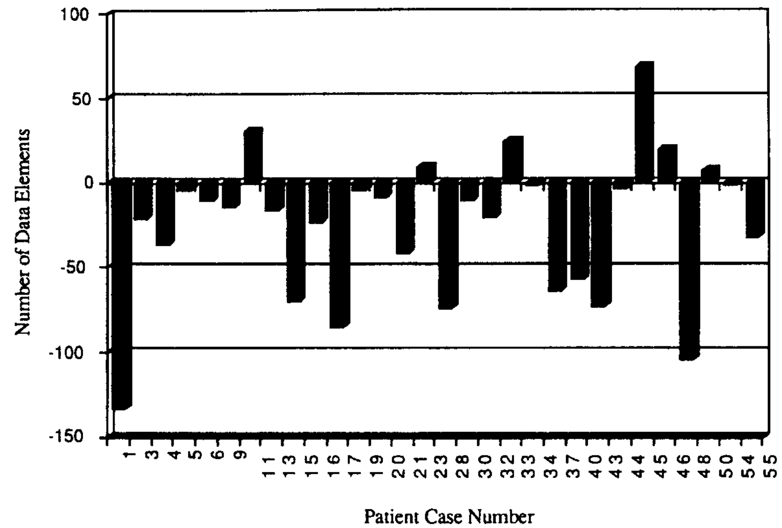

FIG. 2. Type II test case subtract Type I test case in Category II for all 30 patient cases.

The paired-*t* test was used to compare the means of Type I test cases and Type II test cases in the two categories. The differences in Category I and Category II were statistically significant ($P = 0.002$, $P = 0.0056$, respectively).

DISCUSSION

This research investigated two hypotheses: (i) intervocabulary mapping between Iliad and HELP would enable Iliad to obtain patient data from HELP, and (ii) with HELP clinical data, Iliad reduced the manual data entry requirements. The results reported here support these hypotheses. About 4% of Iliad terms have been mapped to HELP terms and MLMs. When Iliad obtained a portion of the required patient-specific data from the HELP clinical patient database, it requested 26% fewer additional data to conclude patients' principle discharge diagnoses. Consequently, as Iliad gains access to HELP's comprehensive clinical database, physicians may more readily use this diagnostic tool since it will require them to enter fewer data.

Significance of This Research

No single computerized medical system is capable of supporting the entire spectrum of medical knowledge. Consequently, hospitals or medical institutions commonly acquire different computer systems from different vendors to meet their information needs. Since information exchange among different computer systems can be difficult, this practice has created "islands of information" within institutions. For the past few years, both academic researchers and commercial vendors have advocated the "open architecture" concept (*25, 26*). The ultimate objective of an open architecture system is to facilitate the integration of diverse computer systems to allow information exchange among these systems. This research was a preliminary effort to explore the problems and issues involved in implementing an open architecture system.

In addition, medical decision-support systems rely heavily on patient data to aid clinicians. Currently, none of the existing hospital/clinical information systems can capture all types of clinical data in usable formats. Expert systems such as Iliad can be used as clinical data acquisition tools to augment the clinical patient database of the HELP system. In addition to generating differential diagnoses, Iliad captures patient data entered by users, such as history and physical examination findings. These patient data can be transferred from Iliad to HELP for use by clinical applications, such as generating discharge summaries.

Limitation and Future Work

As mentioned above, the way of transferring clinical data from HELP to Iliad in this study was not efficient. The future version of interface would provide Iliad with the capability of retrieving data directly from HELP as needed through a standard data exchange protocol such as the Health Level 7 (HL7) during the process of making diagnosis. Physicians will need to enter data into Iliad only if the required data are not available from HELP. Such approach will eliminate unwanted data and minimize the noise phenomenon. As a result, the number of data entered by physicians may be further reduced.

The intervocabulary mapping between Iliad and HELP was also a major determinant of the success of this study. However, various constraints and limited resources allowed only 4% of the Iliad terms to be mapped. In theory, the more synonyms of Iliad terms existing in the PTXT and the more MLMs created to map Iliad with PTXT, the more HELP clinical data will be transferable to Iliad. Thus, fewer additional patient data will required manual entry into Iliad for a consultation.

The bottleneck of information exchange among diverse medical computerized clinical systems is the mapping of the disparate clinical vocabularies that reside in these systems. The medical community is not optimistic about the feasibility of having a single medical vocabulary. Despite the gradual progress of the Unified Medical Language System project, the problem of intervocabulary mapping is likely to remain unsolved in the near future. Based on the experience in this research, intervocabulary mapping mainly involves two issues. These are the feasibility of mapping all the terms in one vocabulary to another vocabulary, or vice versa, and the mapping technique. One approach that simultaneously addresses both issues is developing standard clinical data models, such as the Event Definitions structure suggested by Huff (*27*). Although further research is necessary, the Event Definitions structure has demonstrated its potential in Fu's work (*28*) as a standard clinical data model that will enable clinicians to describe clinical findings in a concise and more organized fashion. With standard Event Definitions, automatic mapping among controlled vocabularies will become feasible.

The intervocabulary mapping between Iliad and HELP also suggests that the clinical data elements in a standard clinical data model should be atomic whenever possible. In essence, the granularity of the standard clinical data model should be as fine as possible. For instance, it is clear from this study that the atomic nature of the PTXT terms allowed MLMs to be created by assembling PTXT terms and decision logic to represent complex Iliad terms.

Conclusions

This retrospective study revealed a statistically significant decrease in manual data entry requirements when HELP data were provided at the beginning of Iliad diagnostic workups. Hence, it may be feasible to interface stand-alone diagnostic expert systems with a hospital information system to minimize the manual data entry requirement of the expert systems.

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References

1. Covell, D. G., Uman, G. C., and Manning, P. R. Information needs in office practice: Are they being met? *Ann. Inter. Med.* **103,** 596 (1986).
2. Mercer, J., and Talbot, I. C. Clinical Diagnosis: A post-mortem assessment of accuracy in the 1980s. *Postgrad. Med. J.* **61,** 713 (1985).
3. Anderson, R. A., Hill, R. B., and Key, C. R. The sensitivity and specificity of clinical diagnostics during five decades. *JAMA* **261,** 1610 (1989).
4. Weinberg, N. S. The relation of medical problem solving and therapeutic errors to disease categories. *QRB* **15,** 266 (1989).
5. Williamson, J. W., Fehlauer, C. S., Griennie, J., and Smith, C. B. Assessing quality of ambulatory care. *Quality Assurance Utilization Rev.* **6,** 8 (1990).
6. Kassirer, J. P., and Kopelman, R. I. Cognitive error in diagnosis instantiation, classification, and consequences. *Am. J. Med.* **86,** 433 (1989).
7. Pelberg, A. L. Missed myocardial infarction in the emergency room. *Quality Assurance Utilization Rev.* **4,** 39 (1989).
8. Bankowitz, R. A., McNeil, M. A., Challinor, S. M., Parker, R. C., Kapoor, W. N., and Miller, R. A. A computer-assisted medical diagnostic consultation service: Implementation and prospective evaluation of a prototype. *Ann. Intern. Med.* **110,** 824 (1989).
9. Barnett, G. O., Cimino, J. J., Hupp, J. A., and Hoffer, E. P. DXplain: An evolving diagnostic decision-supported system. *JAMA* **258,** 67 (1987).
10. Adams, I. D., Chan, M., Cooke, W. M., *et al.* Computer-aided diagnosis of acute abdominal pain: A multicentre study. *Br. Med. J.* **293,** 800 (1986).
11. Lau, L. M., and Warner, H. R. Performance of a diagnostic system (Iliad) as a tool for quality assurance. *In* "Proceedings of Fifteenth Annual Symposium on Computer Application in Medical Care," pp. 104–108. IEEE, Los Angles, 1991.
12. Heathfield, H. A., and Wyatt, J. Philosophies for the design and development of clinical decision-support systems. *Methods Inf. Med.* **32,** 1 (1993).
13. Shiffman, S., Wu, A. W., Poon, A. D., Lane, C. D., Middleton, B., Miller, R. A., Masarie, F. E., Jr., Cooper, G. F., Shortliffe, E. H., and Fagan, L. M. Building a speech interface to a medical diagnostic system. *IEEE Expert* **6**(2), 41 (1991).

14. BERGERON, B. Iliad: A diagnostic consultant and patient simulator. *MD Computing* **8**(1), 46 (1991).
15. PERRY, S. Technology assessment reports. *Int. J. Technol. Assess. Health Care* **2,** 235 (1991).
16. SHORTLIFFE, E. H. Clinical decision-support systems. *In* "Medical Informatics: Computer Applications in Health Care," pp. 466–502. Addison–Wesley, New York, 1990.
17. WARNER, H. R., HAUG, P. J., BOUHADDOU, O., LINCOLN, M., WARNER, H., JR., SORENSON, D., WILLIAMSON, J. W., AND FAN, F. Iliad as an expert consultant to teach differential diagnosis, *In* "Proceedings of Twelfth Annual Symposium on Computer Application in Medical Care," pp. 371–376. IEEE, New York, 1988.
18. PRYOR, T. A., GARDNER, R. M., CLAYTON, P. D., AND WARNER, H. R. The HELP system. *J. Med. Syst.* **7,** 22 (1983).
19. KUPERMAN, G. J., GARDNER, R. M., AND PRYOR, T. A. "HELP: A Dynamic Hospital Information System." Springer-Verlag, New York, 1991.
20. SHERERTZ, D. D., TUTTLE, M. S., OLSON, N. W., ERLBAUM, M. S., AND NELSON, S. J. Lexical mapping in the UMLS Metathesaurus. *In* "Proceedings of Thirteenth Annual Symposium on Computer Application in Medical Care," pp. 494–499. IEEE, Los Angeles, 1989.
21. CIMINO, J. J., AND BARNETT, G. O. Automated translation between medical terminologies using semantic definitions. *In* "Proceedings of the AAMSI Congress," pp. 113–117. AAMSI, Washington, DC, 1989.
22. MASARIE, F. E., JR., MILLER, R. A., BOUHADDOU, O., GIUSE, N. B., AND WARNER, H. R. An interlingua for electronic interchange of medical information: Using frames to map between clinical vocabularies. *Comput. Biomed. Res.* **24,** 379 (1991).
23. PRYOR, T. A., CLAYTON, P. D., HAUG, P. J., AND WIGERTZ, O. Design of a knowledge driven HIS. *In* "Proceedings of Eleventh Annual Symposium on Computer Application in Medical Care," pp. 60–63. IEEE, Los Angeles, 1987.
24. PRYOR, T. A., DUPONT, R., AND CLAY, J. A. MLM based order entry system: The use of knowledge in a traditional HIS application. *In* "Proceedings of Fourteenth Annual Symposium on Computer Application in Medical Care," pp. 579–583. IEEE, Los Angeles, 1990.
25. CLAYTON, P. D., SIDELI, R. V., AND SENGUPTA, S. Open architecture and integrated information at Columbia–Presbyterian Medical Center. *MD Comput.* **9**(5), 297 (1992).
26. JACOBSEN, T. J. Integrating patient-focused information systems in an open-architecture environment. *Comput. Healthcare,* **10,** 38 (1991).
27. HUFF, S. M., CRAIG, R. B., GOULD, B. L., CASTAGNO, D. L., AND SMILA, R. E. Medical data dictionary for decision-support applications. *In* "Proceedings of Eleventh Annual Symposium on Computer Application in Medical Care," pp. 310–317. IEEE, Los Angeles, 1987.
28. FU, L. S. A Public Domain Unified Medical Language System (UMLS) Patient Database. Ph.D. dissertation, Medical Informatics Department, University of Utah, 1992.