AJH 1990; 3:156-163

Computer-assisted Techniques for Evaluation and Treatment of Hypertensive Patients

Patrice Degoulet, Gilles Chatellier, Claude Devriès, Marion Lavril, and Joël Ménard

An integrated approach, progressively implemented in the ARTEMIS system since 1975, is described for the computerized management of hypertensive patients. From a medical point of view, computerized programs can be used to memorize patients' individual records and profiles, to facilitate patient management and follow-up, to store medical knowledge about hypertension and to provide facilities for decision making at the level either of the individual patient or of the population followed up. From a technical point of view, the methodology used integrates data and knowledge management facilities into the same software.

Five hypertension clinics are presently using the system in France and more than 22,000 records have been registered. Answer rates to 12 mandatory questions regarding past history and examination at first visit were superior to 95% in 19,601 records created between January 1976 and December 1987. Patient database interrogation can be used to evaluate the sensitivity and specificity of various signs and symptoms for the diagnosis of secondary hypertension, and to predict, for each patient, his/her cardiovascular risk, the risk of drop-out, the risk of insufficient blood pressure control and the probable blood pressure level. It also serves to test the content and validity of the associated expert system which is progressively built up. A prospective evaluation of the performance of the expert system on 80 cases of hypertension showed overall agreement between the specialists and the expert system ranging from 58 to 91% depending on the decision. The results suggest that a strategy combining data and knowledge management might help the physician to supplement theoretical knowledge derived from the academic environment, and in some cases to replace it by a more pragmatic knowledge derived from his experience stored in the computer. Am J Hypertens 1990;3:156-163

KEY WORDS: **Computers, computerized medical records, artificial intelligence, computer-assisted decision making, expert systems, hypertension.**

Hypertension management is characterized by the large number of patients concerned, the numerous items to be recorded for each patient and the unlimited length of the follow-up. In this domain, as in many other chronic diseases like coronary heart disease, diabetes or asthma, computer techniques proved useful.[1,2] The computer can be used as a tool for patient care, clinical research, education or for various managerial purposes. Although the initial programs developed in the early seventies were clearly focused on a strictly limited number of objectives,[3-5] recent experience has shown the advantage of a more integrated approach.[6-8] In this paper we describe the overall application of ARTEMIS with special emphasis on the integration of data and knowledge management facilities.

From the Medical Informatics Department, Broussais University Hospital, Paris, France (PD, CD, ML), and Hypertension Clinic, Broussais Hospital, Paris, France (GC, JM).

Address correspondence and requests for reprints to Professor Patrice Degoulet, Medical Informatics Department, Broussais University Hospital, 96, rue Didot, 75014 Paris, France.

0895-7061/90/$3.50

MATERIALS AND METHODS

ARTEMIS Development ARTEMIS is the generic name given in 1975 to a computerized system for the medical management and follow-up of hypertensive patients.[9,10] The first version, operational on a Digital Equipment Corp. PDP10 mainframe computer, was implemented in September 1975 in the hypertension clinic of the Saint-Joseph Hospital, a nonprofit private hospital in Paris, and extended in 1979 to the Broussais Hypertension Clinic, a public university teaching hospital, also located in Paris. In October 1983, the ARTEMIS system was transferred from the mainframe computer to a minicomputer (Digital Equipment Corp. VAX) which was located in the Broussais hypertension clinic and used the LIED temporal database management system (DBMS).[11] Between 1985 and 1988 ARTEMIS was also implemented in three nephrology departments in the general hospitals of Charleville-Mézières, Colmar and Macon.[12]

Together with the development of the clinical database, it was decided in 1983 to develop an expert system (ES) on hypertension with its knowledge base, using the SAM expert system development tool.[13,14] The operational version of the ES was progressively integrated into the LIED DBMS.[8,14]

Finally a simplified version of ARTEMIS was progressively designed from 1987 for use by general practitioners (GP) through the French videotex telecommunication network. This version, called ARTEL (the acronym for ARTEMIS MINITEL), is in the process of evaluation by a group of voluntary GPs.[15]

The ARTEMIS Database The ARTEMIS patient database contains 530 different items which can be completed during the patients' visits to each hypertension or nephrololgy department for either inpatient or outpatient care. Information recorded includes items concerning their past medical history, initial check-up, inpatient and outpatient visits, main investigations performed, search for drug contraindications, and the complete history of drug prescriptions and side-effects. Historical information (clinical or biological) is permanently kept in the patient's record. Unlimited free text can be added to any item, whatever its data type (numeric, date or string) and therefore complete standardized and structured input.

Data are interactively entered by the end users (ie, physicians, nurses and secretaries) via video terminals (roughly one video terminal per outpatient consultation office, one per 10 beds of inpatient care, one per head nurse and one per secretary). Depending on the clinical condition of the patient, different updating or interrogation views are proposed to the end user. Each user (or group of users) is able to define his/her own set of views. During database updating, questions proposed by the computer depend on previous information already entered and/or stored. Depending on the physicians' training with the terminal, free text notes are either entered directly or dictated for secondary entry. Help screens concerning protocols and procedures are available on-line. Physicians have the ability to enter default values for the most current medical prescriptions.

Except for the observations made by medical students during periods of hospitalization, the traditional handwritten medical record has been completely suppressed and replaced by the various computer reports and/or displays.

Since ARTEMIS was implemented in 1975, more than 22,000 computerized patient records have been created and updated by the five hypertension clinics which presently use the system. They contain summaries of more than 70,000 outpatient and 20,000 inpatient visits.

The ARTEMIS Knowledge Base and the Expert System The ARTEMIS knowledge base includes both static and dynamic forms of knowledge. Static knowledge is represented in a semantic network in which the various medical concepts (eg, simple facts, such as symptoms or biological results, syndromes, diagnoses, investigations and therapies) are connected by links such as IS-A, BELONGS-TO, DEPENDS-ON, IS-RESULT-OF or ARE-EXCLUSIVE.[13]

The dynamic reasoning of the expert is expressed by means of production rules. The rule is activated if the conditional part is true or if it has a sufficient degree of certainty. The action part of a production rule either adds new elements to the factual database or modifies the degree of certainty or an existing element. Certainty factors, similar to the MYCIN ones,[16] can be linked to production rules. A more extensive description of the knowledge representation model is given in.[13,14] The present version of the ARTEMIS knowledge base (June 1988) includes more than 800 semantic and production rules.

Data and Knowledge Processing Data are processed by the LIED DBMS, which is based on a semantic and temporal data model described in.[11] The LIED data manipulation language is used to provide intelligent data entry (eg, constraint checking and context-dependent branching in questionnaires) and to produce different reports to be kept in the patient record, sent to the referring practitioner or given to the patient. A plain text report, combining data entered in standardized format and in free text, is produced at the end of each visit for inpatient or outpatient care. Automatic alarms (eg, biological values out of limits or drug dosage in excess) and different tabular reports (eg, flow charts of main clinical and biological results) and/or cumulative reports (eg, summary of main drug contra-indications and side-effects) are provided on-line to facilitate the physician decision process and adherence to protocols.

To encourage patients' participation and compliance, duplicates of the records are given to the patients and personalized recall letters are automatically mailed before long-term appointments.[10]

Knowledge management and inferences are provided by the SAM essential expert system described in.[13,14] The inference engine uses both forward and backward chaining. It also handles two kinds of logic which make it possible to conduct two parallel modes of reasoning: a conventional propositional logic and an approximate reasoning, whereby accumulation of evidence for or against a decision permits final conclusions to be reached. For each ES decision, a Global Certainty Factor (GCF), continuously varying from 0 (false or not indicated) to 1 (true or indicated) is produced by the ES. The database and knowledge base management parts of ARTEMIS are connected through a working memory acting as the "short term memory" of the brain and allowing bidirectional exchanges between the ES and DBMS.[17]

Statistical Analyses Several means are compared by the F test. To compare percentages, χ^2 and χ^2 for trends were calculated.[18] Observed agreements and κ values were calculated to compare proposals made by the experts and the expert system.[19]

RESULTS

Quality of the Computerized Medical Record The quality of the medical records was evaluated in 19,601 patient records selected on the following criteria: (1) Patients referred for the first time to the Broussais or Saint-Joseph clinic between January 1, 1976 and December 31, 1987; (2) Age of at least 13 years; (3) At least one past or present blood pressure value above 140 mm Hg for systolic pressure or 90 mm Hg for diastolic pressure. Answer rates to 12 mandatory questions regarding past history and examination at first visit were calculated for the three four-year periods that started in 1976, 1980 and 1984 (Table 1). They all exceeded 90% over the three periods. The best answer rates (mean $\pm$ SD = 99.1 $\pm$ 0.8) were observed in the last period corresponding to the dissemination of terminals all over the clinic and to increasing direct data entry on terminals by the end-users.

Initial Patients' Characteristics Characteristics of the patients at their initial visit were analyzed in the group of 19,601 records defined above. Mean age of patients was 47.6 years at first visit and 50.6% were men (Table 2). Significant trends were observed in the referral modality (Table 3). A decreasing percentage of patients where referred by general practitioners, and increasing percentages were referred by specialists or other hospital departments, or came of their own volition.

Patients examined during the period 1984 to 1987 tended to have more severe hypertension than those seen between 1976 and 1979. This was evidenced by the higher blood pressure values and the larger percentage of patients under anti-hypertensive drugs. The percentage of tobacco smokers and alcohol drinkers at first visit tended to decrease significantly by contrast with the increasing percentage of exsmokers. Significant trends were observed among antihypertensive drugs taken by patient under treatment at the first visit including a steep increase in the percentage of patients under converting enzyme inhibitors and calcium blockers and a progressive decline of other categories of drugs (Table 4).

TABLE 1. ANSWER RATES CALCULATED FROM 19601 INITIAL VISITS OF PATIENTS REFERRED TO THE BROUSSAIS AND SAINT-JOSEPH HYPERTENSION CLINICS BETWEEN 1976 AND 1987

Period	1976-1979 n = 5185	1980-1983 n = 7118	1984-1987 n = 7298	Total n = 19601
Administrative				
Birthdate	5174 (99.8)	7026 (98.7)	7252 (99.6)	19452 (99.2)
Mode of referral	4975 (96.0)	6224 (93.1)	7087 (97.1)	18686 (95.3)
Past history				
Known maximum blood pressure	4739 (91.4)	6007 (88.4)	7155 (98.0)	17901 (91.3)
Previous smoking habits	4728 (91.2)	6024 (84.6)	7240 (99.2)	17992 (91.8)
History of coronary heart disease	4802 (92.6)	6086 (85.5)	7244 (99.3)	18132 (92.5)
History of heart failure	4802 (92.6)	6037 (84.8)	7246 (99.3)	18085 (92.3)
Examination at first visit				
Antihypertensive treatment	5022 (96.9)	6742 (94.7)	7276 (99.7)	19040 (97.1)
Body weight	5048 (97.4)	6734 (94.6)	7255 (99.4)	19037 (97.1)
Tobacco consumption	5144 (99.2)	7084 (99.5)	7291 (99.9)	19519 (99.6)
Alcohol consumption	-	6888 (96.8)	7277 (99.7)	-
Coronary heart disease at first visit	5115 (98.7)	7056 (99.1)	7235 (99.1)	19406 (99.0)
Heart failure at first visit	5107 (98.5)	7046 (99.0)	7244 (99.3)	19397 (99.0)
Mean answer-rate $\pm$ SD	95.8 $\pm$ 3.3	93.2 $\pm$ 5.9	99.1 $\pm$ 0.8	95.8 $\pm$ 3.3

TABLE 2. INITIAL CHARACTERISTICS OF 19601 PATIENTS REFERRED TO THE BROUSSAIS AND SAINT-JOSEPH HYPERTENSION CLINICS BETWEEN 1976 AND 1987

No. of patients	1976-1979 5185	1980-1983 7118	1984-1987 7298	Total 19601	P*
Administrative					
No. (%) of men	2753 (53.1)	3481 (48.9)	3686 (50.5)	9920 (50.6)	<.001/<.02
Mean (SD) age (years)	47.6 (15.4)	46.4 (15.7)	49.2 (15.6)	47.8 (15.6)	<.001
Patient history					
Mean (SD) maximum SBP (mm Hg)	207.7 (34.3)	203.1 (34.0)	203.1 (32.3)	204.3 (33.5)	<.001
No. (%) of smokers	2248 (44.2)	2681 (44.3)	3475 (48.4)	8240 (45.8)	<.001/<.001
No. (%) with history of					
stroke	301 (5.8)	318 (4.5)	420 (5.8)	1039 (5.3)	<.001/NS
coronary heart disease	298 (5.7)	292 (4.1)	340 (4.7)	930 (4.7)	<.001/<.02
heart failure	175 (3.4)	158 (2.2)	210 (2.9)	543 (2.8)	<.001/NS
Examination at first visit					
No. (%) under antihypertensive treatment	1763 (34.7)	3162 (44.4)	4118 (56.4)	9043 (46.1)	<.001/<.001
Mean (SD) systolic blood pressure (mm Hg)	163.5 (28.1)	163.7 (28.4)	166.6 (28.3)	164.7 (28.3)	<.001
Mean (SD) diastolic blood pressure (mm Hg)	95.5 (16.4)	96.1 (16.2)	98.1 (15.3)	96.7 (16.0)	<.001
Mean (SD) body-mass index (kg/m^2)	25.2 (4.5)	25.3 (4.9)	25.3 (4.5)	25.3 (4.7)	NS
No. (%) of smokers	1461 (28.7)	1764 (24.8)	1648 (22.6)	4873 (24.9)	<.001/<.001
Mean (SD) cigarettes/day in smokers	15.3 (11.2)	14.8 (11.2)	14.5 (10.7)	14.8 (11.2)	NS
No. (%) alcohol drinkers (≥1 glass/day)†	754 (48.7)	3106 (43.6)	3151 (43.2)	7011 (43.9)	<.001/<.01
Mean (SD) glasses/day in drinkers†	3.67 (2.83)	3.36 (2.68)	3.02 (2.37)	3.24 (2.57)	<.001
Mean (SD) serum cratinine (μmol/L)	97.5 (74.4)	93.7 (53.1)	93.5 (37.4)	94.7 (55.0)	<.001
Mean (SD) serum potassium (mmol/L)	3.96 (0.45)	3.97 (0.43)	3.96 (0.42)	3.97 (0.43)	NS

*F test for quantitive value and χ^2 (and χ^2 for trends) for qualitative values.

†Information was available in 1550 patients in the period 1976-1979.

Evaluation of the Performance of the Expert System The diagnostic performance of the ES was retrospectively evaluated on 100 cases of hypertension taken from the ARTEMIS patient database[8] including fifty of secondary hypertension (SH) (20 of renal artery stenosis, 20 of primary aldosteronism and 10 of pheochromocytoma) and 50 cases of essential hypertension (EH). The items recorded during the first visit to the clinic (history and clinical examination), and the levels of glycemia, serum potassium, creatinine, cholesterol and triglycerides were extracted from the ARTEMIS database to constitute the initial set of facts for the ES comprising 48 to 64 items. Specialized investigations which would have made the diagnosis obvious were excluded. For the 50 SH cases, the initial diagnosis proposed by the ES from 11 different diagnoses, just after the forward chaining step, was correct in 20 cases (40%). The final diagnosis proposed after several steps of forward and backward chaining was correct in 46 cases (92%). An average of 9.2 questions were formulated by the ES to reach the final diagnosis. For the 50 EH cases, the initial diagnosis was correct in 40 cases (80%). After asking an average of 5 questions, the ES reached the right final diagnosis in 44 cases (88%). For the whole group of 100 hypertension cases, the final diagnosis was correct in 90.

A prospective evaluation of the performance of the ES was undertaken in 80 additional cases of hypertension consecutively referred to the Broussais hypertension clinic. All the 80 patients studied had been referred for the first time, and had been admitted without previous

TABLE 3. INITIAL CHARACTERISTICS OF 18,686 PATIENTS REFERRED TO THE BROUSSAIS AND SAINT-JOSEPH HYPERTENSION CLINICS BETWEEN 1976 AND 1987

	1976-1979	1980-1983	1984-1987	Total
No. (%) referred by				
general practitioner	3273 (65.8)	4416 (66.7)	3406 (48.1)	11095 (59.4)
other hospital departments	377 (7.6)	843 (12.7)	1285 (18.1)	2505 (13.4)
specialists	400 (8.0)	603 (9.1)	938 (13.2)	1941 (10.4)
worksite physicians	532 (10.7)	456 (6.9)	699 (9.9)	1687 (9.0)
spontaneous visit	280 (5.6)	212 (3.2)	699 (9.9)	1191 (6.4)
other modalities	113 (2.3)	94 (1.4)	60 (0.8)	267 (1.4)
Total	4975 (100.0)	6624 (100.0)	7087 (100.0)	18686 (100.0)

TABLE 4. ANTIHYPERTENSIVE DRUGS AT FIRST VISIT IN 9041 PATIENTS (1976 TO 1987)

Period	1976-1979 n = 1764	1980-1983 n = 3162	1984-1987 n = 4115	Total n = 9041
No. (%) under diuretics	1025 (58.1)	1666 (52.7)	1950 (47.4)	4641 (51.3)
No. (%) under beta-blockers	751 (42.6)	1844 (58.3)	2032 (49.4)	4627 (51.2)
No. (%) under central-acting drugs	720 (40.8)	1066 (33.7)	942 (22.9)	2728 (30.2)
No. (%) under converting enzyme inhibitors	0 (0.0)	63 (2.0)	1119 (27.2)	1182 (13.1)
No. (%) under vasodilators	208 (11.8)	496 (15.7)	346 (8.4)	1050 (11.6)
No. (%) under calcium blockers	0 (0.0)	47 (1.5)	485 (11.8)	532 (5.9)

diagnosis which would have made the conclusion obvious. In addition to the ARTEMIS standardized questionnaires, a specific form was completed by one of the four hypertension specialists who participated in the study at the end of their consultation. The possible answers requested from the specialist were "suspected" or "not suspected" for the four main diagnoses considered and "indicated" or "not indicated" for the 7 main investigations. The diagnoses and investigations proposed by the specialists and the ES were compared and the overall percentage of observed agreement (OA) and κ coefficients calculated. Since the global certainty factor (GCF) produced by the ES continuously varies from 0 (rejected) to 1 (certain), an arbitrary threshold of 0.60 was selected by the specialists before the evaluation. For the diagnosis suggestions, agreement was achieved in 65% to 91% of cases with κ values ranging from 0.18 to 0.43 (Table 5). As regards the investigations proposed, agreement was achieved in 58% to 89% of cases with κ values ranging from 0.17 to 0.57. A rapid decrease was observed for GCF thresholds below or above 0.60. However, for certain suggested diagnoses and investigations, it was observed that changing the threshold was beneficial, and that the ES's performance could be optimized. The criteria to be maximalized was the κ value. The results of this optimization, carried out on the same 80 records, are given in Table 5. In every case, significant improvement was achieved. However, it will be necessary to test the robustness of these results on a larger set of independent cases extracted from the patient database.

TABLE 5. PROSPECTIVE EVALUATION OF THE ES IN 80 HYPERTENSION CASES

	GCF§ = 0.60		Optimisation	
	OA*	κ	OA*	κ
Diagnoses				
Essential hypertension	0.65	0.24	0.76	0.31
Renal artery stenosis	0.80	0.43	0.86	0.51
Primary aldosteronism	0.91	0.18	0.92	0.36
Phaeochromocytoma	0.91	0.32	0.94	0.41
Investigations				
Urine electrolytes	0.66	0.10	0.75	0.46
Urine cytobacteriology	0.72	0.40	0.76	0.44
Renin and aldosterone levels	0.60	0.14	0.71	0.24
Urinary metanephrines	0.58	0.19	0.58	0.19
Echocardiography	0.89	0.35	0.90	0.54
Intravenous pyelography	0.74	0.38	0.77	0.49
Renal angiography	0.80	0.57	0.80	0.57

GCF§ = Global certainty factor.

**OA = Observed agreement between the specialist and the expert system.*

DISCUSSION

Since the ARTEMIS system was implemented in 1975, it has undergone many technical and organizational changes. Starting from a record management program in batch mode on a mainframe computer, ARTEMIS has, like many similar products, progressively evolved to a decentralized fully interactive system, implemented on a dedicated minicomputer. Knowledge management capabilities have been progressively added to more traditional data management capabilities. However, data entry still constitutes one of the factors limiting the acceptability of such systems by the end users. Although it is true that most physicians agree to interact directly with ARTEMIS when entering information concerning follow-up visits in the presence of the patient, or hospital inpatient check-ups and summaries, one must admit that for the first visit of a newly referred patient, most physicians still prefer to complete a standardized input form for subsequent entry by secretaries. In ARTEMIS, as it was previously observed with self-administered questionnaires,[20] branching techniques have been found to reduce the effort devoted to data entry drastically. Online checking of constraints and online helps improve medical record consistency and database integrity. In any case, the physical appearance of present terminals (ie, 24 lines by 80 columns) and keyboards will remain a limitation until affordable technology which permits the combination of various inputs and outputs, including pointing devices (eg, mouse and light-pen), images, graphics, texts and voice (eg, voice synthesis and voice recognition), are available.[21,22]

Electronic record quality assessments performed just after the implementation of a computerized system have shown high response rates in questionnaires completed by physicians.[3,9] Present results confirm that a high standard quality was maintained over the twelve years from 1976 to 1987. Immediate alarms prevent the end user from forgetting important elements during data entry. However standardization of input procedures does not completely suppress inter- and intraphysician variability.[9] In addition, the high response rates we observed only apply to the subset of questions selected from the ARTEMIS system, and the reliability and subject matter of free text that physicians and nurses can add to standardized questionnaires should be compared to the quality of paper medical notes.

Medical decisions are based on three kinds of information and knowledge: (1) specific information on the patient; (2) general or academic knowledge which can be derived from textbooks and periodicals; and (3) knowledge based on the physician's personal experience. Patient specific information is mainly contained in or derived from the medical records. Experiences of the two last decades have shown that computer-stored medical records can solve many of the problems of availability, retrievability, legibility and organization of the paper medical record. Access to the electronic record is immediate and several users can share the same record. Physicians and/or the patients can access the medical records at home or at areas remote from their working environment.[22,23] Information, when stored in an appropriate format, can be displayed or retrieved in many different ways according to the physician's needs (eg, flow-sheets, graphical displays, time-oriented or problem-oriented record summaries).[24,25] Well-designed computerized summaries can provide more information than the standard medical record and improve the clinical decision process.[26] In the ARTEMIS system the multiplication of views of the same database and the adaptation of views to the physician's environment were found useful in enhancing flexibility and physician appropriation of the software. It could however in the long run lead to nonconvergent use of the system with the secondary effect of increasing interphysician variability.

A large number of simple decisions can be made easily thanks to the data manipulation language of a database management system or to the deductive capabilities of an expert system. This data-driven approach has been extensively used in ARTEMIS as in other data management systems for hypertensive patients.[27–31] Examples of such decisions reached during the management of individual cases are the conversational checking of constraints (eg, the verification of the range of quantitative values), the continuous recording of drug intolerance history and the provision of adequate alarms (eg, drug allergy or contraindication), the automatic indication of simple follow-up tests[27] and the automatic dispatching of recall letters.[10,30] Online helps and reminders enhance physicians' adherence to protocols and directly participate to a high quality standard of care.[32,33] More complex protocols can be implemented for the calculation of the optimal dosage of a prescribed drug[4] or, in privileged situations, for the direct control of medication administration such as the rate of nitroprusside perfusion in malignant hypertension.[34] These applications, whose impact on the quality of care has been confirmed,[3,30,31] should be pursued in the coming years.

Approaches integrating data and knowledge management facilities, such as the one used in ARTEMIS, CADIAG,[35] CARE[32] or HELP[33] might enhance end user acceptability and overall system performance. Each item of information only needs to be entered once during the follow-up of a patient and suggestions by the computer are byproducts of monitoring or data-management facilities.[36–38] Intelligent data and knowledge driven questionnaires can facilitate the entry of patient history or examination.[37] Extensive interrogation of the database might help to build and/or test medical knowledge contained in the knowledge base.[7,38] In addition, results obtained from the expert system can be recorded in the database and compared subsequently with the decisions taken by experts as in the retrospective evaluation of the ARTEMIS expert system described above. The specificity and sensitivity of each symptom and investigation can be calculated as regards diagnostic, therapeutic or prognostic decisions, as it was done in ARTEMIS for the diagnosis of phaeochromocytoma[39] and integrated in the rules of the expert system. Multivariate statistical methods can be used for the calculation of various risk indices such as coronary risk, risk of poor compliance or risk of insufficient blood pressure control.[40,41] Predictions made from these statistical models can be more accurate than predictions of experienced clinician made from detail case summaries.[42] They might help the physician to focus his attention to the high risk patients[40] and should be included in the knowledge base. In systems which include production rules, like ARTEMIS, certainly factors are initially provided by expert physicians on the basis of their academic knowledge or of the subjective recollection of previous cases. They can be refined by statistical evaluation, based on the real cases recorded in the database.[43] It seems also feasible, as in our prospective evaluation of the ES, to optimize the thresholds used by the ES to propose a decision from the cases contained in the database.

However, several barriers must be recognized before more widespread use of integrated expert database systems can be proposed. The order in which investigations are suggested by an expert system should be compared to the attitudes of various specialists, as in the critiquing approach developed by Miller and Black with ATTENDING.[44,45] The knowledge base of the ES needs to be validated in different medical environments, where the ES might be even more useful than in the present specialized hypertension clinic (eg, in general practice for which the simplified ARTEL system was designed).[15] Explanations provided by the ARTEMIS expert system, as many other ES, are still rudimentary and considerable efforts are needed to allow the physician to determine if computer suggestions are valid or not.[36,46] Finally, although the ARTEMIS patient database is used to evaluate and optimize the performances of the ES, the ES itself does not fully profit from all the information which is presently stored in the database. Only in this way can the theoretical knowledge derived from the academic environment be gradually replaced by the pragmatic knowledge which can be derived from the experience stored in electronic medical records.

ACKNOWLEDGMENTS

The development of LIED is supported by Assistance Publique de Paris. Developments of ARTEMIS and SAM were supported by Ministère de la Santé, Agence de l'Informatique, INSERM and CNAMTS.

REFERENCES

1. Pryor DB, Califf RM, Harrel FE, et al: Clinical data bases. Accomplishments and unrealized potential. Med Care 1985;23:623-647.
2. McDonald CJ, Tierney WM: Computer-stored medical records. Their future role in medical practice. JAMA 1988;259:3433-3440.
3. Bulpitt CJ, Beilin LJ, Coles EC, et al: Randomised controlled trial of computer-held medical records in hypertensive patients. Br Med J 1976;1:677-679.
4. Coe FL, Norton E, Oparil S, et al: Treatment of hypertension by computer and physician—a prospective controlled study. J Chron Dis 1977;30:81-92.
5. Goupy F, Hirel JC, Bloch P, Berger C: CHRONOS: a data bank for physicians and searchers. Comp Prog Biomed 1976;6:149-165.
6. Pryor TA, Clayton PD, Haug PJ, Wigertz O: Design of a knowledge driven HIS, *in* Proc. 11th Annual Symposium on Computer Applications in Medical Care, Washington, DC. 1987; pp 60-63.
7. Degoulet P, Devriès C, Sauquet D: Data and knowledge management integration in hospital information systems, *in* Bakker AR, Ball MJ, Scherrer JR, Willems JL (eds): Towards New Hospital Information Systems. Amsterdam: Elsevier North-Holland. 1988, pp 149-156.
8. Devriès C, Degoulet P, Jeunemaître X, et al: Integrating management and expertise in a computerized system for hypertensive patients. Nephrol Dial Transplant 1987;2:327-331.
9. Degoulet P, Ménard J, Berger C, et al: Hypertension management: the computer as a participant. Am J Med 1980;68:559-566.
10. Degoulet P, Vu HA, Chatellier G, et al: Hypertension management: the role of the computer in improving patient compliance. Med Inform 1982;7:49-55.
11. Degoulet P, Devriès C, Rioux P et al: LIED: a temporal data base management system, *in* Salamon R, Blum B, Jorgensen M (eds): MEDINFO 86. Amsterdam: Elsevier North-Holland. 1986, pp 532-536.
12. Marichal JF, Devriès C, Aimé F, et al: Expérience de décentralisation du système "ARTEMIS" dans un service de Néphrologie en Hôpital Général. Arch Mal Coeur Vaiss 1987;80:888-891.
13. Gascuel O: Un système expert pour la réalisation de diagnostics. Techniques et Sciences Informatiques (TSI) 1985;4:359-372.
14. Morice V, Degoulet P, Jeunemaitre X, et al: Hypertension management: connection of an expert system to the ARTEMIS patient database, *in* Objective Decision Making (Lecture Notes in Medical Informatics, Vol. 28). Berlin: Springer-Verlag, 1986, pp 55-61.
15. Lavril M, Chatellier G, Degoulet P, et al: ARTEL: An expert system in hypertension for the general practitioner, *in* Expert Systems and Decision Support in Medicine (Lecture Notes in Medical Informatics). Berlin: Springer Verlag, 1988, pp 314-321.
16. Shortliffe E: Computer Based Medical Consultations: MYCIN. New York: Elsevier, 1976.
17. Sauquet D, Devriès C, Lavril M et al: Data and knowledge management with LIED, *in* Proc. Medical Informatics Europe, MIE 88, Vol. 1. Rome: Edi-Press. 1988, pp 574-579.
18. Armitage P: Statistical Methods in Medical Research. New York: Wiley. 1971, pp 363-365.
19. Fleiss JL: Statistical Methods for Rates and Proportions. New York: Wiley. 1973, pp 143-147.
20. Slack WV, Hicks GP, Reed CE, Van Cura LJ: A computer-based medical-history system. N Engl J Med 1966;272:194-198.
21. Lind M, Pettersson E, Sandblad B, Schneider W: Computer based workstations in health care, *in* Bakker AR, Ball MJ, Scherrer JR, Willems JL (eds): Towards New Hospital Information Systems. Amsterdam: Elsevier North-Holland, 1988 pp 235-242.
22. Smith MB, Burke KE, Tongerson JS, et al: Logical and efficient conversation between patients and the telephone linked computer system, *in* Proc. 11th Annual Symposium on Computer Applications in Medical Care, Washington, DC. 1988, pp 463-467.
23. Darnell JC, Hiner SL, Neill PJ, et al: After-hours telephone access to physicians with access to computerized medical records. Med Care 1985;23:20-26.
24. Hammond WE, Stead WW: The evolution of a computerized medical information system, *in* Proc. 10th Annual Symposium on Computer Applications in Medical Care, Washington, DC. 1986, pp 147-156.
25. McDonald CJ, Blevins L, Glazener T, et al: Data base management, feed back control, and the Regenstrief medical record. J Med Sys 1983;7:11-25.
26. Whiting-O'Keefe QE, Simborg DW, Epstein WV, Warger A: A computerized summary record system can provide more information than the standard medical record. JAMA 1986;254:1185-1192.
27. Evans AR, Wilkes ER, Absolon PJ, et al: An interactive computerised protocol for the management of hypertension. Meth Inf Med 1985;24:21-26.
28. Laurent D, Mashruwala MD, Lucas CP: A computerized data-handling system in hypertension management. Arch Intern Med 1980;140:345-350.

29. Wilson DH: Patient registries, interviewing, scheduling, and management. Ten years of experience using computers in a specialized clinic, *in* Rienhoff O, Abrams ME (eds): The Computer in the Doctor's Office. Amsterdam: Elsevier North-Holland. 1980, pp 205-211.

30. Barnett GO, Winickoff RN, Morgan MM, Zielstorff RD: A computer-based monitoring system for follow-up of elevated blood pressure. Med Care. 1983;21:400-409.

31. McAlister NH, Covvey HD, Tong C, et al: Randomised controlled trial of computer assisted management of hypertension in primary care. Br Med J 1986;293:670-674.

32. McDonald CJ, Hui SL, Smith DM, et al: Reminders to physicians from an introspective computer medical record. Ann Intern Med 1984;100:130-138.

33. Pryor TA, Gardner RM, Clayton PD, Warner HR: The Help system. J Med Systems 1983;7:87-102.

34. Meline LJ, Westenskow DR, Pace ML: Computer controlled regulation of sodium nitroprusside infusion. Anesth Analg 1985;64:38-42.

35. Adlassnig KP, Kolarz G, Scheithauer W, Grabner H: Approach to a hospital-based application of a medical expert system. Med Informatics 1986;11:205-223.

36. Shortliffe EH. Computer programs to support clinical decision making. JAMA 1987;258:61-66.

37. Haug PJ, Warner HR, Clayton PD, et al: A decision-driven system to collect the patient history. Comp Biomed Res 1987;20:193-207.

38. Bouhaddou O, Haug PJ, Warner HR: Use of the Help clinical database to build and test medical knowledge, *in* Proc. 11th Annual Symposium on Computer Applications in Medical Care, Washington, DC. 1987, pp 64-67.

39. Plouin PF, Degoulet P, Tugayé A, et al: Le dépistage du phéochromocytome: chez quels hypertendus? Etude sémiologique ches 2585 hypertendus dont 11 ayant un phéochromocytome. Nouv Press Med 1981;10:869-872.

40. Degoulet P, Ménard J, Vu HA, et al: Factors predictive of attendance at clinic and blood pressure control in hypertensive patients. Br Med J 1983;287:88-93.

41. Pryor DB, Harrell FE, Lee KL, et al: Estimating the likelihood of significant coronary artery disease. Am J Med 1983;75:771-780.

42. Lee KL, Pryor DB, Harrell FE, et al: Predicting outcome in coronary disease. Statistical models versus experts clinicians. Am J Med 1986;80:553-560.

43. Golmard JL, Rodary M: Weight optimization in a rule based expert system: application to the diagnosis of acute abdominal pains, *in* Objective Decision Making (Lecture Notes in Medical Informatics, Vol. 28). Berlin: Springer-Verlag 1986, pp 25-30.

44. Miller PL, Black HR: Medical plan-analysis by computer: critiquing the pharmacologic management of essential hypertension. Comp Biom Res 1984;17:38-54.

45. Miller PL, Blumenfrucht SJ, Black HR: An expert system which critics patient workup: modeling conflicting expertise. Comp Biom Res. 1984;17:554-569.

46. Degoulet P: Artificial intelligence: its use in nephrology. Nephrol Dial Transpl 1987;2:298-303.