SPECIAL ARTICLE

THE TRAINING OF PHYSICIAN'S ASSISTANTS

The Use of a Clinical Algorithm System for Patient Care, Audit of Performance and Education

HAROLD C. SOX, JR., M.D., CAROL H. SOX, M.A., AND RICHARD K. TOMPKINS, M.D.

Abstract A large-scale audit of patient records was used to educate and evaluate physician's assistants. Clinical algorithms (sets of step-by-step instructions for solving a medical problem) for 11 acute medical complaints were used in patient care by physician's assistant trainees. Each algorithm had a corresponding checklist medical-record form, which was filled out by the physician's assistant as he saw the patient. A computer program analyzed the data from each checklist to determine if the algorithm had been followed correctly. Checklist records from 3024 patients showed that a physician's assistant could have evaluated 45 per cent of these patients accurately without direct physician involvement if he had correctly followed the algorithm logic. This clinical algorithm system provides guidance in problem solving and also measures the ability of a trainee to follow instructions. (N Engl J Med 288:818-824, 1973)

ONE result of the increasing national concern over the shortage of physicians in many regions of the United States has been the creation of a new class of health-care personnel, the physician's assistant. It is hoped that a supervising physician will delegate certain of his health-care duties to such personnel and thus have more time for other activities. The effect of the physician's assistant on medical practice and his ultimate acceptance by the medical profession and the public, however, are still uncertain. Even if the introduction of the physician's assistant results in easier access to medical services at decreased cost, he will probably be rejected if there is a concomitant decline in the quality of medical care. Although there are extensive efforts to assess the effect of the physician's assistant on the economics of health care, there has been relatively little effort to develop mechanisms for assuring an acceptable standard of performance or to measure the quality of medical care actually delivered.

Although a well motivated person without formal education beyond high school can learn to perform certain medical tasks, such as a physical examination, many activities of the physician require both scientific education and extensive clinical training. One such activity is the evaluation of a patient's acute illness. If the physician's assistant is to aid the physician in this common, time-consuming, but often complex task, we believe that he must be provided with unambiguous, step-by-step instructions for solving the clinical problem. Such instructions are referred to here as *clinical algorithms.*

Clinical algorithms for acute illness have been used by others,[1-3] and their use in the training and licensing of paramedical personnel has been discussed by Bjorn.[4]

A system that incorporates clinical algorithms, a checklist medical-record form and a computer program to audit performance may be defined as an *algorithm system.* The objectives of the system are to define precisely the skills required for clinical problem solving (and thus provide a basis for the education of the physician's assistants), and to provide a method for assessing the reliability and thoroughness of the physician's assistants in giving care to each of many patients.

The data presented in this report are the result of use of the clinical algorithm system by the first group of trainees in the physician's assistant training program of MEDEX-New England (April, 1971, to April, 1972). In common with other MEDEX programs, the 23 trainees were former military corpsmen whose average educational attainment was graduation from high school. After three months of formal training that emphasized mastery of the physical examination, each trainee spent one year under the preceptorship of a practicing physician, who assumed responsibility for all patient care given by the trainee. During this year, the trainees performed a wide variety of patient-care tasks, including the evaluation of acute illness by means of clinical algorithms.

OVERALL STRUCTURE OF THE ALGORITHM SYSTEM

The system has three components. A *clinical algorithm* is available for each of 11 different medical problems (Table 1); each algorithm presents in binary logic form the step-by-step method to be used in solving a clinical problem. Each algorithm has a corresponding *checklist medical record form,* which is filled out for each patient at the time the patient is seen (one copy is included in the patient's permanent record and a carbon copy is sent to a central facility for audit). And a *computer program* audits the ability of the physician's assistant to follow the algorithm logic.

USE OF THE CLINICAL ALGORITHMS IN PATIENT CARE

Each of the 11 algorithms for acute illness has a common overall structure, represented in Figure 1. There is a preliminary evaluation of the patient to detect findings suggestive of possible life-threatening illness. If po-

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Table 1. Patient

ALGORITHM
Upper respiratory illness
Ear problems
Cough
Chest pain
Nausea, vomiting & diarrhea
Fever
Laceration
Urinary problems
Headache
Shortness of breath
Pediatric nausea, vomiting & diarrhea (for patients < 5 yr)
All algorithms

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Table 1. Patient Triage According to Algorithm Logic.*

Algorithm	Total Patients	Referred to Physician	Evaluation by MEDEX Only
		%	
Upper respiratory illness	1530	36	64
Ear problems	284	45	55
Cough	231	79	21
Chest pain	164	100	0
Nausea, vomiting & diarrhea	160	94	6
Fever	142	68	32
Laceration	136	46	54
Urinary problems	131	89	11
Headache	99	94	6
Shortness of breath	79	100	0
Pediatric nausea, vomiting & diarrhea (for patients < 5 yr)	68	53	47
All algorithms	3024	55	45

*Results based on rigid adherence to algorithm logic.

tentially serious illness is not discovered, the physician's assistant must ascertain that there is a clinical algorithm for that patient's problem. If there is none, he obtains a history of the chief complaint, examines the patient, and then refers the patient to the physician. The assistant functions only as a data acquirer and makes no medical decisions for these patients. These first two steps theoretically limit the physician's assistant to managing acute medical problems for which algorithms are available. When the patient's problem is one of the 11 for which there is a clinical algorithm, the assistant obtains a history and does a physical examination that is specified by the algorithm and that is directed at the most common possible causes of the problem. He then uses the instructions contained in the algorithm to make decisions about further evaluation, treatment or triage to the physician.

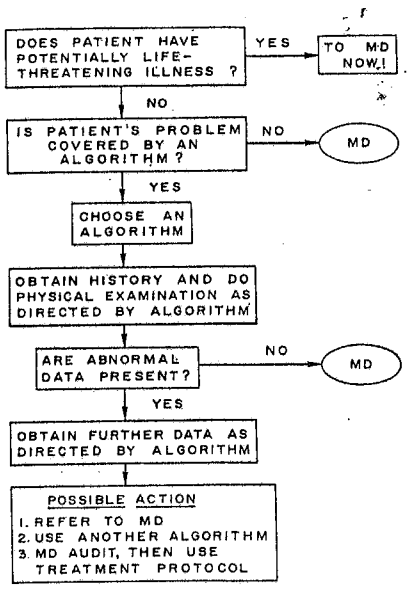

Figure 1. General Structure of the Triage System.

The use of the clinical algorithms will be illustrated by a patient complaining of "sore throat." The screening examination for possible medical emergency is negative in this patient, and the physician's assistant chooses the algorithm for upper respiratory illness on the basis of the chief complaint. When he sees the patient, he takes with him an upper-respiratory-illness checklist medical-record form (Fig. 2), on which every possible abnormal finding encompassed by the primary and secondary data base is listed separately and is numbered according to its place in the algorithm logic. The physician's assistant records on the checklist a description of the patient's illness and asks about any medications, allergies or chronic illness. Referring to the checklist as a reminder, he then asks about each of the symptoms listed under "subjective data" and not enclosed by boxes and records the responses as positive (with a check mark) or negative (with a zero) in the space on the checklist next to the symptoms. For any positive responses, he obtains the information contained in the box below the question that was answered affirmatively. He then does a physical examination whose content is specified under "objective data" by the items that are not enclosed by boxes. If there is an abnormal finding, he obtains and records further information specified within the adjacent boxes. The information within the boxes specifies additional history or physical examination required by the algorithm logic to define the nature of an abnormal finding sufficiently to allow a decision about triage.

When the physician's assistant has obtained all the information specified under "subjective data" and "objective data" on the checklist, he refers to the clinical algorithm for directions on how to act on the data. Figure 3 is the page of the upper-respiratory-illness algorithm that pertains to the abnormal findings in the patient, illustrated by the heavy lines and arrows. In this example, the physician's assistant begins at the top left-hand corner of the page, and, noting from the checklist that the throat examination indicated abnormality, follows the arrow to the part of the logic that provides directions for recognizing and taking action on findings suggesting epiglottitis, peritonsillar abscess and pharyngitis. Referring to the checklist, he notes that the throat examination gave normal results except for redness of the pharynx and tonsillar exudate. In a patient with these findings, he is directed by the logic to obtain a throat culture and initiate treatment for pharyngitis. He should then place check marks next to "throat culture for β-strep only" and a sore throat treatment protocol to remind himself to execute these plans. (In this example, the assistant fails to note the need for throat culture and mistakenly orders a heterophil-antibody test, as shown in Figure 2.) The physician's assistant then scans the left-hand side of the remaining pages of the upper-respiratory-illness algo-

URI CHECKLIST II (#12)

User I.D. No.: 1 Patient Name: JOHN DOE Pt. No.: 1

Today's Date: 1/2/73 Patient's Birthday: 1/2/40 Phone Number: 999-1111

(✓ = PRESENT; O = ABSENT; X, O = PRECEPTOR DISAGREES WITH FINDING OR PLAN)

SUBJECTIVE DATA:

Chief Complaint: SORE THROAT Duration: 2 DAYS Course: WORSENING

Other description: GRADUAL ONSET. NO RELIEF FROM ASPIRIN OR GARGLING. HAS MALAISE AND IS UNABLE TO WORK BUT IS AMBULATORY AT HOME.

Allergies Present (incl. Medications): NONE Regular Medications: NONE

✓ 2 Sore throat/swallowing pain
✓ 30 Hx of infectious mono
✓ 55 Hx of strep exposure
O 53 Cough present
__ 54 Sputum production
__ 59 Chest pain present
O 6 Runny nose
O 5 Facial/Dental pain → Check for periapical abscess

Right Ear	Left Ear	
O 9	O 10	Pain → Check mastoids
O 11	O 12	Tinnitus
O 13	O 14	Loss of hearing
O	O	Hx of T.M. perforation
__ 56	__ 57	Sx relieved by wax removal
__ 29	__ 29	Ear sx present ≥ 2 weeks

Chronic Diseases:
O 90 Heart Disease
O 91 Chronic Kidney Disease
O 92 Diabetes
O 93 Asthma/Chronic Lung Disease
O 94 High Blood Pressure
O 95 Chronic Blood Disease
O 99 Other: __

OBJECTIVE DATA: BP: 110/78 Weight: 163 LBS Temperature: 98.4 (P.O.)

✓ 1 Abnormal throat exam
O 18 Enlarged/swollen epiglottis
O 19 Unilateral swollen tonsil
✓ 20 Exudate ✓; Swollen tonsils O; Red throat ✓
O 60 Other abn: __

O 3 Abnormal nasal exam
__ 21 Purulent nasal discharge
__ 22 Wet/swollen membranes __; or Non-purulent discharge __
__ 61 Other abn: __

__ 23 Periapical abscess

O 15 Neck swelling so severe as to obliterate angle of jaw

O 4 Sinus tenderness present

Right	Left	
__	__	Frontal
__	__	Maxillary

O 16 Cervical lymph nodes enlarged/tender
__ 31 Posterior cervical nodes enlarged
__ 50 Enlarged spleen __; or axillary nodes __

O 17 Abnormal chest exam
__ 32 Localized chest exam abn.
__ 58 Temperature ≥ 101°F.

O 7 (R) O 8 (L) Abnormal ear exam

Right Ear	Left Ear	
__ 24	__ 25	Ext. canal abnormal
__ 34	__ 35	Foreign body present
__ 36	__ 37	Otitis externa present before wax removal
__ 38	__ 39	Wax obstruction present
__ 40	__ 41	Ear wax not removed
__ 42	__ 43	Otitis externa present after wax removal
__ 26	__ 27	Abnormal T.M.
__ 46	__ 47	Perforated T.M.
__ 51	__ 52	Ear discharge present
__ 48	__ 49	Bulging T.M. __; Red T.M. __; no light reflex __; no landmarks __
__ 44	__ 45	Other abn: __

__ 28 Mastoid tenderness R __, L __

PLANS:

Results
__ 103 Throat Culture __
__ 104 Throat Culture for β-strep only __
__ 105 Culture nasal discharge R or L __
__ 107 Culture ear discharge R or L __
__ 109 WBC with Diff. __
✓ 110 Heterophile __
__ 113 Check with M.D. about Chest X-ray __
__ 111 Chest X-ray PA and Lat __
__ 112 Sinus X-ray __
__ 149 Other plan: __

Protocols
✓ 150 Strep Throat Protocol
__ 151 Sympt. Sore Throat Protocol
__ 152 Runny Nose Protocol
__ 153 Acute Sinusitis Protocol
__ 154 Otitis Externa Protocol
__ 155 Otitis Media Protocol
__ 157 Cough Protocol
__ 175 Other Rx. given: __

Disposition
__ 102 Sent to M.D.******
✓ 174 Pt. discharged with M.D. approval

FINAL DIAGNOSIS:

__ 034.0	Strep Pharyngitis	__ 508.4	Epiglottitis	__ 075	Inf. Mono.
__ 462	Non-strep Pharyngitis	__ 501	Peritonsillar Abscess	__ 489	Acute Bronch.
__ 470	Flu Syndrome	__ 460	Head Cold	__ 485	Bronch. Pneum.
		__ 461.9	Acute Sinusitis	__ 481.0	Lobar Pneum.

__ 380	Otitis Externa		
__ 381.0	Acute Otitis Media		
__ 381.9	Serous Otitis Media		
__	Other: __		

✓ 101 M.D. performed audit

John Smith / Mx
(SIGNATURE)

Figure 2. Checklist Medical-Record Form for Upper Respiratory Illness.
The text contains an explanation of the use of this form. The sections enclosed by boxes comprise the data to be obtained only if an abnormality is discovered in the initial screening examination (not enclosed by boxes). As explained in the text, the format of this checklist differs slightly from that used by the trainees in this study and has been used extensively in our practice.

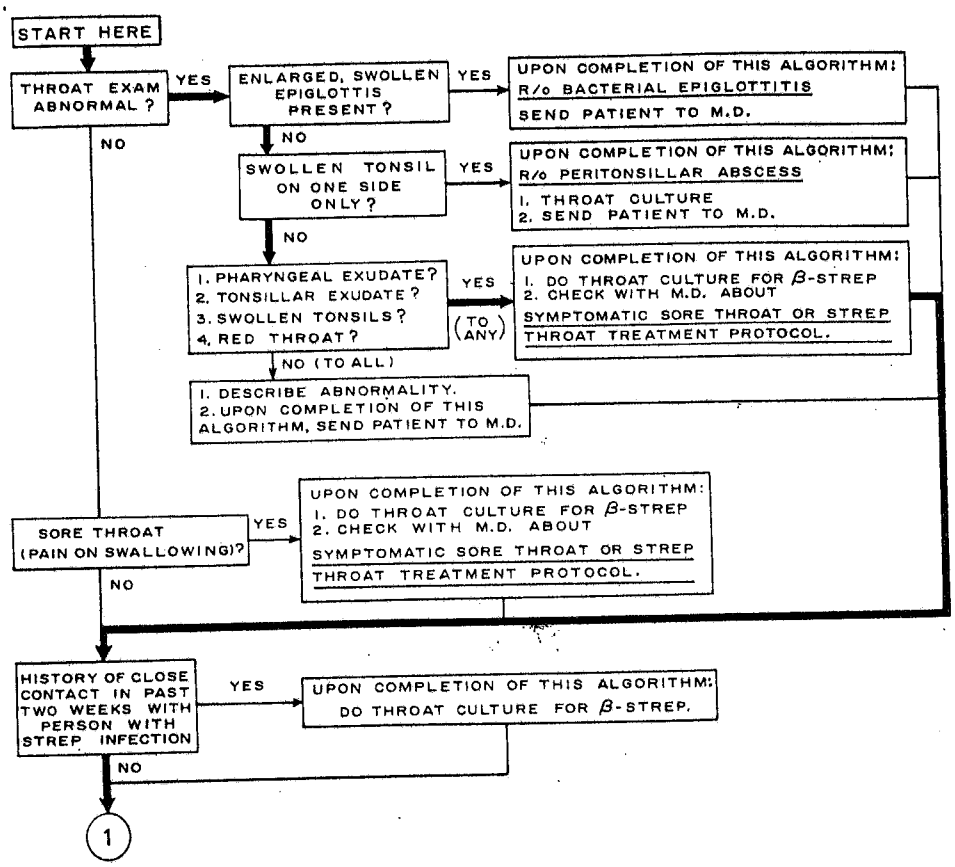

Figure 3. Clinical Algorithm for Upper Respiratory Illness.

The path through the logic for a patient with pharyngitis is indicated by the broad arrows. Only the part of the logic relevant to this patient's problem is shown. The path through the logic begins at the top left-hand frame. The number 2 refers the user to a later point of entry into the algorithm logic (not shown above).

"Check with M.D." implies an oral presentation of the clinical findings to the physician preceptor, who might then check the findings on physical examination. "Send patient to M.D." implies that responsibility for further evaluation has been transferred to the physician.

This illustration is one page from a modified form of the upper-respiratory-illness algorithm that was used by the trainees in this study. It has been used in our practice during the past eight months, but not as extensively as the original version. The modifications entailed adding a throat culture in asymptomatic persons recently exposed to streptococcal infection and screening for bacterial epiglottitis.

rithm; since there are no other abnormal findings, he makes no further plans.

Audit of Performance with the Clinical Algorithms

One aspect of audit occurs shortly after the trainee finishes scanning the algorithm logic and recording his plans on the checklist. He reviews his findings and plans with his preceptor, who may then re-examine the patient before deciding about treatment. If the preceptor disagrees with any findings or plans, he so indicates on the checklist. As the preceptor gains confidence in his assistant, he may allow him to implement the plans suggested by the algorithm without prior consultation and later review the patient record to find out what was done. One copy of the checklist medical-record form, which is printed on self-duplicating paper, becomes part of the patient's permanent medical record.

The second aspect of audit is an analysis of the information on the checklist to see if the clinical logic was followed correctly. The copy of the checklist is mailed to the MEDEX-New England office for audit by a computer program. Identification data and the number next to each checkmark are entered into the Dartmouth Time-Sharing System computer through a teletype terminal. For any set of patient data, there is only one correct path through the logic of the algorithm. Any errors in following the logic are detected by a computer program that prints a statement summarizing the pertinent patient data and indicating the nature of the error. Figure 4 shows the description of the error committed on the checklist shown in Figure 2. In this instance, the MEDEX staff would review the description of the error and discuss with the physician's assistant the medical evidence of the need for throat culture in managing pharyngitis, and might question him re-

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JOHN DOE :  BIRTHDAY - 1/1/40                                    (14)
            DATE SEEN - 1/1/73

ABNORMAL THROAT EXAM
PATIENT DOES NOT HAVE ENLARGED/SWOLLEN EPIGLOTTIS
PATIENT DOES NOT HAVE SWOLLEN TONSIL ON ONE SIDE ONLY
PATIENT HAS SWOLLEN TONSILS OR EXUDATE OR RED THROAT
   NOT DONE ALTHOUGH SUGGESTED BY THE ALGORITHM:
      THROAT CULTURE FOR BETA-STREP

PATIENT WAS RECENTLY EXPOSED TO BETA STREP
   NOT DONE ALTHOUGH SUGGESTED BY THE ALGORITHM:
      THROAT CULTURE FOR BETA-STREP

   DONE ALTHOUGH NOT SUGGESTED BY THE ALGORITHM:
      BLOOD DRAWN FOR HETEROPHILE
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Figure 4. Error Statement from Computer Audit of Checklist Medical Records.

The text contains an explanation of how the data from the checklist medical-record form are entered into the computer and how error statements are used to assess performance of physician's assistant. Errors of both commission and omission are indicated in the printout.

garding the clinical findings that led to ordering the heterophil-antibody test. Detection of an error in management of a patient can thereby provide an opportunity for the trainee to learn.

If a physician cannot readily obtain certain laboratory tests, or if he disagrees with their use at any point in the clinical logic, the audit program can be altered so that omission of the designated data in that practice does not constitute an error. This modification does not affect the audit program for other practices.

Results

Use of the Clinical Algorithms

The upper-respiratory-illness, ear problems and cough algorithms accounted for 50.6, 9.4 and 7.6 per cent of the first 3024 patient records respectively, whereas none of the eight remaining algorithms were used in more than 5.4 per cent of these patients (Table 1).

An estimate of the proportion of all acutely ill patients to whom these 11 algorithms would apply was obtained from the medical records of patients with acute complaints seen on randomly chosen days throughout one year in three different health facilities. The algorithms applied to as many as 56 per cent of acutely ill patients, as determined by the recorded chief complaint, with little variation among a general outpatient practice and the emergency rooms of a medical center and a community hospital.

Results of Triage with Use of the Clinical Algorithms

The effect of the physician's assistant on health care will be in part related to the number of patients for whom he can provide service without direct physician intervention. According to the clinical logic, 55 per cent of the patients seen had clinical findings requiring referral to the physician for further evaluation after initial collection of a defined data base (Table 1). Conversely, 45 per cent of the patients could have been evaluated and treated by the physician's assistant alone, assuming that he had demonstrated his ability to detect abnormal findings and provided there were standard treatment protocols for him to use. Not surprisingly, the proportion of patients that could be seen only by him varied, depending on the nature of the patient's complaint. The actual triage differed from that suggested by the algorithm logic; in general, more patients were referred to the physician than the algorithm logic indicated, the only noteworthy exception being patients with lacerations. Overall, 73 per cent of the 3024 patients seen initially by the assistant were referred to the physician, 22 per cent were seen by the physician's assistant alone, and in 5 per cent there was no indication of referral to the physician although this action was indicated by the algorithm logic.

Errors in Following Clinical Logic

The algorithms are a guidance system for clinical problem solving by physician's assistants and were intended to be followed as precisely as possible during evaluation of patients. The clinical logic was followed perfectly in 47 per cent of the 3024 patients. Five of the 22 trainees followed the logic perfectly in more than 60 per cent of their patients, and a like number were error free in less than 30 per cent of their patients. Of the total of 3581 errors committed, 55 per cent involved performing extra procedures not indicated by the logic. Omission of indicated procedures accounted for 38 per cent of the errors and were considered most likely to reflect performance of the physician's assistant.* Most of the errors of omission were due to laboratory tests not done or treatment protocols not followed (Table 2). Failure to use another algorithm occurred in 150 of the 203 patients in whom it was indicated by the clinical logic. The format of the checklist medical-record form used by this group of trainees has subsequently been modified to enclose certain data in boxes, as shown in Figure 2. The effect of this change on trainee performance in following the algorithm is unknown.

The trainee should place a mark adjacent to the statement "Sent to M.D." for each patient in whom referral to the physician was suggested by the algorithm. Failure of the trainee to record the need for physician consultation when it is indicated is regarded as the most sensitive index of his reliability. This error occurred in 10 per cent of the patients in whom physician referral was indicated, with wide variation among different practices and algorithms. Trainees with a disproportionate number of such errors were readily identified by the audit procedure.

Errors involving failure to denote the need for physician consultation were classified according to the type of data that led to a physician referral (Table 3). There were significantly more such errors ($p<0.003$) when the trainee did not detect abnormal findings to explain

*For the second MEDEX class, manual audit of a large number of checklists was performed by Wayne Kniffin, M.D., and Mrs. Susan Harless. They found noncodable information on the checklist that explained 16 per cent of errors of commission and 26 per cent of errors of omission as due to decisions made by the physicians when they audited the checklist before implementing plans. These decisions reflect the physician's disagreement with the laboratory studies suggested by the algorithm. In addition, 7 per cent of all recorded errors were due to errors in entering data into the computer.

Table 2. Classificati
cedures

Type of Procedure Indicated by Algorithm Logic	
Laboratory test	
Use of another algorithm	
Use of treatment protocc	
Referral to physician	
Other†	
Totals	

*Errors involving omissio
data are derived from all MI
cal-record forms for the cas
computer audit were analyz
actually been obtained. Tho
the checklist & are not incl
only 1 indication for or erro
parentheses denote the pro
formed (expressed as %).

†Includes tuberculin tes
follow-up observation & gi

a patient's comp
tions for physici
ings or because o
group of trainee
directions more
had symptoms

This report de
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Table 3. Ar

Reason for Referri	
Group 1:	
Abnormal finding	
primary data base	
Group 2:	
Coincident chroni	
disease	
Group 3:	
No abnormal obj	
findings	
Other	

*Data are from all
physician referral were
referral to the physicia

†Probability that dif
Groups 1 & 3, p = 0

‡All patient records

Table 2. Classification of Errors Involving Omission of Procedures Indicated by Algorithm Logic.*

Type of Procedure Indicated by Algorithm Logic	No. of Times Procedure Was Indicated by Algorithm Logic	No. of Times Procedure Was Omitted (% of Times Indicated)
Laboratory test	3332	924 (28)
Use of another algorithm	203	150 (74)
Use of treatment protocol	844	139 (16)
Referral to physician	1663	153 (9)
Other†	208	43 (21)
Totals	6250	1409 (23)

*Errors involving omission of a procedure were divided into the categories shown. The data are derived from all MEDEX practices & include all algorithms. The checklist medical-record forms for the cases in which an error in physician referral was detected by computer audit were analyzed for any written indication that physician consultation had actually been obtained. Those with such an indication were considered an error in using the checklist & are not included in the total of physician referral errors. For this table, only 1 indication for or error in physician referral/checklist was counted. The figures in parentheses denote the proportion of times that an indicated procedure was not performed (expressed as %).

†Includes tuberculin testing, weighing patient, discharging patient with 48-hour follow-up observation & giving tetanus toxoid.

a patient's complaints than when there were indications for physician referral because of abnormal findings or because of coexistent chronic disease. When this group of trainees found abnormalities, they followed directions more successfully than when their patients had symptoms unaccompanied by physical findings.

Discussion

This report describes a method for comparing clinical performance in large numbers of patients against a defined standard. The clinical algorithm provides instructions for gathering and interpreting data. The ability to follow these instructions correctly may reflect thoroughness and reliability, two desirable attributes in a physician's assistant. Thus, in the MEDEX-New England program, the clinical algorithm system was used to provide one objective measure of reliability and thoroughness in providing patient care.

The algorithm system allows audit of certain elements of performance but has inherent limitations. It does not measure the accuracy of the observations made by the physician's assistant; this important part of audit is the responsibility of the physician preceptor who examines the patients seen by his assistant. Furthermore, the present clinical algorithms deal only with one aspect of health care, acute illness, and only one aspect of acute-illness management, gathering and interpreting data. In addition, there are several unanswered questions about this approach to training physician's assistants.

Table 3. Analysis of Errors in Physician Referral.*

Reason for Referral†	Physician Referrals Indicated by Algorithms	Errors in Sending Patient to Physician (% of Referrals)‡
Group 1:		
Abnormal findings in primary data base	1517	123 (8.1)
Group 2:		
Coincident chronic disease	102	5 (4.9)
Group 3:		
No abnormal objective findings	268	40 (14.9)
Other	18	0

*Data are from all MEDEX practices & include all algorithms. All indications for physician referral were counted for this table. Since some patients had >1 indication for referral to the physician, the total errors are greater than in Table 2.

†Probability that difference between groups was due to random variation in sampling: Groups 1 & 3, $p = 0.001$; Groups 1 & 2, $p = 0.72$; & Groups 2 & 3, $p = 0.003$.

‡All patient records in this column reviewed manually.

Will the correct use of clinical algorithms lead to satisfactory, cost-effective health care? This question will be difficult to answer quantitatively, in part because of the difficulty of defining and measuring the quality of health care. Furthermore, the quality of health care is determined not only by appropriate data collection and interpretation, which may be affected by the content of clinical algorithms, but also by selection of proper therapy and adequate follow-up observation. The present algorithms are a first step toward well defined methods of solving common, acute medical problems. Their data base and clinical logic must eventually be shown to lead to good clinical results at minimum cost. To achieve this goal will require large prospective clinical studies in which systematic alterations in the logic are coupled to follow-up observation of laboratory studies and patient outcome. The present algorithm system is effective for collecting and analyzing the data obtained on the initial patient encounter, but as yet there is no satisfactory mechanism for equally efficient collection of follow-up information.

What will be the effect of using the algorithm system on the long-term performance of the physician's assistant? Will his handling of acute illness reflect the logical approach of the clinical algorithms? Does appropriate use of the clinical algorithm system during training accurately predict future reliability and thoroughness? Documentation of the educational value of the clinical algorithms and of the audit of performance will require analysis of the performance of the physician's assistant over a period of years after the end of formal training.

The medical profession is currently discussing methods for certification and recertification of physicians, and increasing reliance is being placed on examination of performance in patient care. The American Board of Internal Medicine has recently replaced the traditional oral examination with certification of competence by the director of each residency.[5] If a similar approach is followed for recertification of physicians, methods for large-scale audit of performance in patient care will be needed. In MEDEX-New England, certification of the physician's assistant is at present based on demonstration of satisfactory clinical performance, documented in part by audit of the use of the clinical algorithms. The experience gained trying to achieve an optimum system of audit for physician's assistants may provide insights that will be of value to other health professions.

Although many important questions about clinical algorithms cannot be answered at present, the system described is an example of one component of a clinical

support system for paramedical professionals. It demonstrates one possible use of available technology to help provide many patients with access to a defined standard of medical care.[6]

Since this paper was written, the clinical algorithm system has been used in 4165 patients in the 2d MEDEX-New England class and in 2655 patients in the Seattle, Washington, MEDEX program.

We are indebted to Dr. Bella Strauss, Dr. Nicholas Danforth, Dr. Robert Chapman, Philip Nelson, Pamela Wood, the physician preceptors of the MEDEX-New England program, and the trainees themselves for contributions to this study, to Margaret Long for preparing the algorithms and the checklists, to Drs. Robert Maxfield and William Boyle, who principally devised the algorithms for laceration and pediatric nausea, vomiting and diarrhea, respectively, to Dr. Charles Burger, who reviewed the algorithms before their use in the MEDEX program, and to Drs. Thomas Almy, Kenneth Johnson and Henry Tufo for criticism of the manuscript.

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MEDICAL INTELLIGENCE

INFANTILE METHEMOGLOBINEMIA CAUSED BY CARROT JUICE

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THE toxic threat of nitrate contained in commonly ingested vegetables has recently been reviewed.[1] Concern has been stimulated by reports of methemoglobinemia in German and French infants after ingestion of spinach puree[2] and carrot soup.[3] In the following case cyanosis developed after ingestion of fresh carrot juice by an American infant.

Case Report

A 2-week-old black male infant (S.L.C.H. 72-6245) was taken to the Emergency Room because his grandmother had noted that his lips and nail beds had a "dark color." In the previous 24 hours he had consumed 500 ml of carrot juice. Fever, diarrhea, lethargy and the administration of medicines were denied. He had been discharged from the nursery with a modified milk formula containing vitamins and minerals (Similac), which he had taken well, with concomitant gain in weight until 2 days before admission. His twin brother, who had received only this formula, was asymptomatic. The family history was negative for hematologic disease.

Physical examination revealed an alert, irritable infant with marked cyanosis of the nail beds and lips. The weight was 3200 g, and the head circumference 35.5 cm. The temperature was 36.6°C, the respirations 40, and the pulse 190. Blood pressure (Doppler method) was 80/60 in the upper and 75/40 in the lower extremity. A Grade 3 of 6 systolic murmur was heard at the left sternal border and over the precordium. A chest radiograph taken on admission showed slight increase in the pulmonary vascular markings, without cardiomegaly. An electrocardiogram indicated right-axis deviation of +180° and right ventricular enlargement. Arterial blood, obtained while the patient breathed room air, revealed a pH of 7.49 and oxygen tension of 95 and carbon dioxide tension of 35.5 mm Hg. Other laboratory studies included a hemoglobin of 14.4 g per 100 ml, hematocrit of 47 per cent, negative Venereal Disease Research Laboratory reaction, blood urea nitrogen of 16.7 and serum calcium of 9.2 mg per 100 ml and sodium of 137.0, potassium of 4.1 mEq, chloride of 114 mEq and bicarbonate of 13.9 mEq per liter.

A single injection of contrast material administered through a catheter introduced into the right side of the heart revealed only a small atrial septal defect. A methemoglobin determination revealed 9 g per 100 ml, representing 60 per cent of the total hemoglobin. Methylene blue (1 mg per kilogram of body weight) was given intravenously, and the patient's color improved promptly. Subsequent methemoglobin determinations 1 and 12 hours later revealed 0.9 and 0 g per 100 ml, respectively. The nonaffected twin's methemoglobin level was less than 0.1 g per 100 ml. The patient remained well for the remainder of the hospital stay. Cultures of a gastric aspirate revealed a moderate growth of a candida species, and slight growth of streptococcus and neisseria species. The pH of the gastric aspirate was 5.0. Hemoglobin electrophoresis showed 33 per cent fetal hemoglobin. Subsequent examination of the twins on several occasions in the outpatient department showed no health problems of any consequence.

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Methods

Epidemiologic Investigation

The patient's home was visited on three occasions, the family interviewed, and the premises inspected, with special attention to possible sources of nitrite or nitrate, interruptions of refrigeration, alteration in water supply, etc. The supermarket where the suspect carrots had been purchased was visited with the family member who had made the original purchase, and similar bags of carrots were bought (Table 1). Details of the shipping, storage, and origin of the carrots were obtained by interviews with the manager of the market, the dispatcher of the regional clearing warehouse and the shipper at the point of origin in Florida.

Refrigeration monitoring records from the truck