Microbiology Subsystem of a Total, Dedicated Laboratory Computer System

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The computer system used by the Microbiology Service of the Clinical Pathology Department, Clinical Center, National Institutes of Health is discussed. This microbiology subsystem is a part of a dedicated on-line laboratory computer system used by the entire department. The laboratory computer is connected on-line to a hospital computer which provides patient admission, transfer, and discharge data. Mark sense worksheets and cathode ray tube terminals are used for result entry and correction. Cumulative patient reports are printed. Results for both active and completed accessions can be easily retrieved on cathode ray terminals in the laboratory. All laboratory data are archived on magnetic tape from which a research data base and microfiched laboratory records are generated. The manner in which the system is integrated in the routine operation of the microbiology laboratory is emphasized. In addition, some of the costs, benefits, liabilities, and pitfalls associated with the introduction of the computer in the laboratory are reviewed. Finally, we have presented our concept of some of the future enhancements to our present system and some of the directions in which any future microbiology system might develop.

The Clinical Pathology Department of the National Institutes of Health (NIH) provides laboratory services for inpatients and outpatients seen in the Clinical Center, a 541-bed research hospital and clinic. The chemistry and hematology services of the department have been using computers to report laboratory results since 1965. In contrast, the microbiology service began to use computers to support the daily operation of the laboratory in July 1976.

In June 1974 the Clinical Center signed a contract with Honeywell Inc. for a "turn-key" laboratory computer system. Honeywell, like the other vendors competing in the laboratory computer system market at that time, did not have a fully developed microbiology subsystem which could be readily adapted for use in our laboratory. (The microbiology laboratory in the Clinical Center is staffed by 25 technologists and performs routine and special microbiological and serological studies on approximately 50,000 specimens per year.) The contract, therefore, required that a usable system be developed. However, the requirements for a microbiology subsystem were not completely defined at the time the contract was signed; the extent to which these requirements were defined before selecting

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the Honeywell computer system have been described elsewhere (9). This made it difficult for both Honeywell and the Clinical Pathology Department to agree on precisely what functions the microbiology subsystem should perform and how they should be implemented. It was eventually agreed that a workable system from the laboratory's point of view should be provided, and a cooperative development effort ensued. The result of that development effort was a microbiology subsystem which we have used effectively since July 1976 and which Honeywell felt it could market to other customers. It does not have all of the features which we believe would be valuable in a microbiology system, and the method of implementation of some features could be improved.

The system differs from most previously described systems in several respects (2-6, 8, 10, 11). It is an integrated part of a total, stand-alone, laboratory computer system. The data structures for the storage of microbiology culture results are basically the same as those for other laboratory data. They differ only in some details of record format and the use of two accessory files for the storage of antibiotic susceptibility results and the results of procedures such as a Gram stain which may have multiple observations. The system is quite flexible and is adaptable to a variety of different operating environ-

ments. This flexibility is achieved through the use of easily modified tables that describe the tests which the laboratory will perform, the antibiotics used in sensitivity testing, the organisms which will be reported, the body sources from which a specimen might be obtained, etc.

The description of the system which follows presents the details of the way in which the system is used in our laboratory. There are a number of features and options which we have elected not to use and which we have not attempted to describe. Specifically, although the system can generate patient billing information, we have not discussed this aspect of the system because our patients are not billed.

MATERIALS AND METHODS

System hardware and software. The Honeywell laboratory computer system is run on a Honeywell 716 minicomputer. (The reader may obtain some help with the specialized vocabulary of computer science in the reference provided [10], or from several other specialized dictionaries.) The Clinical Pathology Department hardware configuration includes 64K of 16-bit/word memory, four 15-megabyte moving head disk drives, two 1,600-bpi (bits per inch) tape drives, a 650-line/min line printer, analog to digital converter, and communications equipment for 17 cathode ray terminals (CRT), 11 keyboard printers (Texas Instruments Silent 700), four label printers (Terminet T1200), two medium speed printers (Texas Instruments 810), three mark document readers (MDRs; Bell and Howell), and numerous instrument interfaces. The peripheral equipment required by the microbiology service includes three CRTs, one label printer, one Silent 700, and one MDR.

The real-time operating system is unique to Honeywell's laboratory system and is not used in other 716 computer applications. All application programs are written in FORTRAN IV, and there is an extensive subroutine library for special laboratory functions, e.g., for interfaced instruments, for programs using a CRT, etc. All programs must be compiled and loaded through an off-line batch operating system which cannot be used simultaneously with the real-time executive, which operates the laboratory system. This has been a relatively minor inconvenience since there is also a real-time executive compatible on-line batch operating system which permits editing of tables and programs while the laboratory is in operation.

RESULTS AND DISCUSSION

Functional description of the microbiology subsystem. Figures 1 and 2 present an overview of the interactions between the computer system functions and laboratory work flow. We will now examine in greater detail each step in the process.

Accessioning. At the initial visit to the Clinical Center, each patient is assigned a unique seven-digit, check-digited, hospital identification number. On the first visit, and on every subsequent visit either as an inpatient or an outpatient, the patient is admitted to the Clinical Center's total hospital information system, Technicon Medical Information System (TMIS). This admission is automatically communicated to the Honeywell laboratory computer system via an on-line communications link between the TMIS computer and the Honeywell computer. This same link keeps the laboratory computer up to date on all transfers and discharges from the Clinical Center. Information transferred at the time of admission includes patient name, hospital number, birth date, sex, race, nursing unit or clinic, attending physician, and Institute. There are nine Institutes which admit patients to the Clinical Center to be studied under specific research protocols. Knowledge of the Institute which is studying a particular patient is necessary for proper routing of certain laboratory reports.

The TMIS is used by physicians to request laboratory services. A physician may direct a nurse or laboratory technologist to request laboratory services on TMIS as his "agent." Such requests appear in the patients' charts and are countersigned by the physician. Studies may be requested for immediate action, e.g., "stat," to be performed at some future time, or on a recurring basis. At the appropriate time and in the appropriate location(s) TMIS prints a laboratory request document which accompanies the specimen to the laboratory. In addition to patient identification and tests requested, the request document contains the laboratory accession number assigned by TMIS. A preprinted label containing patient identification but not the laboratory accession number is attached to the specimen by the person responsible for collecting the specimen.

When the specimen and request form arrive in the microbiology laboratory, the request is entered in the laboratory computer on a CRT. (We are presently implementing a direct TMIS to Honeywell laboratory test request and result link but this is not yet fully operational.) The information entered on a formatted screen (Fig. 3) includes the patient hospital identification number, the TMIS-assigned laboratory accession number, the collection date and time if the current date and time are not appropriate, the body source from which the specimen was obtained, the tests requested, and any additional textual information which may be of help to the technologist working with the specimen or to the doctor interpreting the results. After the test request information is entered into Honeywell, a label (Fig. 4) containing the laboratory acces-
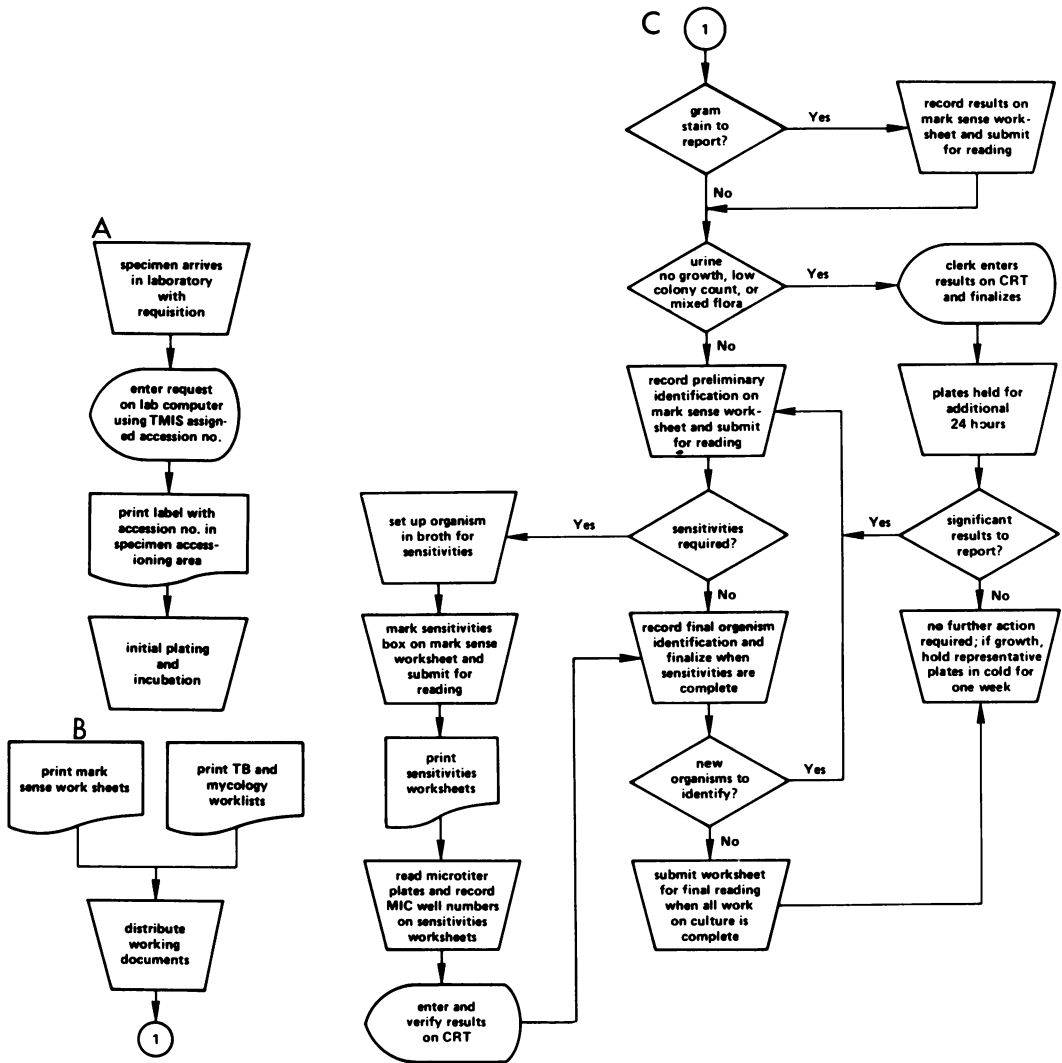
FIG. 1. *Interactions between computer system functions and laboratory work flow showing (A) initial specimen handling, (B) worksheet generation, result entry, and verification, and (C) specimen handling for routine (except blood cultures) and anaerobic bacteriology.*

sion number is printed on the microbiology label printer. The same accession number is assigned to all cultures to be performed on a given specimen.

Mark sense worksheets. Mark sense worksheets are printed at about 6:00 p.m. each evening and 5:00 a.m. the next morning. Worksheets are printed for all specimens which have been accessioned in the laboratory since the previous time worksheets were printed. Although the worksheets are not needed by the technologists until the day after the specimen arrives in the laboratory, the 6:00 p.m. printing insures that

most of the needed worksheets will be available if there is a computer malfunction which prevents timely printing of worksheets in the morning. A separate worksheet is printed for each test requested, e.g., routine bacterial culture, anaerobe culture, tuberculosis culture, etc. If necessary, worksheets can be reprinted on demand.

A sample worksheet is pictured in Fig. 5. The computer prints human-readable specimen and patient identification on the left side of the mark sense worksheet. Computer interpretable identification information is printed on the right side of the page. This information is used by the
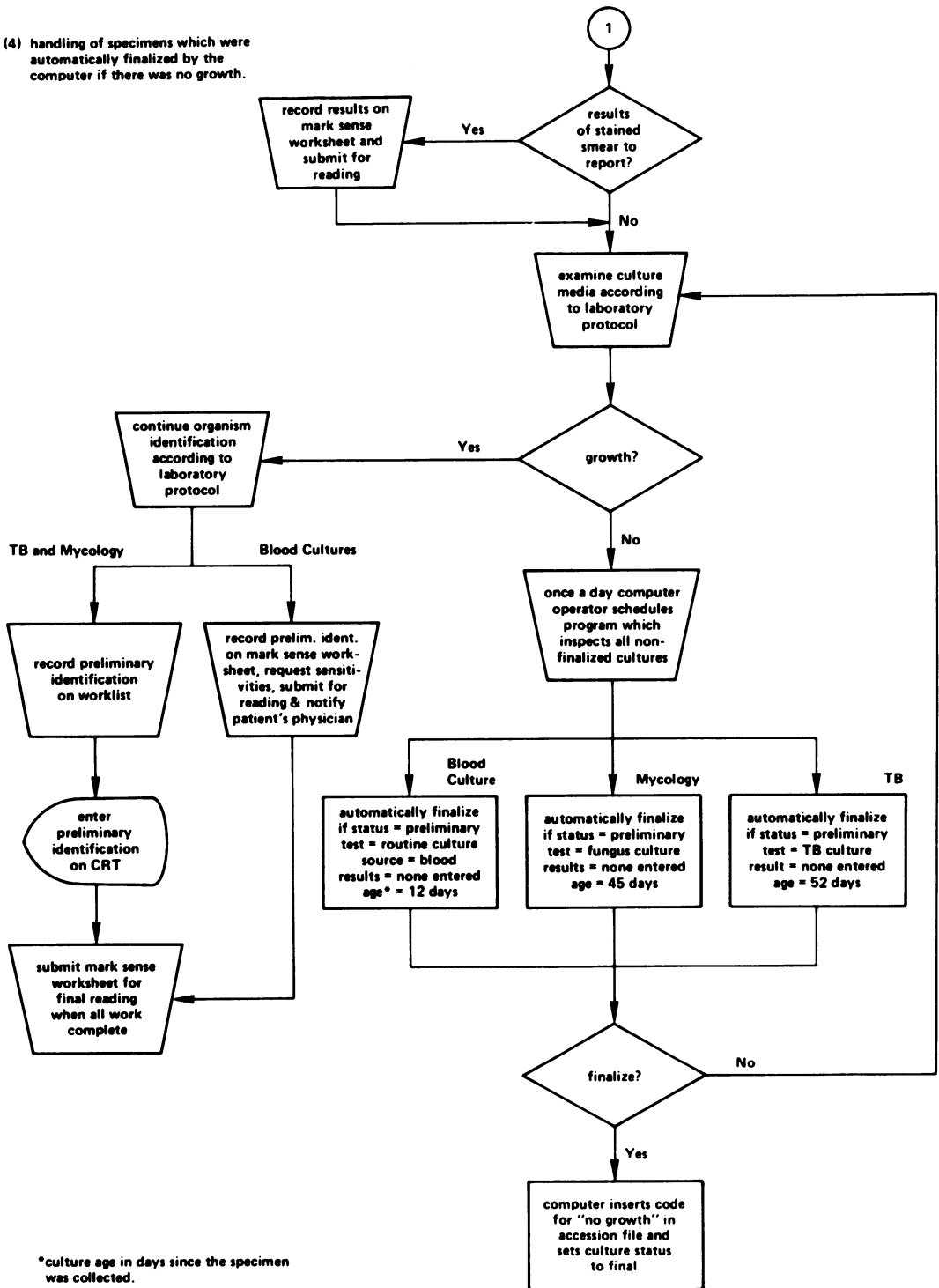
FIG. 2. *Interactions between computer system functions and laboratory work flow for mycobacteriology, mycology, and routine blood cultures, which are automatically finalized when there is no growth.*

FIG. 3. *CRT test request display. Data are entered only in fields indicated by dots. The tab key is used to move from one field to the next.*

FIG. 4. *Accession label printed by the laboratory computer. The four repetitions of the accession number MB-0189 are printed on separate "split" labels (0.5 by 0.5 inch [ca. 1.2 by 1.2 cm]). Information on the label includes patient name, hospital number, location, accession number, specimen body source, receipt date, and tests requested.*

technologist as a guide to pencil marking the identification field because the printed numbers are not sensed by the mark document reader. The blank space on the left side of the worksheet is used by the technologist to record biochemical reactions, Gram stain characteristics, organism identification, and other pertinent information that becomes available during the work-up of a specimen. Some of this information is encoded in machine-readable form on the right side of the worksheet. Specific biochemical reactions are not recorded for computer interpretation. If a Gram stain of the clinical specimen is prepared, the results are marked on the worksheet.

The mark sense worksheet is the only preprinted machine-readable form used to enter culture results into the computer. The same form is used by all microbiology work stations.

The computer-readable identification infor-

mation in the first six rows of the worksheet uniquely identifies the worksheet by specifying the accession number, the page number, and the work station, e.g., routine, anaerobe, etc. More than one page may be required if more than three organisms are to be reported.

A user configurable file called the card definition file specifies the meaning of each box or group of boxes, called a "field," for all mark sense forms, microbiology and nonmicrobiology, used in the system. Each work station has a separate entry in the card definition file. Thus, the worksheet for each work station may be defined in such a way that the same box on the form may have a different meaning. Each box may be translated through the card definition file into text which is stored in another file called the qualitative dictionary. It is also possible to translate the marks in a field of boxes into a numeric value.

When we first began using the computer in microbiology, a plastic overlay was used as a guide to marking the worksheets. This allowed us to use a worksheet with unlabeled boxes. Although very flexible, it was subsequently recognized that the overlay could be eliminated by preprinting on the worksheet information identifying the purpose of certain fields of boxes and numbering the rows of boxes. At the bench the technologist now has a typewritten sheet indicating the meaning of each box. The typewritten

FIG. 5. *Mark sense worksheet with human-readable identification information including requesting physician's name and accession comment. The marks on the sheet are translated by the computer as shown in Fig. 6 and 8.*

sheets are different for each work station; however, each work station uses the same preprinted form.

The types of information which can be entered in the machine-readable portion of the worksheet will now be discussed. The technologist may record general observations that apply to the culture as a whole, e.g., Gram stain results, colony counts on urine cultures, the number of positive bottles in a blood culture set, no growth, free text when desired, etc. For routine bacterial cultures, organisms which are considered to be "normal flora" in the body site from which the specimen was obtained may be recorded. Information unique to each organism not identified as "normal flora" is recorded. Three organisms per page and up to 15 organisms, not counting "normal flora," may be reported on the mark sense worksheets by copying the computer-readable header to a blank worksheet, and marking the appropriate page number box. Individual organism information includes the following: (i) preliminary observations, statements about an organism which are automatically deleted by the computer when the final organism identification is recorded; (ii) quantitation of growth on a culture plate, e.g., scant, light, moderate, or heavy; (iii) a seven-digit octal API (Analytab Products, Inc.) profile number when appropriate; (iv) organism identification; (v) antibiotic susceptibility request; and (vi) for each organism up to 580 characters of free text may be entered on a CRT.

If, for example, a fungus is encountered during the routine bacteriological work-up of a specimen, a preprinted referral slip is filled out by the technologist working up the specimen. When the final identification is completed by the mycology laboratory, the referral slip is returned to the bacteriology laboratory and the identification is entered on the mark sense worksheet on which the routine bacteriological identifications were recorded. The increased amount of time which may be required to identify a fungus does not affect the timely reporting of bacteriological results. As the work-up of a specimen proceeds, the technologist will make appropriate notes on the left side of the worksheet and record the information in machine-readable form on the right side of the worksheet. Each time important new information becomes available the worksheet is read through the mark document reader. Thus, most worksheets are submitted for reading several times before the final identification of all isolated organisms is complete.

Worksheet processing errors. Like Williams et al. (11) we have experienced a low error rate associated with the machine reading of mark sense forms. Over a recent 2-week period

we measured our MDR read error rate. A total of 1,073 worksheets were read. Errors were detected in 8% of the worksheets. Of the worksheets, 6% had errors that were immediately detected by the computer, and most of these could be corrected by the clerk and immediately reread through the MDR. The remaining 2% of the errors occurred because the technologist marked the wrong box in a result field and later recognized the error during the verification process which will be discussed next. The MDR misread only one worksheet. MDR misreads have occurred with occasional increase in frequency in the past. At these times the field engineer was called in to adjust the alignment and sensitivity of the MDR, usually with immediate resolution of the problem. Such service has been required approximately once every 3 to 4 months.

Worksheet verification. After a batch of worksheets have been read through the MDR, verification sheets (Fig. 6) are requested and printed in the computer room. The worksheets and verification sheets are collated by a clerk and returned to the technologists. The technologists then review the verification sheets, cancel or correct any erroneous results, and certify the rest. Certified results are automatically moved from a temporary worksheet verification file to the active microbiology accession file. Data in the worksheet verification file cannot be reviewed on a CRT, nor can they be printed on a patient report. Data appearing on a report are certified data from the accession or cumulative files. Erroneous data in the accession file can be corrected either on a CRT or by reading the corrected mark sense worksheet through the MDR.

Antibiotic susceptibilities. Antibiotic susceptibilities are requested for an organism by marking the appropriate box on the mark sense worksheet. After the day's last batch of mark sense worksheets is certified, antibiotic susceptibility worksheets are printed on the line printer in the computer room (Fig. 7). There is one worksheet per organism. These worksheets are used to record results and as a working document for CRT entry of results. For each antibiotic, a microdilution well number corresponding to the minimal inhibitory concentration is entered on the CRT. S, I, or R is entered for neomycin, sulfa/trimethoprim, and sulfisoxazole, respectively. The technologist compares the well numbers entered on the CRT to those on the worksheet, makes any necessary corrections, and transmits the data to the computer. A review screen is presented in which the well number has been translated to minimal inhibitory concentration, and any illegal well numbers

```
TIME  11:04                MICROBIOLOGY VERIFICATION            PAGE 38
DATE  03/28/79             WORKSTATION 850 - MAIN LAB           MDR    2

----------------------------------------------------------------------------
 BATCH   1 SEQUENCE  36                      TECH 99
----------------------------------------------------------------------------
 PATIENT, TEST?                       00-00-00-0    LAB        SEX-M        AGE 31
 MB-0189  REQUESTED 03/21 15:00   BY 257-LAWRIE, D. JAMES
 COLLECTED  03/21  15:00  BY     0              ROUTINE        WORK SHEET PAGE    1

 3100-ROUTINE CULTURE                    SPUTUM


 OBSERVATIONS
 STATUS               PRELIMINARY                                    *ADDED
    4003-GRAM POSITIVE COCCI IN CHAINS                               *ADDED
    5111-GRAM POSITIVE DIPLOCOCCI                                    *ADDED
    5112-GRAM POSITIVE BACILLI                                       *ADDED
    5087-GRAM NEGATIVE DIPLOCOCCI                                    *ADDED
    5095-COLUMNAR EPITHELIAL CELLS                                   *ADDED
    5098-GRANULOCYTES-MANY                                           *ADDED
    4036-NORMAL FLORA  IDENTIFIED AS:                                *ADDED
    1441-STREPTOCOCCUS - ALPHA HEMOLYTIC                             *ADDED
    1065-STREPTOCOCCUS, NONHEMOLYTIC (GAMMA)                         *ADDED
    1024-NEISSERIA SPECIES                                           *ADDED
    1445-CORYNEBACTERIUM SPECIES                                     *ADDED
    4064-          **SENSITIVITY RESULTS CODE**                      *ADDED


 ----------------------------------------------------------------------------
 ORG#001
    1052-STREPTOCOCCUS PNEUMONIAE                                    *ADDED
    7078-HEAVY                                                       *ADDED


 ----------------------------------------------------------------------------
 ORG#002
    0513-KLEBSIELLA PNEUMONIAE                                       *ADDED
    0248-LIGHT                                                       *ADDED
    API NUMBER    1215753                                            *ADDED
    BATTERY       MIC 2000                                           *ADDED
    SENSITIVITIES     AMIKACIN                                       *ADDED
                      AMPICILLIN                                     *ADDED
                      CARBENICILLIN                                  *ADDED
                      CEPHALOTHIN                                    *ADDED
                      CHLORAMPHENICOL                                *ADDED
                      CLINDAMYCIN                                    *ADDED
                      COLISTIN                                       *ADDED
                      ERYTHROMYCIN                                   *ADDED
                      GENTAMICIN                                     *ADDED
                      KANAMYCIN                                      *ADDED
                      NALIDIXIC ACID                                 *ADDED
                      NITROFURANTOIN                                 *ADDED
                      OXACILLIN                                      *ADDED
                      PENICILLIN G                                   *ADDED
                      STREPTOMYCIN                                   *ADDED
                      TICARCILLIN                                    *ADDED
                      TETRACYCLINE                                   *ADDED
                      TOBRAMYCIN                                     *ADDED
                      VANCOMYCIN                                     *ADDED
                      AZLOCILLIN                                     *ADDED
                      SULFISOXAZOLE                                  *ADDED
                      NEOMYCIN                                       *ADDED
```

FIG. 6. *Verification sheet corresponding to the worksheet shown in Fig. 5. The word "*ADDED" indicates that a particular result is a new result. Other possibilities include "*CHANGED," "*DELETED," or blank, indicating no change.*

not corrected previously are noted. If correct, the data on the review screen are certified.

Culture finalization and result correction. When all organisms in a culture have been identified and all other data have been entered, the culture is finalized. Ten days after a culture is finalized the results are transferred in the computer from the active, or accession, file to the historical, cumulative file. All results of a culture can be easily corrected or modified before they are transferred to the cumulative file. Although microbiology data in the cumulative file can be corrected, it has been made somewhat difficult to do and is necessary for at most one culture per month.

CRT data entry. Use of a CRT in the Honeywell system for entry of culture and organism data other than antibiotic susceptibilities has been mentioned. In fact, any data which can be entered on a mark sense worksheet can also be entered on a CRT. There are several reasons why we have elected not to use a CRT routinely for all microbiology data entry. First, a mark in a single box on a mark sense worksheet may translate to a phrase of English language text, e.g., organism name, which is identified in the qualitative dictionary by a four-digit code. This four-digit code must be entered on a CRT to communicate the same information to the computer. In our laboratory the average number of

NIH-1514-2 4·69	UNIT	PATIENT NAME		INIT.	PHYSICIAN NAME	INIT.	PATIENT NO.		INST.

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TIME    19:14                    MIC 2000                      PAGE 9
DATE    03/28/79                 SENSITIVITY WORKLIST
--------------------------------------------------------------------------

MB-0189,3100,02    03/21/79      ROUTINE CULTURE                    SPUTUM
           CALL GRAM STAIN RESULTS TO DR. LAWRIE   496-4433
           PATIENT,TEST?                 00-00-00-0       LAB
                                                          PRELIMINARY
     ORG#02 KLEBSIELLA PNEUMONIAE
```

```
         AMIKACIN      --1--   AMPICILLIN      --3--   CARBENICILLIN   --2--
         CEPHALOTHIN   --2--   CHLORAMPHENICO  --7--   CLINDAMYCIN     --3--
         COLISTIN      --6--   ERYTHROMYCIN    --4--   GENTAMICIN      --1--
         KANAMYCIN     --4--   NALIDIXIC ACID  --1--   NITROFURANTOIN  --6--
         OXACILLIN     --1--   PENICILLIN G    --1--   STREPTOMYCIN    -----
         TICARCILLIN   --5--   TETRACYCLINE    --2--   TOBRAMYCIN      --1--
         VANCOMYCIN    --8--   AZLOCILLIN      --1--   SULFISOXAZOLE   --2--
         NEOMYCIN      ----    SEPTRA          --1--
```

	NOTE	REVIEWED BY:
ANTIBIOTIC---RESULT---ANTIBIOTIC---RESULT---ADD.SENS---		

CLINICAL PATHOLOGY REPORT

			SPECIMEN DATE MO. DAY YR.	REPORT DATE MO. DAY YR

FIG. 7. *Antibiotic susceptibility worksheet with microdilution well numbers recorded. The well numbers are translated as shown in Fig. 8.*

four-digit codes per culture that would have to be entered on a CRT is eight. Thus reliance on a CRT for routine data entry would considerably increase the time required to accomplish this task and would probably be more error prone than use of mark sense worksheets, even though the codes entered on a CRT are automatically translated to English text on the review screen which is displayed before the data can be stored in the computer. Second, when multiple organisms must be entered for a culture, the process of using the CRT to verify the entered data becomes quite time consuming compared with the equivalent process for mark sense worksheets. Third, the additional time requirements of CRT data entry would leave the technologist with less time to devote to bench work, and additional CRTs would have to be purchased to handle our present workload.

In spite of the drawbacks mentioned above, we have found it useful to use the CRT for entry of the results of no growth, mixed flora, and low colony count (1,000 to 10,000 colonies per ml or less) urines. This task is performed by a clerk and requires the knowledge of nine qualitative dictionary codes and the entry of usually only one code and rarely more than three codes for a single culture. These results are entered and finalized when the culture is 24 h old. If additional information must be added at 48 h, the culture status is changed to "corrected," and the new results are entered.

Automatic no growth. Certain cultures for which no growth is the most frequent outcome are handled automatically by the computer (7), i.e., after an appropriate elapsed period of time the qualitative dictionary code for no growth is entered by the computer (Fig. 2) as a general observation, and the culture is finalized. No growth will be automatically entered for blood cultures and fungal and mycobacterial cultures after 12 days, 45 days, and 52 days, respectively, if no other results, e.g., results of a smear, or organism data have been entered. A log of the automatically finalized cultures is printed and a clerk compares this log to the mark sense worksheets which have been stamped no growth by the technologist at the time the culture is discarded. This process saves considerable technologist time and has reduced to zero the number of occasions on which there was a failure by a technologist to enter or finalize a no growth result.

Microbiology worklist. In addition to the

mark sense worksheets described above, the mycology and mycobacteriology laboratories use another type of working document, a microbiology worklist. This document is printed on the line printer on plain paper (8.5 by 11 inches [ca. 21.6 by 27.9 cm]) once a day. There are nine accessions per page organized in ascending accession number order. Only accessions which have not appeared on a previous worklist are printed. Between each accession there is sufficient space for the technologist to make notes about the progress of the culture. The worklists offer several advantages to the technologist working with tuberculosis or fungus cultures. Because the incubation times are frequently 6 to 8 weeks, there are often several hundred tuberculosis or fungus cultures in progress. Therefore, instead of having to manage 200 to 300 pages of individual mark sense worksheets, all of the active work will be contained in 20 to 30 pages of worklists. The technologist need only use the mark sense worksheets for cultures on which

there are positive results to report, a relatively small percentage of the total. Those cultures for which there was no growth are handled automatically by the computer as noted above.

Patient reports. Three types of patient reports are printed: cumulative report (daily and weekly), interim report, and physician's report. The format of the microbiology data (Fig. 8) is the same for the three reports. Interim reports are printed daily at 1:00 p.m. and are delivered to inpatient nursing units by the laboratory specimen pickup team. Interim reports contain all laboratory results certified since the previous cumulative report. Cumulative reports are printed daily at 5:00 p.m. and are delivered to inpatient nursing units by the hospital messenger service. The daily cumulative report contains all data since the previous weekly cumulative report. Once printed on a weekly cumulative, results do not reappear on any report unless they have been corrected or unless new data have been added to an accession. Weekly cu-

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14:57                        NATIONAL INSTITUTES OF HEATH              PAGE 1
03/29/79                         CUMULATIVE REPORT

PATIENT, TEST?                      AGE:  31Y     SEX:  M
00-00-00-0        LOC:  LAB        PHYS:  LAWRIE, D. JAMES                    CC-CP
---------------------------------------------------------------------------------
03/21  (1500)    SPUTUM           ROUTINE CULTURE       MB-0189    PRELIMINARY
                 CALL GRAM STAIN RESULTS TO DR. LAWRIE  496-4433

OBSERV GRAM POSITIVE COCCI IN CHAINS
       GRAM POSITIVE DIPLOCOCCI
       GRAM POSITIVE BACILLI
       GRAM NEGATIVE DIPLOCOCCI
       COLUMNAR EPITHELIAL CELLS
       GRANULOCYTES-MANY
       NORMAL FLORA IDENTIFIED AS:
       STREPTOCOCCUS - ALPHA HEMOLYTIC
       STREPTOCOCCUS, NONHEMOLYTIC (GAMMA)
       NEISSERIA SPECIES
       CORYNEBACTERIUM SPECIES
              **SENSITIVITY RESULTS CODE**
        S=SENS       R=RESIST        RP=RESIST,PENASE PRODUCER
       MR=HIGH IM OR IV DOSE NEEDED, IV=VERY HIGH IV DOSE NEEDED
       US=SENS ONLY IF LOWER URINARY TRACT INFECTION

ORG#1  STREPTOCOCCUS PNEUMONIAE
       HEAVY

ORG#2  KLEBSIELLA PNEUMONIAE
       LIGHT

       ANTIBIOTIC SENSITIVITIES  (MCG/ML)
       AMIKACIN       <=4 S     AMPICILLIN      16 MR, US   CARBENICILLIN   120IV, US
       CEPHALOTHIN    12 S      CHLORAMPHENICO  20 MR       CLINDAMYCIN     >5 R
       COLISTIN       <=5 S     ERYTHROMYCIN    >4 R        GENTAMICIN      <=3 S
       KANANYCIN      <=6 S     NALIDIXIC ACID  <=10 US     NITROFURANTOIN  <=50 US
       OXACILLIN      >6 R      PENICILLIN G    60 US       STREPTOMYCIN    <=25 S
       TICARCILLIN    120IV,US  TETRACYCLINE    4 MR,US     TOBRAMYCIN      <=3 S
       VANCOMYCIN     >25 R     AZLOCILLIN      <=12        SULFISOXAZOLE   SEN
       NEOMYCIN                 SEPTRA          SEN

---------------------------------------------------------------------------------
PATIENT, TEST?                       AGE:  31Y      SEX:  M      03/29/79   14:57
00-00-00-0        LOC:  LAB        PHYS:  LAWRIE, D. JAMES                    CC-CP
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FIG. 8. *Cumulative report. The "sensitivity results code" indicates the meanings of the abbreviations which follow the minimal inhibitory concentration for each antibiotic.*

mulatives are printed for both inpatients and outpatients. Outpatient reports are delivered to medical records and filed in the patient's chart. Physician's reports are printed daily after cumulative reports and include all data not printed on a previous physician's report. Physician's reports are printed only for outpatients unless a physician specifically requests that his inpatients be included as well. The morning after being printed, physicians' reports are delivered to physicians' offices in the hospital.

The format of the microbiology report is the same for each culture type, e.g., routine, fungus, etc., and begins with general observations. General observations are followed by specific organism identifications with antibiotic susceptibilities where appropriate. Results are sorted in the following manner: first by date, within date by body source, and within body source by accession number.

CRT data retrieval. In addition to the "hard copy" provided by patient reports, it is possible to use a CRT in the laboratory for retrieval of a patient's results. The data are displayed in reverse chronological order, and it is possible to look up the results of all active accessions, a specific accession, or to scan the cumulative file within a specified date range. The data displayed on the CRT are the same as the data printed on patient reports. The CRT retrieval is used routinely by technologists to answer telephone inquiries. The CRT is also used routinely by the infectious disease consultant physician for the hospital because the data for many patients in a variety of locations in the hospital can be reviewed in one place.

Additional reports. An incomplete work report is printed weekly. This report identifies all cultures which have not been finalized. A routine culture more than 3 to 4 weeks old or a mycobacterial culture more than 10 weeks old, for example, would be reviewed, and the reason it was not finalized would be identified.

Each day a specimen log which lists all specimens accessioned in microbiology during the previous 6 days is printed. This list is printed alphabetically by patient, within patient by body source, and within body source by date. The 6-day specimen log provides a quick reference for identification of patients from whom specimens are being obtained for culture more often than clinically necessary.

An infection control, epidemiology report can be printed weekly, biweekly, or monthly to provide a summary of all cultures positive for any one or more of up to 100 specific organisms. A table of organism versus patient location is printed for each body source. The body of the report is the count of the number of times a given organism was isolated from a given body source at a particular location in the hospital. In practice this report has not been particularly useful for several reasons. First, the patients whose organisms are counted in the report are not specifically identified. Second, the data in the infections control report are retrospective and do not provide day-to-day information about infection in the hospital. To provide the nurse epidemiologist with timely information, a report, printed nightly, summarizes all cultures to which new results have been added during the previous day.

A workload summary available for daily, monthly, or yearly statistics is printed. It provides raw counts of the number of cultures, e.g., routine or anaerobe, performed during the period of interest. The workload summary would be more useful if cultures were enumerated by body source.

Long-term data storage. Data are stored on computer output microfiche for long-term laboratory records. Once a week all certified results in the cumulative file not previously archived are written on tape, taken to the NIH central computer facility, the Division of Computer Research and Technology, and incorporated in the large central laboratory data base. The processing of the archive tapes results in the generation of microfiche for chemistry and hematology data and the transfer of all data into disk files for three different data bases; chemistry and hematology, bone marrow results, and microbiology. Once every 3 months data in the microbiology data base are transferred to microfiche. The mark sense worksheets for the most recent 3 to 6 months are filed in the laboratory and are discarded once the data have been microfiched. Two years' worth of data representing approximately 90,000 cultures have been stored on 85 sheets of microfilm (4 by 6 inches [10.1 by 15.2 cm]).

Although laboratory results are archived on tape weekly, all laboratory data for a patient are purged from the laboratory computer only if the following conditions are met: (i) the patient must have been discharged from the hospital, i.e., the patient is in outpatient status; (ii) all pending results must have been certified at least 30 days before purge; and (iii) all data must have been archived on tape. Certified results in the cumulative file may be partially purged if a particular patient is using a large amount of space in the cumulative file. If patient data are partially purged, the most recent 6 weeks of data will always be maintained.

Microbiology research data base. The microbiology data base, the data bases mentioned above, and other data bases are all part of a

larger system called the Clinical Information Utility. Anyone who is permitted access to charts in the medical records department may be given access to the Clinical Information Utility data. The research potential for both retrospective and prospective data analysis is significant. The data have been used to support the research of clinical investigators at NIH and by the Microbiology Service to determine policy regarding the laboratory work-up of certain types of specimens and to support research.

System down time. When a decision has been made to install a computer system in a laboratory, it must be recognized that there will be periods of time during which the computer will be unavailable due to malfunction or power failure. One must be prepared with a carefully organized plan which will permit the laboratory to continue to function without the computer. It must be possible to implement the plan flexibly to appropriately accommodate a variety of situations which can arise, e.g., a mark document reader is unavailable but the rest of the system continues to function, or the entire computer is down for 1 h or for 8 h, etc.

The reliance of the laboratory on the hospital computer system, TMIS, for assignment of accession numbers slightly complicates our down-time planning. However, all specimens arriving in the laboratory can be accessioned on the laboratory computer by using accession numbers in the laboratory system which will never be assigned by TMIS.

Costs, benefits, and liabilities. In discussing the costs, benefits, and liabilities associated with our use of a computer system in microbiology we will identify some of the elements involved without attempting to assign a dollar cost, except to say that the microbiology subsystem represents one-third of a system the original total cost of which was approximately $620,000, including 24-h/day, 7-day/week maintenance on all hardware for 5 years. The peripheral computer hardware required to operate the microbiology system have been described above. In determining the cost of hardware one must include maintenance and, depending upon the availability of maintenance personnel, the cost of backup hardware for crucial devices. Each of 18 technologists spends an average of about 25 min per day (range: 5 to 60 min/day) on computer-related functions, e.g., marking worksheets, reviewing verification sheets, and entering data on CRTs. These functions replace analogous functions from our previous manual operation, but the technologist time required has increased by a factor of about 1.3. The modest increase in work required to enter data into the computer is justified in our setting since, as a

byproduct of routine daily patient care-related operations of the laboratory, we are now capturing data for our research data base. In addition to the technologists, there are two other people who perform computer-related functions. First, a clerk spends 3 h/day putting mark sense worksheets through the MDR, entering results on a CRT, and performing other tasks described above. The second person is a former technologist who spends about 4 h/day performing a wide variety of computer-related tasks, some of which include training new microbiology personnel in the use of the computer, reviewing the weekly incomplete work report and resolving all problems raised by the incomplete work report, helping technologists with difficulties they may experience in their routine use of the computer, identifying and documenting hardware and software problems, and preparing file change requests, e.g., for adding a new organism to the qualitative dictionary, adding a new test to the test file, etc.

The cost of all preprinted documents and computer paper must also be considered. Because all cultures are reported on the same mark sense document, our expenditure for preprinted forms is relatively small. The only other form used exclusively by the microbiology section is the worksheet (5.5 by 8.5 inches [13.9 by 21.6 cm]) used for antibiotic susceptibilities.

The savings directly attributable to the computer will now be described. First, our previous manual system required one full-time secretary devoted to typing reports. Second, 3 to 4 h/week were spent reporting no-growth mycobacterial and mycological cultures. A secretary is no longer involved with reports, and no growth for mycology and mycobacteriology are automatically handled by the computer. Report distribution for microbiology is now integrated with distribution for the rest of the department, thereby eliminating about 2 h spent by a clerk performing this function per day.

There are a number of additional benefits attributable to the computer which enhance the service provided by the department. (i) Antibiotic susceptibility result recording has been simplified so that the technologist need only record the microdilution well number. Previously, the well number had to be converted to antibiotic concentration by the technologist before recording the result. The computer now automatically performs the conversion, resulting in some savings of time and reduction of error, particularly for inexperienced technologists. (ii) Patient demographic data including hospital location and attending physician are immediately available in the laboratory. This is particularly valuable in the specimen accessioning area

where it is frequently necessary to contact someone caring for the patient regarding a variety of questions which may arise concerning specimens sent to the laboratory. (iii) When a physician calls the laboratory with a question about a particular culture, it is no longer necessary to locate the results by searching through a number of worksheets belonging to the technologist working on the specimen in question. Most inquiries can be answered by retrieval of the information on a CRT. (iv) Archived data are now kept on microfiche, resulting in a very substantial saving in filing space and frequently simplifying retrieval of old results. (v) The value of the system for creating a research data base which is a byproduct of routine laboratory operation has been discussed. (vi) The system generates a readable, standardized report for the medical record.

It should be emphasized that some of the benefits noted above could be realized in a well-designed manual system and that others that are important in the environment of our laboratory would not be important in a different setting. Such potential benefits must be weighed carefully against the liabilities of introducing a computer system in the laboratory.

The installation of a computer system can be a very traumatic experience for people at all levels in the laboratory and for those caring for patients. The installation of the system in our microbiology laboratory was quite smooth, a marked contrast to the installation of the system in the chemistry and hematology departments. The relative ease of the installation in the microbiology laboratory is attributable to several factors: (i) the system had been operating in chemistry and hematology departments for 9 months, so most of the initial hardware and operating system software problems had been resolved; (ii) the microbiology applications software was very completely checked out by Honeywell, and there were no serious deficiencies detected after installation; (iii) the computer had been used for accessioning and for reporting serology results since its original installation in the chemistry and hematology laboratories; (iv) more time was devoted to teaching the technologists how to use the system before they had to use it in daily operation in the microbiology lab; and (v) the computer did not substantially change the relationship of the technologist to the bench work, i.e., there were no instruments directly on-line to the computer, and the hand-written aspect of recording the work-up of a culture was unchanged.

Once a computer has been installed, the laboratory becomes dependent upon it in many respects. Therefore, when the computer is down, as occasionally it will most certainly be, the disruptions of daily routine and of the level of service which we all have come to expect can be significant. Such disruptions can be minimized only with careful planning and careful review of the manner in which the laboratory has dealt with previous periods of computer down time.

The other major liability associated with the use of the computer is the limitations which even the most flexibly designed systems can impose on the reporting of new types of data. We have emphasized the flexibility of the Honeywell system in permitting the routine types of changes the laboratory usually needs to make. It is not always possible to anticipate new types of results which one may wish to report. Therefore, the types and characteristics of data which are permitted by the system must be carefully studied. For example, API has recently enlarged their numeric scheme from seven to nine digits for nonfermentative gram-negative rods. Although we do not print the API number on patient reports, the data are entered and stored for research purposes. The manner in which the API number is stored in the computer precludes the possibility of storing a larger API number. Although a larger API number could be entered as free text, it would then appear on patient reports. It would not be distinct from any other free text comment, and the data could not be easily identified and archived for our research. In addition, the program which processes the mark sense worksheets does not recognize an API number of more than seven digits. The limitation just discussed could be corrected at a considerable expense of reprogramming, not to mention the changes which would be required to add two more digits of API number for each organism on the mark sense worksheet.

Thus, in the process of selecting a computer system for a laboratory or any other environment, one must clearly delineate the functions the system must perform, attempt to anticipate the future uses of the system, and analyze the limitations of the system. Finally, it must be recognized that any system cannot be all things to all people and that most decisions must be made balancing benefits and liabilities.

Potential enhancements to clinical microbiology computer systems. There are a number of areas in which we believe substantial enhancements could be made to our microbiology system. Some of these enhancements are specific to the Honeywell system, and some would be desirable in any system and are not to our knowledge presently available.

There are two features that would improve the mark sense worksheets. First, considerable flexibility in the design of the worksheets could

be achieved if more than three organisms could be reported on a single page. Second, it might be desirable to have more extensive error checking of the final organism identification. For example, one might check the organism identification against the API number or compare the sensitivity pattern of the organism against the sensitivities of other isolates of the same organism. It must be emphasized that although it is often possible to implement sophisticated error checking and other complicated procedures, this may be done at considerable expense in terms of system performance or programming time. The potential benefits must be weighed against the cost.

In our laboratory the computer could be helpful in facilitating intralaboratory referral. For example, if the routine bacteriology laboratory isolated a yeast, a box on the worksheet would be marked which automatically causes the computer to generate a mycology worksheet, and to generate on the patient report a comment such as "yeastlike cells isolated, identification to follow." Data collection for some of our research projects would be facilitated if the system could be easily modified to uniquely recognize new types of data, e.g., staphylococcal phage types, pseudomonal grouping, a nine-digit API number, etc. In addition, there may be new types of information of clinical utility which should be printed on a patient report and which should be identifiably separate from existing data types in the computer. The system as presently designed has little flexibility for the introduction of new data types which do not correspond to existing categories.

Workload reporting in microbiology could be substantially improved. It would be possible to implement a system based on organism identification, rather than the number of cultures performed regardless of growth. Since the path by which the final identification of an organism from a specimen of a given source is usually known, it is possible in most cases to assign a weighting factor which accurately reflects the amount of work required to make the identification. Only a computer could make such a workload reporting system economically feasible.

The present CRT data entry scheme is cumbersome and can be time consuming to use, especially as the number of organisms identified in a culture increases. A redesign of the CRT data entry scheme would result in some improvement. However, any scheme which depends upon the entry of code numbers or even mnemonic abbreviations is difficult for the new user to learn. The use of a very fast CRT equipped with a light pen would avoid the necessity of using codes or abbreviations if the screens presented lists of organisms, minimal inhibitory concentrations, etc., which would be selected with the light pen. Such a system, if properly designed, could be a considerable improvement on the use of mark sense documents. However, to function smoothly, a CRT-based system might require one device per technologist, an expensive proposition at this time. In addition, there would be considerable idle time for each device, thereby requiring such a terminal to be very inexpensive for it to be cost-effective.

Instrumentation for the automatic identification of microbial organisms is being developed. One must anticipate the time when it will be desirable to interface such devices with a laboratory computer system.

The ability to perform cross-patient retrieval of laboratory data might be a useful function to incorporate into a dedicated laboratory system. There are several major obstacles to this application. First, the mass storage required to maintain the total output from the laboratory rapidly becomes very large. Retrieval of data across patients from a data base stored on magnetic tape, relatively inexpensive mass storage, is very slow and cumbersome. Second, the minicomputers used in most laboratory systems simply could not perform efficiently for the laboratory and simultaneously search a large data base.

Archival of purged patient data presents another problem for the minicomputer-based laboratory system. Although the Honeywell system provides the capability to transfer data to magnetic tape, it is very difficult to retrieve the data from tape for a single patient or for a group of patients using the programs provided with the system. In addition, the output does not provide a readable report. These problems could be corrected; however, it would become necessary to maintain a computerized indexing system to help locate the tapes on which the desired data are stored.

There is a growing interest in the use of computers to provide interpretative reports of laboratory data (1) based on a synthesis of a variety of discrete parameters. It might be possible to provide a physician with therapeutic recommendations based on the body site from which was isolated an organism with a given antibiotic susceptibility pattern. Similarly, through integration of laboratory and medication data one might provide the clinician with an early warning of possible harmful side effects of antibiotics or other drugs the patient was receiving. Integration of drug and laboratory data would not be practical without a hospital information system. However, a dedicated laboratory system

could provide the capability of retrieving and displaying laboratory data relating to organ systems or diseases, e.g., a meningitis profile might include cerebrospinal fluid cell count, differential, protein, glucose, culture, etc.

It should be noted that Honeywell is no longer actively marketing the system we have described. However, there is an active users group, and the possibility exists that Honeywell will develop a laboratory system for use on their new generation of minicomputers.

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