A computer system for clinical microbiology

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SUMMARY The Department of Clinical Microbiology at St Thomas' Hospital has been producing bacteriological reports on a computer for more than three years and is now producing some 2300 reports per week. The system is operated entirely by laboratory staff without special training, and involves the use of optical mark reader (OMR) forms as worksheets, automatic validation and release of most reports, the use of local terminals, and scrutiny of reports by pathologists using a visual display unit. The OMR worksheet records not only the final result but also most of the tests and observations made on the samples; it is the only working document used by technicians. One specialist clinic submits its laboratory requests on an OMR form, which is subsequently used to record the results. The reports are printed and also filed in the computer to produce analyses for hospital, laboratory, and clinical management.

Andrews and Vickers (1974) described a clinical bacteriology reporting system based on optical mark reader (OMR) documents. Our system was developed from this but differs from it in several ways, the most important of which are: that we record the results of most of the technical manipulations, making possible automatic validation of reports; that reports can be scrutinised on a visual display unit (VDU) before being printed; that the actual report slips are delivered directly from the computer room to hospital departments; and that a significant part of the program suite is table-driven for easier and quicker implementation of changes in laboratory practice. The equipment in the laboratory consists of a fast VDU, two medium-speed typewriter terminals, and an OMR, which is integrally linked with its own typewriter terminal. These are all on-line to the hospital's own computer which runs in time-sharing mode (usually with 24 terminals and background batch jobs).

Objectives

Many workers have identified a variety of objectives to which an acceptable computer system should aspire, and those at St Thomas' broadly concur with those listed elsewhere (Andrews and Vickers, 1974; Goodwin and Smith, 1976). Our system differs from many others in that it was designed to produce part

of an integrated patient computer record to be centrally printed for direct distribution in the hospital. In this context our objectives were to implement a workable computer system, without an increase in either laboratory staff or revenue cost. At the outset it was not intended to produce directly quantifiable savings, and the laboratory undertook the process mainly to gain the benefits of easier analyses, including statutory returns and cross-infection control statistics. There was also a requirement that results should be available for clinical research.

The system we describe differs from that originally intended in that, as a temporary measure, we still produce our own report slips, now computer-printed on plain paper.

The system

Each specimen arrives in the laboratory accompanied by a conventional request card except those from the Department of Genito-urinary Medicine, which are accompanied by an OMR worksheet containing the request details marked in the clinic. Periodically, all the work for a particular section is collected by a technician who either enters the request details into the computer, thereby causing a standard OMR worksheet to be immediately generated, or, when prenumbered, multisample OMR worksheets are to be used, hands the cards to a secretary, who enters request details in batches. Each request is logged as a

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HHHHH
NEXT?999111;GCB;CAS;8770(VENOUS ULCER);AJW

ST. THOMAS' HOSPITAL ROUTINE MICROBIOLOGY REPORT FORM

SSUE 5 (MAR. 77) FORM 2

CB= 999111 NAME: JOHN SMITH DOB: 13 APR 10 SEX: M

DOB: 13 APR 10 SEX: M

REQUESTER: DR. G.C. BROWN DEPT: ACC & EMERGENCY RET. TO: CASUALTY

RECEIVED AT 15:17 ON 20 SEP 77 BY A. J. WILLIAMS

SPECIMEN : WOUND SWAB- KEY-IN - VENOUS ULCER (8770)

BENCH: WOUND SWAB LAB NO= 1406

OLD LAB NOS= 949 06 APR

[illegible]

Fig. 1 *Entering details of the request into the computer.*

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[illegible]

Fig. 2 *Record of initial observations.*

message of some 30 characters, which contains the sort of information shown in Figure 1. A hospital number is used to identify the patient, and the computer extracts from its files the appropriate name, age, sex, and other details; patients for whom no number is given are identified by name alone. Clinicians are identified by their initials, wards and clinics by simple mnemonics, and specimens by numeric codes. Although about 600 specimen codes exist, most technicians easily memorise those they most often need since each section of the laboratory deals with only a limited range of specimens. The computer then interprets, decodes, and prints an expanded version of this message and either allocates a laboratory number (standard worksheet) or uses the number supplied as part of the message (specialised worksheets). Should the technician find a mistake in the decoded message, he cancels that OMR worksheet, thereby wasting the document, and enters the correct information or edits the details on another terminal.

We have devised five different OMR worksheets to cater for three distinct types of sample: those that are all processed by similar, often extensive, procedures and together make up some 30% of specimens received (for example, stools, wound swabs, sputum, and cerebrospinal fluid); those that are sent in large numbers but may require less elaborate investigation (urine specimens and samples to be examined for acid-fast bacilli or gonococci); and those that are processed by elaborate procedures which differ considerably from most other specimens (blood cultures). The first category is handled by the standard OMR worksheet, which is described in detail since it is the most comprehensive.

STANDARD WORKSHEET

The document has a large working area ($17\frac{1}{2} \times 11\frac{1}{2}$ in; 43×28 cm) with 1298 OMR cells and is supplied as continuous fanfolded stationery with sprocket holes on both sides to permit its use in a typewriter terminal. Request details are entered by technicians who usually log in batches of requests and then separate the documents for inclusion into a folder. The computer allocates a laboratory number and defines, according to the specimen type, which section of the laboratory is to undertake the work; the laboratory number is also bar marked on the form (last line of Fig. 1) so that it can be identified by the computer when the form is subsequently entered.

There is then a logical progression down the form, corresponding with the order in which the work is done.

The next section (Fig. 2) is filled in shortly after receipt of the specimen and is concerned with the specimen appearance, microscopy, culture plates

set up, and general comments. Numbers are recorded in an additive fashion (for example, marking 80, 10, and 4 would mean 94); rough quantification is indicated by the marking of the appropriate cell or, if nothing is seen, of all four. The culture media used are marked and, if any comments are appropriate at this stage, they are indicated in one or more of three ways: directly (for example, 'NO SITE' if no site was stated for a wound swab); by a numeric code from a dictionary of comments; or, if more than one code is required or if the comment is not in the dictionary, by the marking of the 'Ext' cell and the writing of the extra codes or comments on the left of the form for subsequent entry via a keyboard.

The next section is divided into four identical columns and is concerned with the detailed work of identifying organisms; a second OMR form is used if more than four organisms are investigated from one specimen. Each column includes space for recording the colonial appearance and almost all confirmatory biochemical tests. There are 56 recordable tests in each of the four columns.

Most test results are recorded with only two cells instead of the three that might otherwise be needed to record a total of four states. The use of 'done' and '+ve' can be seen in Fig. 3, in which the distinction between 'set up' (but not completed) and 'negative' is not apparent to the OMR, which cannot see the vertical mark, treating both as 'negative'. It is, of course, important for the technician to be able to distinguish between the two conditions, and this technique saves 208 cells from an already large OMR document. It is possible to cancel a mistake by filling in the whole of the bottom half of a square.

The organism identified and its sensitivities are recorded at the bottom of the column. The 25 most frequently isolated organisms may be marked directly on the form; for others the technician marks the 'Ext' cell and writes the name of the organism and its code on the left of the form. The 'NI' cell is used to signify

<div style="border: 1px solid black; padding: 2px; display: inline-block;">LACTOSE d +</div>	not set up
<div style="border: 1px solid black; padding: 2px; display: inline-block;">LACTOSE d +</div>	lactose set up
<div style="border: 1px solid black; padding: 2px; display: inline-block;">LACTOSE d +</div>	lactose positive
<div style="border: 1px solid black; padding: 2px; display: inline-block;">LACTOSE d +</div>	lactose negative

Fig. 3 Use of two cells to record investigations performed and positive and negative results.

Please use a separate row for each specimen.
Write the Lydia number below for the first specimen from a patient, otherwise just mark [] As above.
Do not split specimens from the same patient over more than one sheet.

To be completed by LYDIA DEPT.										To be completed only by MICROBIOLOGY																
Nature of Specimen										Microscopy																
Ur	Cerv	Vag	Rect	GC+	GC-	GC+	GC-	GC+	GC-	Com-ment	Negative	24 hr	48 hr	FA	Sig	Glucose	N	Men	N	Conc	sp	22°C	NA	Peng	Report	
1	Lydia number																									
	if other plate please specify:																									
2	Lydia number																									
	if other plate please specify:																									
	Lydia number																									
	if other plate please specify:																									

Fig. 5 Part of the request/report forms for specimens from the Department of Genito-Urinary Medicine (LYDIA).

ogist. The criteria used in determining whether or not a result can be automatically released have evolved over a long period of careful deliberation to prevent the automatic release of misleading or erroneous results. In general, any result with a computer-detected error, any from a sample from a site that is normally sterile (but not urine and urethral samples), any from a site with a normal flora that yields a potential pathogen, or any that can be considered to differ from a previous result for a given patient is held back for scrutiny.

The request cards are sorted in laboratory number order for each type of specimen, this being the order in which the results appear for scrutiny. During scrutiny the computer displays each report in turn, showing first any errors it may have detected, then the version of the report that will go to the clinician, and, finally, if required, the technician's workings. Having taken note of the errors and warnings, and of the clinical details given on the request card, the pathologist may either change or add to the report, delete it for correction by the technician and subsequent re-entry, or release it. Most are released without amendment; those that are amended usually have a comment added or have alterations made to the list of antibiotics being reported. Further facilities exist, such as leaving a result for later examination. The pathologist is informed if a result has been automatically released so that the request card may be removed or so that he may recall the report if necessary.

At fixed times during the day and on demand by the laboratory all outstanding reports that have been released are printed in the computer room and delivered to their final destination without further attention by the laboratory. All reports for each destination are printed together to help the porters.

Each morning the laboratory receives a variety of computer-printed documents. These include cumulative results of the week's reports to date, a daysheet of the previous day's reports, a list of work in hand (all in patient name order), a list of specimens for which a report should have been issued, and a number of lists identifying particular types of results for clinical and laboratory management purposes. Each weekend the computer archives the previous week's results to magnetic tape for long-term storage, removes results more than two weeks old from the immediate-access file, accumulates statistics, and produces listings which are available to the laboratory on Monday morning.

The statistics accumulated by the computer are printed at the command of appropriate laboratory staff who use any terminal to enter details of their requirements. These statistics include analyses of laboratory workload for the Department of Health

and Social Security (DHSS), hospital and laboratory management, the detailed incidence and antibiotic sensitivity patterns of organisms from the various clinical sources for cross-infection and quality control, and specialist analyses for laboratory and clinical purposes, such as the control of the selective medium used for the isolation of gonococci by a continuous comparison of culture results with positive findings on microscopy of the original sample. In addition, a more precise evaluation of laboratory work content is done based on a unit-costing scheme (Statistics Canada, 1976).

COMPUTER CHARACTERISTICS

The programs and software routines were developed in Rank Xerox Data Systems (RXDS), Extended Fortran IV, and RXDS Metasymbol. The low-level subroutines are concerned mainly with input/output and the manipulation of variable length, and string, data items. Considerable effort was devoted to ensuring a high content of table-driven processing. This technique is used for interpreting the OMR forms, for converting the internal data representation to text, and for accumulating and analysing the costing statistics; other programs are also generalised wherever possible. This emphasis was intended, firstly, to enable functional changes in the system to be made with minimal changes in program logic and, secondly, to encourage interchangeability between applications.

The method inevitably carries an overhead in the use of hardware resources, particularly disc channel time; however, we have no reason to believe this to be excessive. Our machine load compares well both with that imposed on our own computer by other applications of comparable load and complexity and with microbiology systems implemented on other computers. The total central processing unit time for all functions equates to 6.3 seconds per report issued, and the average number of disc accesses is 354 per report; if, however, one excludes all ancillary facilities not directly concerned with report production these figures drop to 3.3 seconds and 194 respectively. Each report is held on disc as a variable-length record of between 100 and 500 bytes (average 350 bytes). Up to three weeks of reports are maintained on line, with a disc requirement of 2 megabytes: a further 8 megabytes are required for the storage of programs and other work files.

The central hardware consists of an RXDS Sigma 6 with 128K 32 bit words of core, five exchangeable disc drives each of 48 mB capacity, two tape drives, card reader, and line printer. Up to 24K words is available to on-line programs and 32K words is the usual batch partition size in use during the day. Our OMR is a Data recognition 8301B with a Dataterm

3 reader, the VDU is a Case Vistar operating at 1800 BAUD, and the typewriter terminals are 30 character-per-second Diablo 1620 Zygol printers.

Transferring the system to other computers would not be a simple task, not only because of its inherent complexity but also because it relies on other computerised applications run by St Thomas' project; these are patient registration, a medical staff code sub-system, and a bed state application. Despite these problems we can, by extrapolating experience gained transferring another application (Williams *et al.*, 1975), estimate that such a transfer might take some 18 man-months. This comprises seven man-months transcribing the low level subroutines, five man-months transferring and testing predominantly unaltered Fortran modules, and some six man-months reprogramming to accommodate differences in system and user environments. Since Rank Xerox no longer manufacture computers transfer might now be more difficult and take longer.

Results

The design of the computer system was started in late 1971 and a pilot trial was undertaken in the spring of 1973. This was of benefit to the computer department which was able to evolve the table-driven techniques for handling laboratory results and OMR forms. The final system was implemented on a section-by-section basis from July 1974 onwards, one of us (ER) joining each in turn to resolve computer-related problems. In this way, most of the sections using the standard OMR worksheet and the section dealing with samples from the Department of Genito-urinary Medicine were implemented within five months. The remaining sections (dealing with blood cultures, urines, and mycobacteria) were included as the detailed design of their particular worksheets was completed so that by November 1975 nearly 90% of the laboratory's results (excluding immunology) were being reported through the computer system. Phased implementation meant that the disruption arising from the change to the computer system was confined to small areas of the laboratory at a time.

The system eventually issued some 2300 reports per week, which, allowing for multiple specimens on the same report, involved results from over 2600 specimens. The capacity of the system may be gauged from its ability to cope with 950 reports in a single day after a prolonged breakdown.

Technicians found little difficulty in booking in their specimens through the terminals, thus undertaking the work that would require at least one clerk (Goodwin, 1976). However, one chief

technician (ER) still spends 25% of her time dealing with problems arising from the computer. One problem was that only 43% of request cards contained correct patient hospital numbers and only 80% adequately identified the requester. In these circumstances, it was highly desirable to avoid the error correction cycles inherent in some systems and to operate request entry on-line. It was found necessary to install a second terminal to book in specimens to prevent congestion at peak times, and this had the added benefit of providing backup.

The use of OMR forms as worksheets presented few problems, and technicians adapted with very little difficulty. The only problems with OMR documents as such occurred outside the laboratory when clinical staff were involved. They tended to use inappropriate marking instruments such as ball point pens and to mutilate the 'read area' of the form with manuscript comments. Many of these OMR forms had to be transcribed by laboratory staff before they could be read by the OMR; not unnaturally this led to errors and delays. It was several months before the encouragement of those in authority led to a satisfactory level of marking skill by clinicians, and this has since been maintained.

Technical staff in the laboratory used HB pencils and soon achieved a very high standard of marking; few forms had to be returned to the technician because the OMR could not read them. The incidence of *misreading* by the OMR was very low and arose at worst about once every two months (that is, 10 000 forms) usually from the submission of soiled or mutilated documents. On such occasions the results have been so nonsensical that the errors were quickly noticed. We have a backup OMR, which enables us to read our forms via punched paper tape. This is a very slow process, however, and we have used it only twice in three years.

The first version of the standard OMR worksheet was printed in black, red, and blue but, although this had a pleasing effect, the printers experienced technical difficulties in producing it and this, in conjunction with its extra cost, led us to print subsequent issues in black and red only. We found it inadvisable to use forms of differing thicknesses and have since standardised on 80 gsm paper weight.

Secretarial staff had no major problems with the system either in dealing with the computer or in their increased responsibility and close liaison with technical staff.

On average 1000 forms were entered through the OMR each week; the maximum observed rate for our large forms was 18 per minute. The task of entering OMR forms proved tiresome only when the marking quality was poor.

Manual annotation by keyboard entry was necess-

ary for 15% of forms (5% of reports) and was a job the secretaries found to be easy.

About 35% of reports were scrutinised by a pathologist who devoted about 90 minutes per day to this job. The previous manual system required all reports to be scrutinised, and the job was shared among all pathologists who did it at their convenience. The new system required scrutiny by a single individual and at set times, and pathologists found the task somewhat irksome at first. They found little difficulty in using the computer although some facilities proved too unwieldy and, rather than edit the computer's record of an erroneous report, they preferred to cancel it and have the corrected OMR form re-input. The change they most frequently made altered the standard decision as to which antibiotic sensitivities should be released to the clinicians. The computer's response time varied with load imposed by other users but was normally instantaneous. At worst there could be a delay of about 5 seconds between successive reports.

The printing of reports was originally done only on the command of the laboratory staff, but as it was often overlooked with consequent delay the computer operators took it over. Porters saved half an hour each day because reports were already sorted into destination order.

Hospital clinicians, other ward staff, and general practitioners have made no comment, adverse or otherwise, on the new format and typeface of the microbiology reports, the only change that has affected them.

The computer time involved in the running of the complete system equates to 6.3 seconds per report, although direct comparison of such times is an inaccurate way of assessing a system's cost or efficiency other than on closely similar computer system configurations.

Machine breakdowns have been a regular feature of the system's operation. Failure of the OMR itself has occasionally caused reports to be delayed; the typewriter terminals also break down occasionally but this causes little trouble as spare equipment is available. The lack of reliability of the central computer itself has, however, emphasised the need for well-defined backup procedures. Fortunately, these central failures seldom last long enough to prevent report production on the appropriate day but they do cause considerable problems in catching up with current requests. Normally the perceived up-time is of the order of 95% but we have experienced periods of several weeks when recurrent machine failures have reduced this considerably. In the event of prolonged breakdown the laboratory issues preliminary photocopied reports, and, for new specimens requiring the standard OMR work-

sheet, the technicians use a supply of pre-numbered forms until the emergency passes. This procedure is laborious and time-consuming and is resented by all laboratory staff.

Bearing in mind our objectives, we believe that any analysis of the total cost of our system is inappropriate and, in our context, difficult, as we should properly include all related costs such as our proportion of those of the computer department, of the computer itself, of its running costs, all of which were part of a DHSS-sponsored experimental scheme, and of the time spent by laboratory staff in designing the system. Furthermore, it is difficult to assess qualitative benefits and the provision of services through the computer that were not practicable under a manual system. For our purposes, therefore, it is sufficient to list changes within the laboratories, which are: a marginal saving in stationery costs; no nett saving on technician, clerical, or pathologists' time in the routine servicing of requests; a considerable saving in time throughout the laboratory in the production of analyses for hospital, laboratory, and clinical management, and quality control; a variety of unquantifiable benefits such as improved accuracy and legibility of reports, better control of our work, improved technician training through the comprehensive nature of the OMR worksheets, release of the pathologist from routine scrutiny, enabling him to concentrate on the clinical implications of the results, and an increase in the information available to the laboratory on its work and results.

Discussion

We believe that our system represents advances in the use of a computer in clinical microbiology, which stem mainly from our ability to record the technician's workings. Since our reports will eventually be replaced by an integrated document containing results from other laboratories we had to design a system in which scrutiny could occur before the reports were printed. We chose a VDU for this task but, since terminal capacity is limited, it was practicable only if most results could be automatically released. The detailed workings were therefore required not only so that the validation could be sufficiently rigorous that results could be released without scrutiny, enabling the pathologist to concentrate on clinical problems, but also so that scrutiny of the remainder could occur without recourse to hand-written documents. At scrutiny the pathologist must be able to check the technician's conclusions against his observations.

We have found that OMR techniques are an effective way of recording large quantities of informa-

tion with a high degree of accuracy and acceptability to the user (the technician). It does not impose an undue clerical load on technical staff nor does it delegate the task to specially trained typists. One deficiency is that we have not yet solved the problem of recording the results of serological investigations on potential gut pathogens. The design of the OMR worksheets themselves is of crucial importance to their eventual utility and, if the use of a document is kept within an administratively and spatially localised area, very large documents can be used successfully at a cell density approaching 100%. We have not found it practicable, save in one area, to use OMR for request entry and instead we use a keyboard for this information; even so we do not enter the clinical comments, and this restricts our ability to construct more sophisticated algorithms by which we would automatically release a greater proportion of our reports. In our experience, the OMR technique cannot easily be extended to include the clinical information provided on the request form.

The computer-produced analyses save time for all types of laboratory staff, releasing them for the tasks for which they were trained. This is especially so in the area of infection control where, without the computer, we were restricted to a routine investigation of *Staphylococcus aureus* only, whereas now we can also study other microorganisms and spend time in infection control that was previously spent collecting statistics.

We also believe that the analyses, particularly those of our workload, are more accurate than those produced manually. The unit costing analysis of workload based on the 1976 Canadian Schedule (Statistics Canada, 1976) is of particular interest and will enable us to assess the real workload imposed on the laboratory by different specimens, hospital firms, and so on. Once again this analysis would not be possible unless the technicians' workings were recorded. The results of this exercise may well be useful in other hospitals after further evaluation.

Control of work in progress has been greatly improved by the computer, three facilities being of particular value. These are a list of all work for which a report should have been issued, a table listing the number of outstanding reports for each section of the laboratory, and details of work completed or in hand for a particular patient. All three are available on-line and are also printed daily.

Cumulative reports are available within the laboratory, but we have delayed their introduction elsewhere until an integrated patient record, using the results of other applications, can be produced.

In general, we have been neither unduly surprised nor disappointed by our computer, which has produced the results that we expected of it. We look

forward to the extension of the system to the rest of the laboratory. We also look forward to a linking of laboratory and clinical information which will come when the whole project is complete. This, we believe, will enable us to detect incipient problems and to move more quickly than we now can to assist in the diagnosis and control of infection in the individual, and in preventing its spread to others.

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