# ELECTRONIC-DATA-PROCESSING IN CLINICAL BIOCHEMISTRY

By I. K. Tan, B. S. Tay, S. H. Lim, C. K. Taw* and M. C. Ng†

## SYNOPSIS

**Increasing laboratory workloads and mechanisation of chemical analyses by the use of various forms of automatic analysers and/or work-simplification devices have hastened the introduction of electronic-data-processing (EDP) to facilitate the handling of laboratory information. This paper describes the use of a NOVA 1220 mini-computer system for (1) acquisition and storage of patient information and analytical results and the processing of these data, (2) automatic preparation of daily worksheets for the various biochemical estimations, (3) automatic generation of laboratory reports, (4) production of summary of daily work performed and (5) generation of quality control statistics. The organisation of the work-flow in the laboratories is also presented.**

With the greater application of scientific methods to medicine, the care of patients increasingly relies on various types of laboratory investigations. Routine testing has increased and time-consuming specialised techniques have become more common. Over the past 10 years, many laboratories have reported dramatic increase in workload, and there is no reason to expect that the load will level off at any particular level in the near future. The increase is over 10 per cent per annum in most hospitals but others, better equipped and/or with more academic interests, are estimated to double their workload every five years. Table I shows the tremendous increase in the demand for biochemical analyses during the period 1963 to 1973 as observed in the Clinical Biochemistry Laboratories of the Government Department of Pathology in Singapore. Larger number of patients being investigated, more tests being carried out on each patient and an increase in the range of tests are responsible for this increase in workload which is mainly technical and clerical in nature.

TABLE I

WORKLOAD OF CLINICAL BIOCHEMISTRY LABORATORIES, SINGAPORE, FROM 1963 to 1973

| Year | Number of Analyses* |
|---|---|
| 1963 | 38,053 |
| 1964 | 53,408 |
| 1965 | 78,757 |
| 1966 | 118,631 |
| 1967 | 147,266 |
| 1968 | 154,429 |
| 1969 | 171,169 |
| 1970 | 159,735 |
| 1971 | 202,107 |
| 1972 | 242,557 |
| 1973 | 373,882 |

*Potassium, sodium and chloride determinations have been grouped as one single analysis.

Many laboratories have introduced work simplification devices and various forms of continuous and discrete automatic analytical equipment to relieve the technical burden. In our laboratories, a number of direct digital-read-out spectrophotometers equipped with flow-through cells and suction pumps, single or dual-channel AutoAnalysers and more recently a six-channel SMA 6-Plus machine have been used to overcome the problem. However, the increased speed of testing, when test procedures are mechanised, has highlighted the clerical burden of data-processing. In fact data-processing rapidly becomes the bottleneck of the biochemistry laboratories. In highly mechanised biochemistry laboratories, it has been estimated that up to 30 per cent of a technician's time is spent on purely clerical work involved

Clinical Biochemistry Laboratories, Government Department of Pathology, Outram Road, Singapore.

I. K. TAN,
B. S. TAY,
S. H. LIM,
C. K. TAW,*
M. C. NG,†

*Dataprep (Singapore) Pte. Ltd., Singapore.

†Ministry of Health, Palmer Road, Singapore.

in identifying specimens, in composing worksheets, in reading, calculating and checking results and transferring these onto his/her worksheet and onto a laboratory report. This is indeed a serious waste of professional skill. Unless something is done to speed up and streamline this aspect of the overall process, much of the advantage of automating analytical procedures will be lost. It is therefore not surprising that many highly automated laboratories began to employ electronic-data-processing (EDP) techniques to solve the clerical burden as well as the increasing problem of data storage and retrieval. Since routine analytical results of biochemical laboratories are almost entirely in numerical form, they are most suited for processing by a computer. This accounts for the relatively earlier introduction of EDP methods in these laboratories. Transformation of experimental readings by calculating machines has been a routine activity to laboratory staff so that they tend to take naturally to the introduction of computer techniques. The present paper presents our 5 months' experience in the use of a minicomputer for EDP in our laboratories.

## SCOPE OF LABORATORY DATA-PROCESSING

The general work-flow scheme summarising the activities of a biochemistry laboratory unassisted by EDP system is shown in Fig. 1.

Data-processing in the laboratory includes all those steps in handling information between the clinician's requesting a laboratory test and his receiving the report and includes the following activities:—

1. Linking test specimen with the request form.
2. Preparing worksheets from request forms and filing the latter to await results.
3. Recording the raw test-result data and calculating the results on worksheets.
4. Checking the quality of each batch of results.
5. Transferring the results from worksheet to appropriate request form which is also used as a report form.
6. Editing the report.
7. Sending the report to the appropriate address.
8. Filing copy of report in the laboratory for temporary or permanent storage.

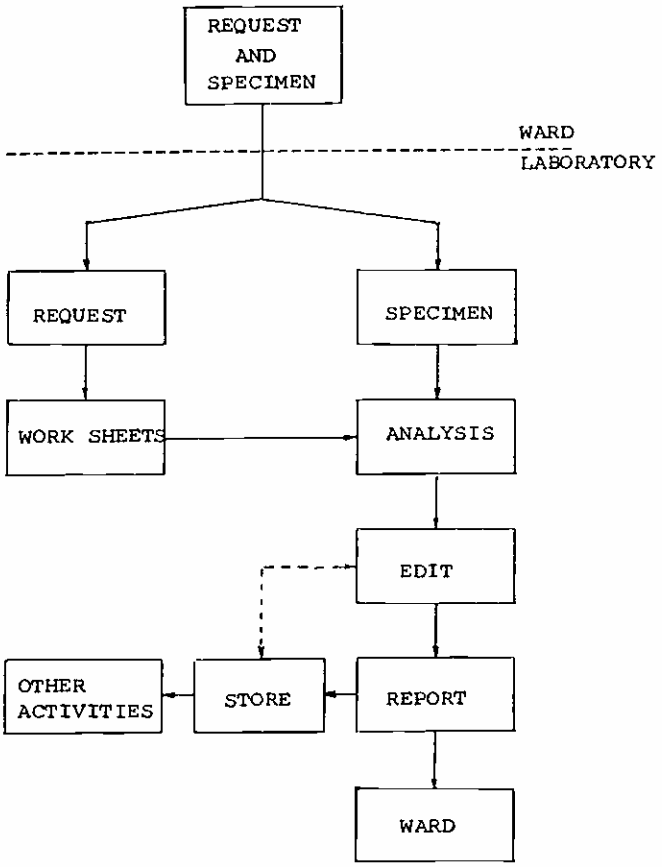


Fig. 1. Laboratory Work-Flow Chart.

It is obvious that expansion in laboratory workload inevitably leads to a considerably increased load of the listed activities which can be handled in a much more efficient manner by a digital computer. The reorganised computer assisted work-flow in the laboratory is given in Fig. 2. Once patient and laboratory information are entered into the computer, the latter stores these information and processes them to produce a variety of printouts as decided by the laboratory.

## SYSTEM DESCRIPTION

For work presented in this paper, a computer system consisting of the following components was used.

(a) One Nova 1220 central processor with 24K words (16 bit per word), with Real-time Disc Operating System (RDOS) (Fig. 3).

(b) Two removable disc cartridge drives driving two discs. (Disc capacity of 1·24 million words each).

(c) One Centronic character printer which prints at 165 characters per second (Fig. 4).

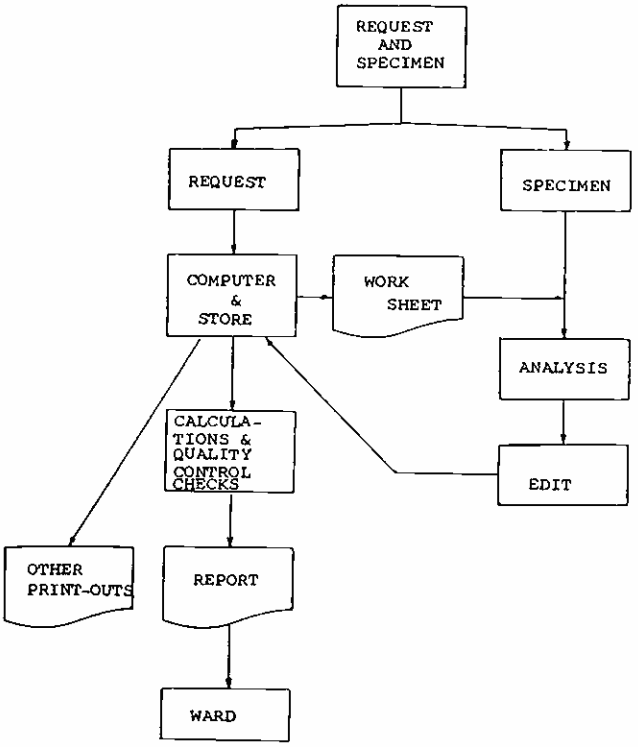


Fig. 2. Computer-Assisted Work-Flow Chart.

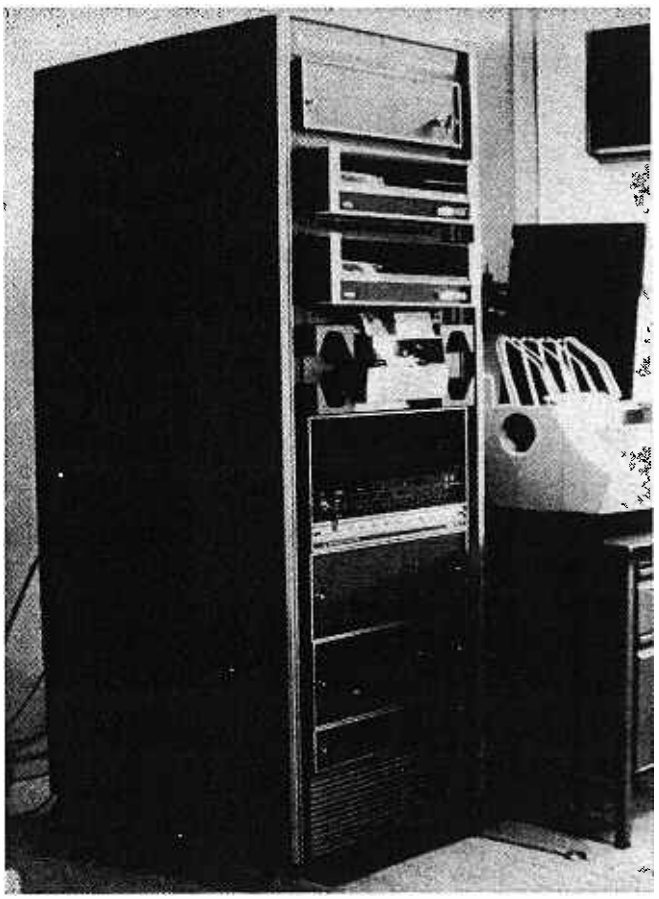

Fig. 3. Nova 1220 Central Processor with two Disc Cartridge Drives and Fast Paper-Tape Reader.

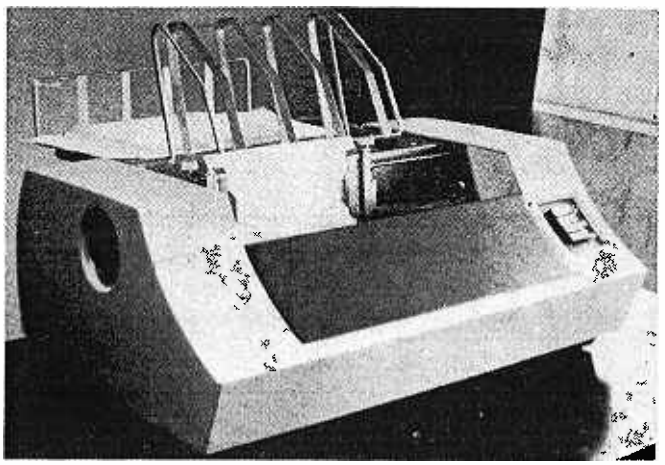

Fig. 4. Centronic Character Printer.

(d) Three teletypes, one of which has been modified for interfacing with the 6-channel SMA 6-Plus AutoAnalyser (Fig. 5).

(e) One Infoton visual display unit linked with the central processor.

(f) One fast paper-tape reader, with reading speed of 300 characters per second.

Most of the computer programs for data-processing have been the work of the computer group in Warwick Group Pathology Laboratory in Britain obtained per kindness of Dr. Kenyon Alexander. As no two laboratories have identical set-up and requirements nor do they have the same operating circumstances, it has not been possible to fully implement the Warwick Scheme locally. A number of modifications to the original programs were made. These included the editing procedure for patient information and laboratory data and the print-out format for reports. Some new programs were also developed to suit the particular needs of the laboratory. One such program was the merging of patient information with results from the 6-channel

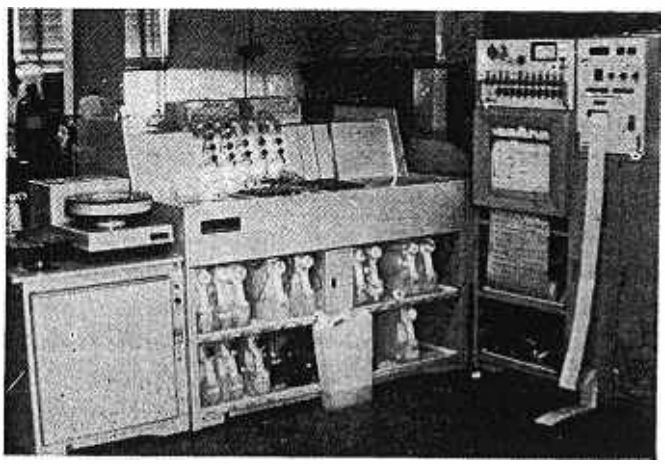

Fig. 5. SMA 6-Plus Technicon AutoAnalyser.

AutoAnalyser. A number of file-handling programs were written to facilitate a more efficient work-flow. A full list of the programs is given below:—

1. *Entry of Patient-Information Tape* which enters patient information into a temporary file.
2. *Edit Program* which checks patient information and test requests before aligning these in the main daily working file.
3. *Worklabel Generator* which allocates accession number and cup number to test specimens.
4. *Worksheet Generator* which produces worksheet for each type of biochemical investigation.
5. *Realignment Program* which realigns any patient information in the main daily working file which has been rejected by the Edit Program.
6. *Laboratory Result Entry Program* which allows entry of results from laboratory data paper tapes either produced by manual punching on a teletype or from results tapes produced automatically by the 6-channel AutoAnalyser.
7. *Delete Data* which clears patient records from the main file when these records have been reported.
8. *Error Correction Programs* which allow operators to make both major or minor alterations whenever necessary.
9. *Check/Alter Main Patient File Programs* which checks the proper alignment of patient and laboratory data, checks any corruption of the main file and allows for minor alteration of main file.
10. *Reporting Program* which generates laboratory reports.
11. *Summary Program* which produces summaries of all biochemical investigations performed on patients, arranging these in alphabetical order of patient names.
12. *Quality Control Programs* which permit statistical calculations of means and standard deviations of various biochemical tests performed on the patients each day and printing these data.

With a 24 K memory, it has been possible to run all the programs, after modification, on a RDOS system instead of on the Disc Operating System (DOS) for which the Warwick software was developed.

## OPERATION AND COMPUTER OUTPUT

A summary of the computer-assisted system of operation is shown in Fig. 6. All request forms and specimens were checked and matched when they reached the reception area of the laboratory. They were separated into the scheduled and the non-scheduled tests. Scheduled tests were defined as (A) those which were batch-analysed on the day after they were received and for which individual test worksheets were available before analyses were carried out and (B) those which were batch-analysed on the 6-channel machine on the same day the samples were received and for which worksheets were not produced. Non-scheduled tests, which included all types of urgent investigations, were tests which had to be performed on the day of specimen reception and for which no worksheet was prepared.

### Work-flow for Scheduled Tests

Laboratory numbers were assigned to all specimens and corresponding forms which carried request for any of the scheduled tests. The forms were sent to the data-processing centre for patient and request information to be punched on paper tapes. After verification, the paper tape information was read into the computer through the fast paper tape reader. Accession numbers or laboratory numbers for each specimen and working cup numbers for each test were automatically assigned according to the order in which patients' information was punched on paper tape and read in the computer. Work labels such as that shown in Fig. 7 were then produced by the computer printer. These labels linked patient information with accession numbers and cup numbers for each test which was requested and enabled laboratory staff to arrange specimens in ascending order of cup number for each type of investigations to be carried out. The accession number for any specimen should agree with the temporary laboratory number which was manually assigned at the time of specimen reception. If the two numbers did not agree, then alteration of the manually assigned number to the computer-assigned number was made on the specimen tube and the request form. Worksheets were produced by the computer for each type of investigation, showing the entire list of speci-

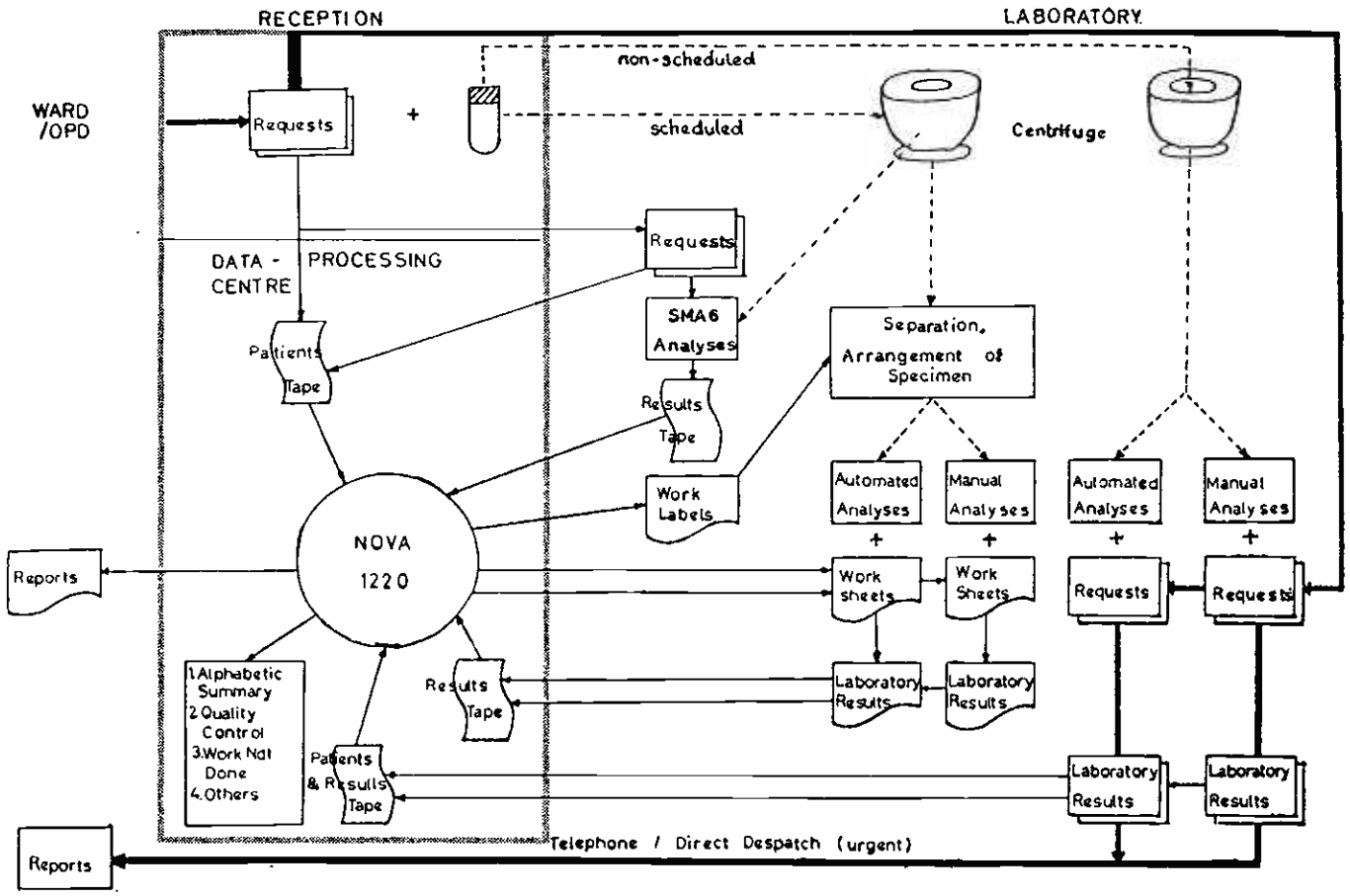


Fig. 6. Computer-Assisted System of Operation.

WORK LABELS

| | | | | | | |
|---|---|---|---|---|---|---|
| LEE YEOK<br>MH 12 IC0805179 | LABNO: | 6245 | CUPNO 55<br>BIL | CUPNO 71<br>GPT | CUPNO 66<br>ALP | CUPNO 78<br>TP |

CUPNO 78
ALB

WORK LABELS

| | | | | |
|---|---|---|---|---|
| PUNG CHENG QUEE<br>TRGH4 IC157184 | LABNO: | 6246 | CUPNO 59<br>CA | CUPNO 55<br>P |

Fig. 7. Work Label.

mens to be analysed in the order of the assigned cup number (Fig. 8). On completion of analyses, laboratory results with the corresponding cup numbers were keyed through a teletype onto paper tapes. In the case of the SMA 6-Plus multi-channel AutoAnalyser, analytical results and cup numbers were automatically produced on paper tape by a teletype interfaced with the machine so that no manual typing was required. After transfer of paper tape information into the computer, the latter was directed to print out laboratory reports in the format shown in Fig. 9. For ease of sorting, the reports were printed in the alphabetical order of the hospital and out-patient departments and the numerical order of the wards. A summary listing of results on all patients arranged in alphabetical order of patients' names was also produced at the end of each working day (Fig. 10).

### Work-flow for Non-scheduled Tests

Specimens and request forms for non-scheduled tests were sent direct from the reception area to the laboratory for analyses and entry of results. When analyses were completed, request forms containing patient information as well as laboratory results were handed over

15.11.74 WORKLIST: CALCIUM

IF RESULT TO FOLLOW, ENTER 0
IF NO RESULT TO COME, ENTER—WITH REASON

| DATE | HOSP | WD | NAME | LAB. NO. | CUP |
|---|---|---|---|---|---|
| 15/10 | PATH | LAB | JACOB CONTROL | 15001 | 11 |
| 15/10 | PATH | LAB | WELL C ASSAYED | 15002 | 12 |
| 15/10 | PATH | LAB | WELL C UNASSAYED | 15003 | 13 |
| 15/11 | ORGH | 49 | CHUA YIM KWEE | 15028 | 14 |
| 15/11 | AH | OPD | WAH KWAI KHENG S/O | 15029 | 15 |
| 15/11 | ORGH | 54 | RENGANATHAN R. | 15030 | 16 |
| 15/11 | ORGH | 55 | CHAN CHOON TAI | 15031 | 17 |
| 15/11 | TTSH | 23 | CHEW TECK JUAN | 15032 | 18 |
| 15/11 | TTSH | 33 | HAMEED CHAKKATTIL | 15033 | 19 |

Fig. 8. Worksheet.

NAME: MOCK SAN YIA SEX: M AGE: 53
NRIC: 2111168 HOSP: ORGH WARD: 44 LAB NO: 5079

BIOCHEMIST'S SIGNATURE

| | | |
|---|---|---|
| UREA | (MG/DL) | 66 |
| SODIUM | (MMOL/L) | 127 |
| POTASSIUM | (MMOL/L) | 4·3 |
| CHLORIDE | (MMOL/L) | 85 |
| TOTAL PROTEIN | (G/DL) | 7·2 |
| ALBUMIN | (G/DL) | 3·6 |

5.11.74

Fig. 9. Laboratory Report.

to the data-processing centre for these data to be entered either on-line or off-line through paper tape to the computer. Laboratory reports were produced by the computer printer at suitable times of the day (Fig. 9). When both scheduled and non-scheduled tests were requested on the same specimen, one composite report containing results of both types of investigations was generated.

## DISCUSSIONS AND COMMENTS

In changing from manual mode of data-handling to computer-assisted data-processing, considerable amount of reorganisation of work and reorientation and education of staff were required. Various activities such as specimen identification, labelling, centrifuging, preparation of worksheets, and reporting which used to be performed by individual staff in the laboratory had to be batch-processed at a defined time by a defined group of staff. Indeed, the batching of laboratory activities and the observation of a strict time schedule were most essential for successful EDP operation. However, it must be emphasized that batching of activities is only worthwhile and can only be successfully carried out in highly automated laboratories.

The major problems encountered in our initial trial operation have been the time of specimen arrival and the large number of "urgent" requests. The late arrival of specimens

| 26/9/74 | | "**"=RESULT OUTSTANDING | | | "ND"=NONE DETECTED | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | UREA | NA | K | CL | CRE | GPT | CO2 | ALP | P | CA |
| PENAGATTIEI<br>NRIC: 1988793 | LABNO: | 37<br>HOSP: ORGH | 143<br>WD: 43 | 4·1<br>SEX: M | 102<br>AGE: 60 | 1·3 | 27<br>DATE: 26/9 | | | | |
| PHEE AH GEK<br>NRIC: 49359 | LABNO: | 24<br>HOSP: ORGH | 137<br>WD: 48 | 4·3<br>SEX: F | 105<br>AGE: 56 | 0·9 | 26<br>DATE: 29/9 | | | | |
| PHEE AH GEK<br>NRIC: 49359<br>GLUCOSE= 63: | LABNO:<br>TIME= 1030: | HOSP: ORGH | WD: 48 | SEX: F | AGE: 56 | | DATE: 26/9 | | | | |
| PILIAI RAYAPPA<br>NRIC: 0280019 | LABNO: | 21<br>HOSP: ORGH | 135<br>WD: 3 | 4·4<br>SEX: M | 98<br>AGE: 52 | 1·3 | 28<br>DATE: 26/9 | | | | |
| PNG BEE GEOK<br>NRIC: 0862951 | LABNO: | 27<br>HOSP: ORGH | 135<br>WD: 5 | 4·0<br>SEX: F | 100<br>AGE: 43 | | DATE: 26/9 | | | | |
| POH CHAR BOH<br>NRIC: 0471991 | LABNO:<br>25011 | HOSP: TTSH | WD: 23 | SEX: F | AGE: 46 | | DATE: 24/9 | | 27 | | |
| POH CHAR BOH<br>NRIC: 0471991 | LABNO:<br>25052 | HOSP: TTSH | WD: 23 | SEX: F | AGE: 46 | | DATE: 24/9 | | | 2·1 | 10·6 |

Fig. 10. Summary Listing of Patients' results.

| | UREA | NA | K | CL | CA | P | TP | ALB | BIL | ALP |
|---|---|---|---|---|---|---|---|---|---|---|
| N | 112 | 125 | 124 | 124 | 41 | 27 | 61 | 61 | 40 | 49 |
| MEAN | 35·82 | 136·02 | 4·16 | 94·64 | 8·48 | 4·29 | 6·38 | 3·28 | 0·60 | 10·73 |
| S. D. | 16·42 | 8·27 | 0·76 | 16·74 | 2·56 | 1·25 | 1·98 | 1·28 | 0·59 | 5·55 |
| CUSUM | −1·18 | −2·48 | −0·14 | −5·36 | −0·92 | 1·04 | −0·52 | −0·42 | 0·00 | 1·73 |

Fig. 11. Quality Control Statistics.

in the afternoons and the appearance of large number of "urgent" requests have often caused a sudden intensification of activities requiring both teletype and computer time. This has occasionally led to a bottleneck situation resulting in delay in reporting at the end of the working day. However, these problems could be solved by streamlining of ward procedure in blood collection.

A much more comprehensive quality control and more extensive checking procedures become practical with the use of a computer. Quality control statistics of daily means and standard deviations on each batch of analysis and for each type of analysis can be derived without additional labour and delay (Fig. 11). Good quality of analytical performance is indicated by the calculated values varying within defined limits. Other statistics such as daily list of work performed, list of work outstanding and list of paying patients to be billed can be produced without extra effort.

Storage and retrieval of laboratory record has been a problem to many laboratories using conventional record file method simply because of the large volume of data which needs to be stored each day. Retrieval of laboratory results from old files for answering a telephone enquiry or for making a statistical analysis is not easy and can only be made at great cost in labour. Storage of laboratory information in computer readable form has made possible instantaneous retrieval and manipulation of any stored data.

## ACKNOWLEDGEMENTS

The authors wish to thank Dr. K. Alexander and his data-processing team of Warwick Group Pathology Laboratory in U.K. for his kind assistance and for the computer programs. They also wish to thank Dr. Edward Jacob and Dr. L. F. Chio for the discussions during the preparation of the script, Mr. C. S. Leong for the preparation of the photographs and Mrs. T. H. Koh for typing the script.