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# Automated Interpretation of the Mackay–Marg Tonograph by Digital Computer

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A program for the multiphasic health testing of outpatients and scheduled admissions at the Latter-day Saints Hospital in Salt Lake City has been in operation since May of 1968. Approximately 10,000 per year are tested in the facility with an average patient flow of ten patients per hour during peak usage hours. The initial set of tests developed for the facility included (1) a self-administered history questionnaire, (2) and electrocardiogram, (3) pulmonary function analysis, (4) blood pressure, (5) temperature, (6) SMA 12-channel chemistry determination, (7) hematology analysis, and (8) urinanlysis. Prior to administration of these tests a computerized medical record is generated for the patient with the results of the screening tests becoming the initial set of data on this medical record. These results and all other data collected on the patient during his stay in the hospital are used to create a problem list on the patient and aid the physician in his decision (*1*).

In operating the facility we have been continually concerned with evaluation of the present tests and searching for new tests which could be added to the existing service. In order to add a new test, however, the test must meet the following criteria —be cost effective, have a high yield of positive results, be simple to administer, and be reproducible. One of the common tests administered at other multiphasic health testing facilities is tonometry for detection of patients with glaucoma. After evaluating the test and the patients which are screened in our facility, the ophthalmologists of the hospital felt that the inclusion of tonometry would be advantageous since (1) the average age of admission to the Latter-day Saints Hospital is greater than age 40, (2) the expected yield of positive tests from tonometry is between two and three percent for individuals over age 40 (*2*), and (3) with the Mackay–Marg tonometer the procedure is easy to perform, extremely safe, reliable, and has an electrical output that can be interfaced directly to our computer allowing the entire procedure to be automated.

Figure 1 is a picture of a patient being tested at the facility. As noted in the figure, the patient is seated on a chair with his eyes fixed on a focal point directly in front of him. The technician stands to the right of the patient in a position to apply the

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probe directly to the cornea of the patient's eye. Also seen in this figure is a terminal which is used to communicate with the computer. This terminal is connected to a Control Data 3300 Computer system on the seventh floor of the hospital. Through the terminal, digital and analog information is transmitted to the computer for processing, and digital information from the computer is received and displayed.

To administer the test, the technician first places a small drop of anesthetic in each eye. Even though an anesthetic is not considered essential with the use of the Mackay

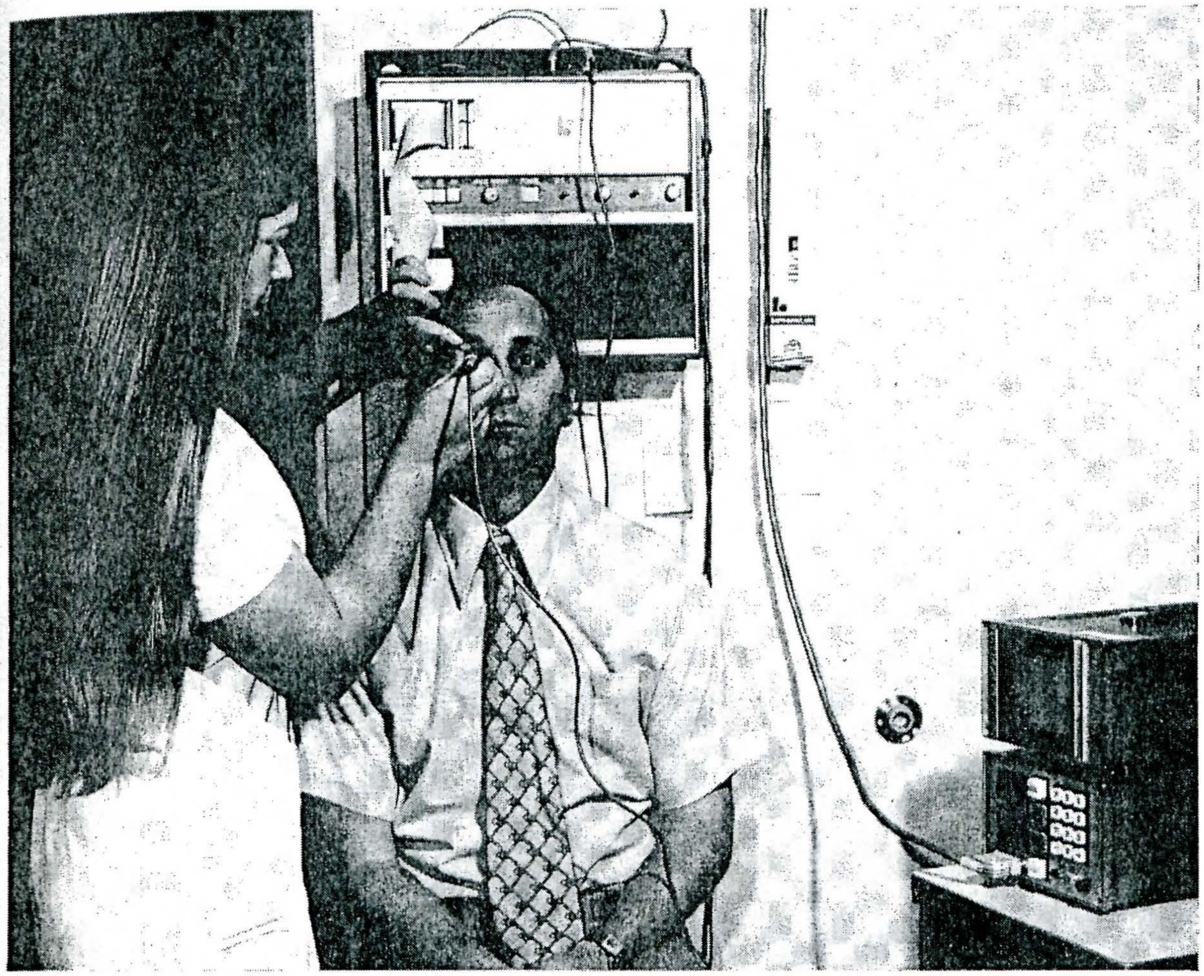

FIG. 1. Technique used in administering test.

Marg tonometer, our experience has shown that the patient will be less sensitive to the application of the probe under anesthetic, causing the procedure to be accomplished in less time with more reliable and reproducible tracings. The computer program is activated from the terminal by the technician who presses an interrupt button. The computer responds by displaying a series of options. These options are (1) calibrate the probe, (2) administer a test, or (3) review the results of the previously administered test. If she desires to calibrate the probe, she chooses that option from the terminal and then adjusts the gain of the tonometer such that the difference in pressure between the upright and inverted probe is 1 cm on the paper (this corresponds to 20 mm Hg). When she has satisfied herself that the gain is properly adjusted, she holds the probe in the upright position, presses the interrupt to the computer, which samples this analog level. She then inverts the probe and again interrupts the computer in order that the inverted level is also transmitted to the computer. The

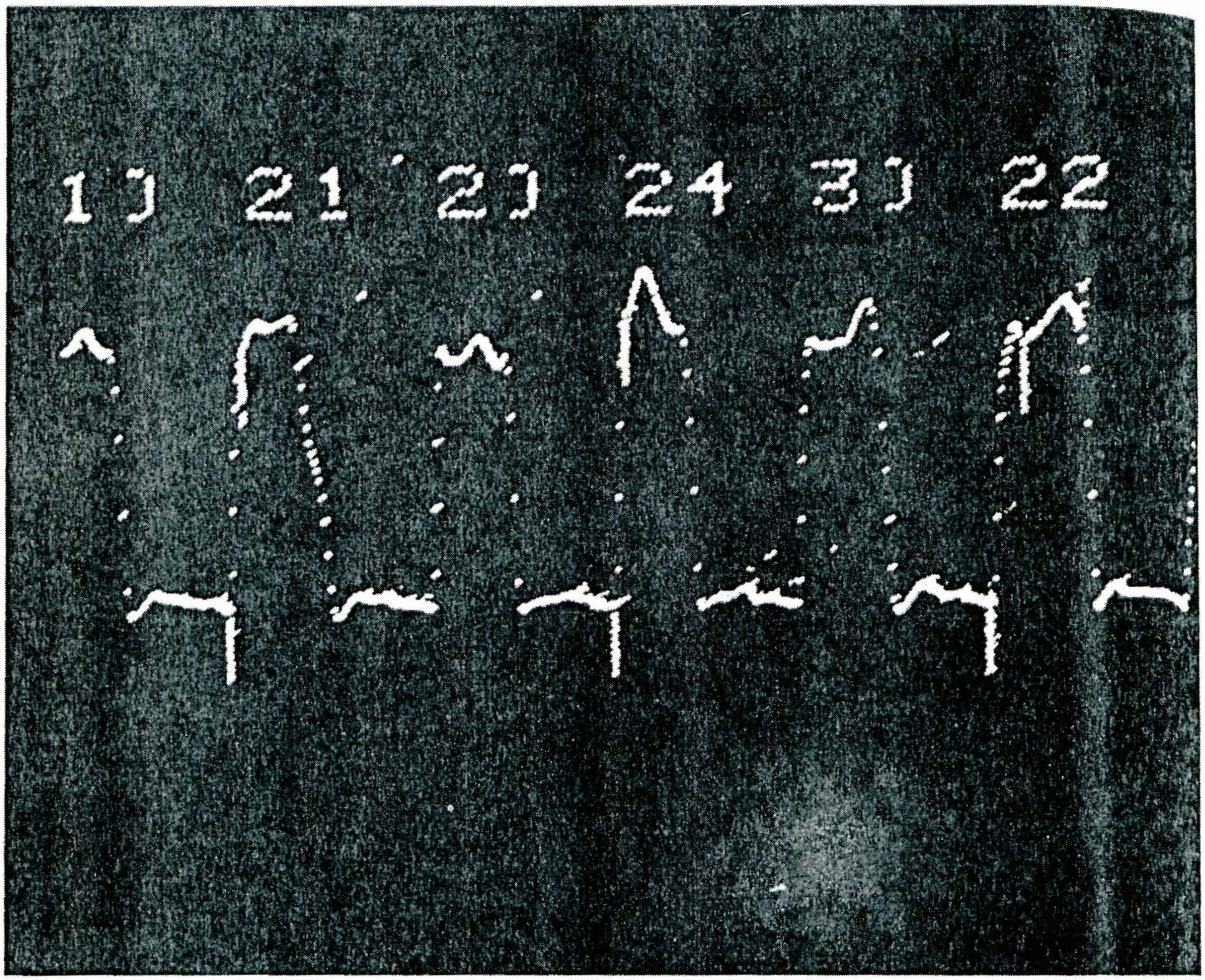


FIG. 2. Scope plot of analyzed complexes.

differences in these levels become the calibration value. No zero level is required since the final calculation involves only a difference in pressure values. Since the electronic drift in the gain of the instrument is small, there is no need to calibrate the probe on each patient. Our present procedure is to calibrate once per day.

With the probe calibrated the technician chooses which eye is to be tested. The computer now displays a message stating that it is ready to receive the tonograph. The technician instructs the patient on the technique to be followed for accurate administration of the test. When the patient is prepared the technician again interrupts the computer. The computer waits 5 sec after receipt of the interrupt and then samples the probe output signal. The 5 sec delay is to allow the technician sufficient time after pressing the interrupt to position the probe on the eye, thus, eliminating the need for two technicians for the procedure. The computer samples the tonograph for 7.5 sec at a sampling rate of 200 SPS during which time the technician repeatedly applies the probe to the cornea.

Once the data has been sampled, the computer displays on the scope the waveforms which have been analyzed by the computer (Fig. 2). The marks on each of the complexes indicate the baseline and the trough of the complex from which the pressure difference is measured. The decision for storing a measurement is left to the technician. She chooses the complex and associated pressure which is most indicative of the true intraocular pressure, (i.e., the waveform exhibits classical shapes expected from a Mackay–Marg tonometer) and causes the value to be stored in the patient's computer medical record. If none of the waveforms are satisfactory (none exhibits a satisfactory wave shape expected from a properly administered test), she discards that set of data and repeats the procedure on the same eye until satisfactory results are obtained. She now follows the same procedure for the other eye. Using this interaction between the technician and the computer the ultimate control and decision is made by the technician with the computer used as a tool for waveform recognition and automatic storage of the processed data.

Figure 3 is a flow diagram of the computer program for determining the intraocular pressure from the tonogram. This program is written in CDC* basic assembly language to run under the MEDLAB time-sharing system (*3*). The crucial logic of the program is, of course, the location of the trough or inflection point of the waveform from which the difference in pressure as measured. Two and one-half seconds of data ($\frac{1}{3}$ of the total data) are processed at a time. This is to conserve the storage requirements of the program. The program first searches for the maximum first difference within this $2\frac{1}{2}$ sec buffer. This difference is assumed to occur on the upward limb of a complex. A tolerance level is set equal to $\frac{1}{4}$ of that maximum difference. A search is then made through the data locating those points whose first difference is greater than the tolerance value. Once such a point is located the data is skipped forwards 0.5 sec in order not to locate subsequent points on the same complex. With the location of these feducial points on the complex a search may now be executed on each complex to find the baseline value as well as the trough value of that particular complex. The baseline is located by searching backwards from the feducial point comparing first differences until a first difference is located whose value is less than two analog/digital units. An initial search for the trough is made by finding that point (temporary trough point) where the first difference is less than $\frac{1}{8}$ of the maximum first difference previously determined. From this point a search is made forward to locate a local maximum value. The search interval is for 100 msec (20 points) starting at 50 msec beyond the temporary trough point. A final search for a

* Control Data Corporation.

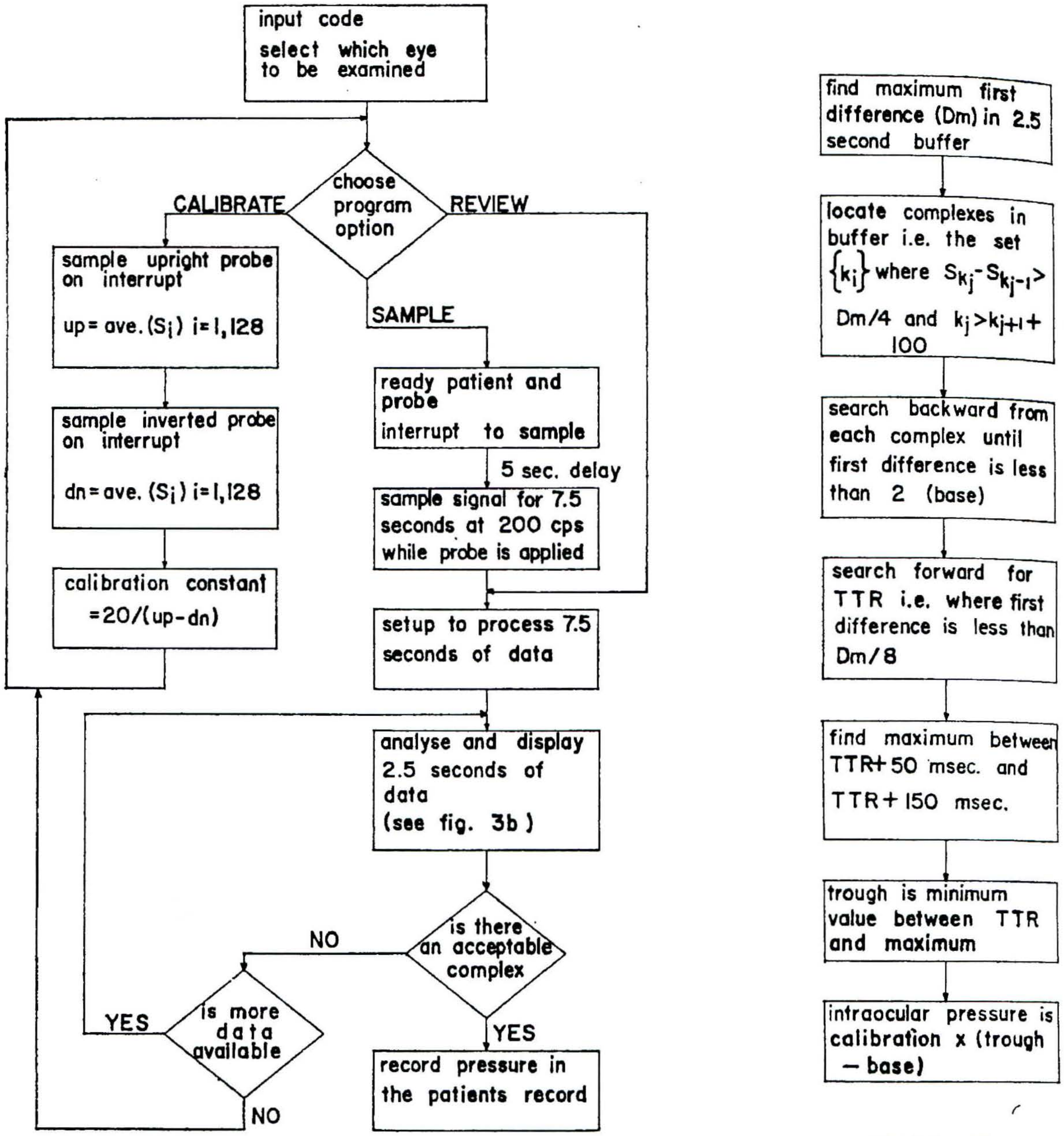


FIGURE 3a

FIGURE 3b

FIG. 3. Program logic for tonometry program.

minimum is executed from the temporary trough point to that maximum just located. That minimum is flagged as the trough point and the intraocular pressure calculated as the calibrated difference of the baseline value and that minimum trough value.

Using this logic the program will locate the minimum value when a trough is present or will use the point of inflection if no such trough is there. Note that the algorithm assumed that the width of the complex is at least 100 msec at the top of the complex. To insure this width the technicians are instructed to be deliberate in the performance of the test. After each wave in the $2\frac{1}{2}$ sec buffer is searched and marked the buffer is displayed on the terminal to the technician. She may now choose a waveform or review the remaining buffers. In most cases she will review the results of all three buffers before making a decision. After viewing all three buffers she then chooses the appropriate complex. This is done by using the review option to re-display the data and choose the complex. As with most computer algorithms, the success of this algorithm is dependent on the quality of the data on which it operates. Training of the technicians become an important factor in sorting valid results.

To study the accuracy of the algorithm a series of 50 tests was measured independently by an ophthalmologist on the hospital staff and by the computer. The mean difference in the two readings was 0.19 mm Hg with the standard deviation of the difference equal to 1.54 mm Hg.

The program has been in operation since September 1, 1972 with approximately 35 patients per day being tested within the facility. Figure 4 is a histogram of the pressures reported by the automated tonometry program. Using this histogram as a data base for automated detection of abnormals, a 3 percent cut off level was chosen. This level was felt by the ophthalmologists to give a good compromise between the occurrence of false positives and false negatives since that is about the expected rate of positives for this population. In those patients whose intraocular pressure in a given eye is less than 26 mm Hg, the statement, "within normal limits," is typed following the reported pressure. For those patients whose value is equal to or greater than 26 mm Hg, the message, "outside normal limits," is typed on the chart following the pressure value. Figure 5 is an example of a report generated at the testing facility.

Inclusion of this test as a part of the routine screening package at Latter-day

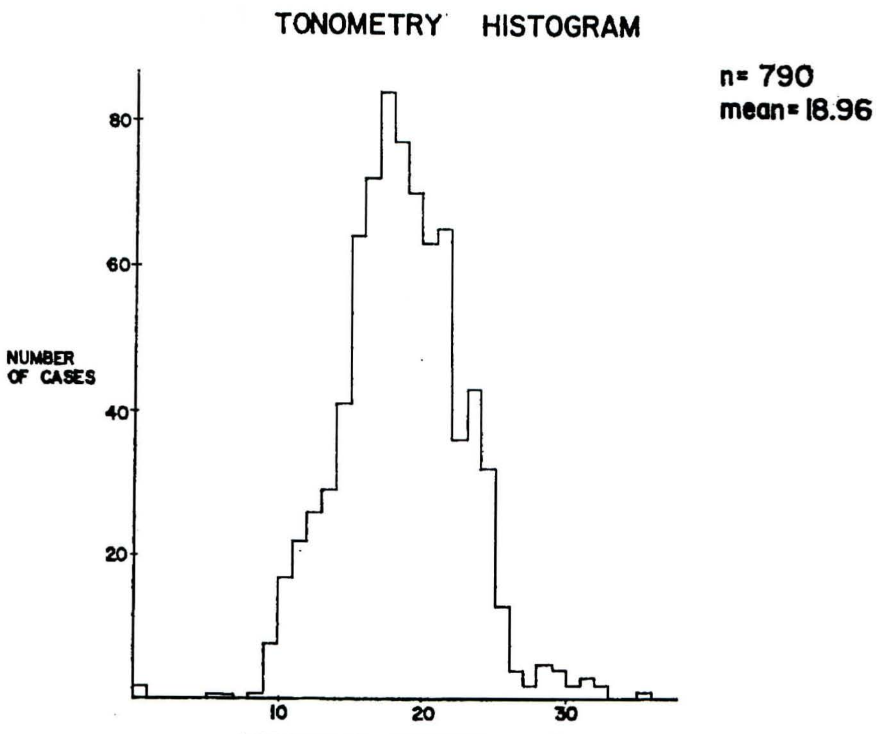


FIG. 4. Histogram of 780 tests administered at the facility.

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                    LATTER-DAY SAINTS HOSPTIAL
                    **************************
                    MULTIPHASIC.SCREENING REPORT

                **** P A T I E N T   C H A R T ****

                    DATE 11/27/72      TIME  13.16
NAME                                        NO.            SEX MALE
DR.                             AGE 52  HEIGHT 65 IN.  WEIGHT 134
TEMPERATURE     98.4       BLOOD PRESSURE  120/ 80
TONOMETRY DATA
***********.
  INTRAOCULAR PRESSURE FOR LEFT EYE = 17 MMHG. - WITHIN NORMAL LIMITS
  INTRAOCULAR PRESSURE FOR RIGHT EYE = 19 MMHG. - WITHIN NORMAL LIMITS
E.C.G. DATA
**********
  FINDINGS
    HEART RATE = 83  QRS DURATION = 80  PR INTERVAL =140
    SINUS MECHANISM
    QRS CRITERIA FOR ANTERIOR INFARCTION
    T INVERSION IN LEAD X
    FLAT T IN LEAD Z
  DIAGNOSIS
    ABNORMAL ECG
    ANTERIOR INFARCTION AGE UNDETERMINED

SPIROMETRIC DATA
****************
                              VALUE       PERCENT OF PREDICTED
    FORCED VITAL CAPACITY      5145          136
    ONE SECOND VOLUME          2131           70
    %FEV1/FVC                    41
PULMONARY DATA SUGGESTS-
 SEVERELY OBSTRUCTED.AIRWAY
PATIENT PUT FORTH BEST EFFORT POSSIBLE
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FIG. 5. Sample multiphasic report.

Saints Hospital required the addition of one technician and an additional computer terminal. Patient flow through the facility remained at the same level as before. A cost of $2.00 per patient is charged to cover the additional expenses to the facility. This charge includes a computer cost of $0.75. The addition of tonometry to the multiphasic tests has been strongly supported by the ophthalmology division and they are cooperating in a follow-up program to evaluate patients reported as having abnormal tonometry.

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