COMPUTERIZED BLOOD GAS INTERPRETATION AND REPORTING SYSTEM

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Introduction

With the increased sophistication of laboratory instrumentation, physician and nursing staffs are being presented with large amounts of clinical data which they are expected to interpret in order to formulate proper therapy for their patients. One of the recent advances has been the development of arterial blood gas analysis. This test now provides reliable, accurate data on the blood gas status of patients, thereby presenting information to clinical staffs which was not available before. Accompanying these improvements in technique has been a steady increase in knowledge and studies performed on various blood gas disorders.1-8

Because new information can be rapidly incorporated into a computerized system, computers have been used to assist and educate staff physicians, house staff, and nurses by providing interpretations of blood gas results. Bleich in his work at Beth Israel Hospital in Boston,9,10 Goldberg and his associates at the University of Pennsylvania,11 and Cohan in Arizona12 have been pioneers in this area. These investigators require the physician to enter raw data via punch cards, teletypes, or slow-speed video terminals. Experience indicates that physicians will interact with this type of system for only a short time. They find they can analyze the data more rapidly through their own thought processes with the aid of nomograms such as the one recently published by the American Thoracic Society.13

January 1975
To address this problem, the Latter-day Saints Hospital in Salt Lake City has undertaken the development of a system for automating the ordering, reporting, and interpretation of blood gas results. Acquisition and correction of blood gas and oxygen saturation were already semiautomated, and a large computer system that recorded data on all patients admitted to the hospital was in use; hence a good deal of the groundwork for such a system had already been completed.

The Computerized Blood Gas Interpretation and Reporting System, described in the following paragraphs, permits reports and interpretations to be generated from the computer database at Latter-day Saints Hospital without direct physician interaction. Reports are generated in a serial format which makes them ideal for long-term patient follow-up.

Methods

The Pulmonary Function or Blood Gas Laboratory is the focus of blood gas determinations. In the Pulmonary Function Laboratory are located two Astrup blood gas machines, an Instrumentation Laboratory, Model 182, CO-oximeter, computer terminals, and a GE Terminet 30-cps printer. A technician begins the blood gas analysis procedure by entering the patient identification number through the computer terminal, whereupon the name of the patient is displayed for verification. The computer then leads the technician through procedural steps acquiring analog data from the blood gas machines at critical points during the process. As each piece of information is acquired, the data is corrected for pH and patient temperature, where appropriate, and stored in the patient's file.

Figure 1. Blood acid-base map used for clinical interpretation of blood gas data.
System Design The system operates on a Control Data 3300 computer through the MEDLAB system. In addition to the terminal in the Pulmonary Laboratory, there are eight nursing divisions, three open-heart surgical operating suites, and four intensive care units with 23 beds of computer monitoring which order and receive hardcopy blood gas results from the computer. The nursing division communicates with the computer through telephones adapted for use with a voice-response system. Recently the voice response system has been implemented on a Votrax supplied by the Federal Screw Works of Troy, Michigan. Ordering is performed by a nurse or ward clerk dialing the computer extension, and then, as directed by the voice-response system, entering the patient number, room and bed number, and desired test time. When the order is complete, a status light is turned on and a request is printed in the Pulmonary Laboratory. Orders from surgical suites and computerized intensive care units are made through CRT terminals and have been designed so the staff can quickly and easily place orders.

The ordering system is convenient for the ICU staffs and laboratory staff because no phone answering is required and verbal errors are eliminated. Orders can also be placed when no technician is in the laboratory.

Interpretations Several techniques for interpreting blood acid-base and oxygen status were evaluated. The technique selected for evaluating clinical acid-base status is a combination of confidence bands for various respiratory and metabolic acid-base disorders from several authors. Goldberg’s general approach was followed with latitude corrections for Salt Lake City. The modified map is shown in Figure 1. There are six major classification areas: 1) metabolic acidosis, 2) acute respiratory acidosis, 3) chronic respiratory acidosis, 4) metabolic alkalosis, 5) acute respiratory alkalosis, and 6) chronic respiratory alkalosis. Regions between the “pure” acid-base disorders are interpreted as mixed disorders. The map is also divided into normal, mild, moderate, and severe regions. In the mild region no interpretation is specified, since nurses and physicians will usually not take any therapeutic action as a result of slight abnormalities.

Figure 2 shows the oxygen hemoglobin dissociation curve with the criteria for classification of oxygen status. The five classifications are 1) severe hypoxemia, 2) moderate hypoxemia, 3) mild hypoxemia, 4) normal, and 5) supranormal PO2. Alveolar-arterial oxygen gradients are computed from the blood gas data and inspired oxygen concentration, if available. Inspired oxygen concentration is estimated from oxygen flow rate.

Once the blood gas data is entered into the computer the results are automatically evaluated using the acid-base map of Figure 1. This is automatically performed by the HELP (Health Evaluation through Logical Processing) program (Figure 3) described in the preceding paper by Pryor et al.

HELP allows logical determinations to be made from the blood gas data as well as from data entered from other sources contained in the patient’s data file. Decisionmaking criteria are stored on a separate disk in a logical format which allows easy implementation of medical decisions. HELP permits medical decision criteria to be stated in a high-level computer language, thereby simplifying the entry of the medical decision logic. Once the blood gas test is run it is automatically evaluated by the criteria logic and an interpretation is made. The interpretation is stored on a problem-oriented record file, and a hardcopy report is generated.

Figure 4 shows a typical serial blood gas report. All of the data is available through the computer terminals and the voice response system. This is especially convenient during the evening hours when no one is in the Pulmonary Laboratory to read the reports over the telephone. Reports are printed for the Pulmonary Laboratory and ICU’s on video terminals and on a hardcopy printer for distribution to the patient charts. No physician involvement is required. A pulmonary technician and the computer perform quality control.

Evaluation

Physician Experts Four pulmonary specialists and three nephrologists—current or past members of the University of Utah faculty—were asked to participate in an evaluation of the system. Each specialist was given a list of 137 separate test results which contained pH, PCO2, HCO3, and base excess measurements. Table 1 shows the results from which the 137 test cases were randomly selected. After a consultation with the physicians, the 12 categories used by the computer were chosen as the best means of classifying the disorders.

Because not all physicians completed all 137 classifications, and some physician responses were ambiguous or obviously incorrect, there were only 49 sets of values for which the responses of all seven experts could be compared with the computer.

Analysis was difficult because none of the interpretations could be taken as absolutely correct. In comparing the responses, no interpretation was taken as a standard.
Instead, responses were tested for agreement among themselves by noting the number and percentage of cases in which each participant agreed with the majority of the others. Table 2 shows these results. The computer ranks second among the experts, is nearly as good as the best expert, and is far better than the worst expert.

Most of the specialists commented on the difficulty of classifying acid-base disorders without clinical bedside information. Corrective therapy of disorders can influence test results. If blood is drawn before a patient has stabilized, the values can lead to an incorrect interpretation. Also, two sets of slightly differing values lying near the border of an area on the map may give two different interpretations. These criticisms point to the need for incorporating further clinical information into the interpretation, which will be done as the program becomes more sophisticated. However, in its present state of development the program does as well as a specialist in interpreting blood gas disorders based on laboratory results alone.

The study points out the need for standardization of interpretations. Even the best expert disagreed with the majority 25% of the time. Standardization and verification of interpretations are crucial to any computerized technique for medical decisionmaking. Before computers can be made to provide better interpretive results, these problems must be resolved by either local or national standardization.

Figure 3. Oxygen hemoglobin dissociation curve with interpretive areas outlined.

Figure 4. Serial blood gas report with computerized interpretations.
Table 1. Distribution of Acid-Base Disorders and Oxygen Classifications

<table>
<thead>
<tr>
<th>Total Blood Gas Determinations</th>
<th>Normal Acid-base Chemistry</th>
<th>Mild Acid-base Disorder</th>
<th>Moderate Acid-base Disorder</th>
<th>Severe Acid-base Disorder</th>
<th>Percentage of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2130</td>
<td>486</td>
<td>1011</td>
<td>546</td>
<td>87</td>
<td></td>
</tr>
</tbody>
</table>

**DISTRIBUTION OF MODERATE AND SEVERE DISORDERS**
- Metabolic Acidosis: 36 (1.7%)  
- Mixed Metabolic and Respiratory Acidosis: 76 (3.6%)  
- Acute Respiratory Acidosis: 52 (2.4%)  
- Mixed Acute and Chronic Respiratory Acidosis: 5 (0.4%)  
- Chronic Respiratory Acidosis: 146 (6.9%)  
- Mixed Respiratory Acidosis and Metabolic Alkalosis: 78 (3.7%)  
- Metabolic Alkalosis: 35 (1.6%)  
- Mixed Metabolic and Respiratory Alkalosis: 36 (1.7%)  
- Acute Respiratory Alkalosis: 155 (7.3%)  
- Mixed Acute and Chronic Respiratory Alkalosis: 14 (0.6%)  
- Chronic Respiratory Alkalosis: 51 (2.4%)  
- Mixed Respiratory Alkalosis and Metabolic Acidosis: 8 (0.4%)

**DISTRIBUTION OF OXYGEN CLASSIFICATIONS**
- Normal Oxygen Saturation and PO$_2$: 648 (30.4%)  
- Mild Hypoxemia: 357 (16.8%)  
- Moderate Hypoxemia: 415 (19.5%)  
- Severe Hypoxemia: 87 (4.1%)  
- Supranormal PO$_2$: 210 (9.9%)  
- Arterial PO$_2$ Abnormally Low for Inspired O$_2$: 662 (31.1%)  
- Arterial PO$_2$ May Be Abnormally Low for Inspired O$_2$: 375 (17.6%)

Table 2. Comparison of Interpretations of Seven Specialists with the Computer

<table>
<thead>
<tr>
<th>Computer</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Agreement with Majority</td>
<td>74.0</td>
<td>74.0</td>
<td>52.5</td>
<td>61.0</td>
<td>65.5</td>
<td>65.0</td>
<td>62.5</td>
<td>74.5</td>
</tr>
<tr>
<td>Rank</td>
<td>2</td>
<td>2</td>
<td>8</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

**Staff Review and Results** In order to assess the helpfulness of the computer to the physician and sample his opinion as to the accuracy of the computerized interpretations, a survey was conducted over a 17-day period. During this time each interpretation was followed by a short evaluation note, and the physician’s attention was drawn to the note by a red stamp indicating that an evaluation was desired. Attending staff members were notified of the survey by a note in the staff newsletter, and individual letters were sent to each of the house staff members.

Results of the survey were collected by visiting the wards and looking at the charts on the day following the blood gas tests. Survey results are shown in Table 3. Due to pressing demands on physician staff members, only 68 of the 360 reports (19%) sent out were evaluated. Of those evaluated, 19 (28%) were helpful and changed patient care. We found that 80% of the responses were helpful and 20% were not helpful. In only one case did the clinician feel that the computer interpretation was incorrect.

**Future Plans and Conclusions**

With serial interpretations and reports already available, as shown in Figure 4, the next logical step is to have the computer make interpretations based on the time course of the laboratory results. The HELP system has recently been modified to permit time sequential interpretation. Automated entry of data from the clinical laboratory will allow check of anion gap, electrolyte levels, and other information which will broaden the data base from which interpretations will be made.

Other clinical information, such as drug information, IV solutions, and other therapeutic interventions, are entered for patients in the intensive care units. Higher-level
decisions will be made from this data and suggestions will be made for clinical therapy—e.g., changes in respirator parameters and drug administration.

Experience with the computerized interpretation system has shown that 1) computerized interpretation is accurate, and reporting of serial blood gases is accepted and appreciated by physicians and nurses; 2) interpretations aid in providing better care to a growing number of patients; 3) quality control in the laboratories is enhanced by computer checks for internal consistency of results; 4) computerization was the catalyst for standardization of classification criteria; 5) terminology has been standardized because of computerization; 6) computerized interpretation provides an educational benefit to the staff and nurses; and 7) turnaround time between sample withdrawal and result reporting was decreased. The time was decreased most dramatically in the critical care units where the test is most common and most urgently needed.

The computerized blood gas laboratory presently performs more than 1800 blood gas determinations each month. The computer has aided in providing 24-hour-per-day, 7-day-per-week service to intensive care and general hospital divisions. The computer has speeding response and made more legible and usable the data from the routine clinical determinations. A computer charge of $.75 per blood gas sample is made and is a nominal fee for the advantage of computerized interpretation and computation.

The future use of microprocessors in the acquisition and calibration of blood gas instruments will 1) increase the reliability of results; 2) make the tests much less operator-dependent; 3) decrease the time required to obtain results; 4) make the test more available in critical care areas, since nurses can draw samples from existing arterial catheters and "inject" them into the automated machine; and 5) possibly reduce cost of the test, which currently requires highly skilled technicians around the clock.

With the addition of better measurement methods there will be a need to improve interpretation decision criteria; therefore, a primary requirement for new systems which are designed to be used in a medical environment will be the ability to store and retrieve data for medical decision-making.

Acknowledgment

Supported in part by a Health Resources Administration Grant (1 PO1 HS 01053-02).

Table 3. Survey Results

<table>
<thead>
<tr>
<th>Total Reports Checked for Physician Response</th>
<th>Percentage of Slips Checked</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reports Without Response</td>
<td>360</td>
</tr>
<tr>
<td>2. Reports With Response</td>
<td>292</td>
</tr>
<tr>
<td></td>
<td>81%</td>
</tr>
</tbody>
</table>

Percentage of Total Responses

<table>
<thead>
<tr>
<th>Breakdown of Responses</th>
<th>81%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Helpful: Changed Patient Care</td>
<td>19</td>
</tr>
<tr>
<td>2. Helpful: Educational</td>
<td>16</td>
</tr>
<tr>
<td>3. Helping: Interesting</td>
<td>19</td>
</tr>
<tr>
<td>3a. Not Helpful: Interesting</td>
<td>5</td>
</tr>
<tr>
<td>4. Not Helpful: No Contribution</td>
<td>5</td>
</tr>
<tr>
<td>5. Not Helpful: Incorrect Interpretation</td>
<td>1</td>
</tr>
</tbody>
</table>

References


George H. Cannon is a third-year medical student at the University of Utah. He is a member of Phi Beta Kappa and recently presented a paper at the student seminar of the Western Meetings of the American Federation for Clinical Research. He received his BA degree in medical biology from the University of Utah in 1973.

Alan H. Morris is an assistant professor in the College of Medicine at the University of Utah, and Medical Director of the Pulmonary Laboratory at the Latter-day Saints Hospital. His current research interests fall within the general category of clinical or applied pulmonary physiology. Dr. Morris received his BA degree in chemistry from Princeton University and his MD degree from Yale University.

Kenneth R. Olsen is associated with the University of Utah, Department of Biophysics & Bioengineering, as a systems programmer, with special interest in operating systems and use of computers in solving mathematical problems, and was responsible for implementing the programming for the Pulmonary Function Laboratory and the blood gas analysis system. Olsen received his BS degree in political science from Utah State University.

W. Gary Price is working towards his PhD degree in the Department of Biophysics and Bioengineering on a voice response system for hospital use. He is presently employed by MEDLAB Computer Services with special interest in computer application to patient care. Price received his BA degree in electrical engineering from the University of Utah.