A Computer Program for Studying Blood Gases in Respiratory Care

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We developed a computer program in a style of a game to help study blood gases in respiratory care. The program generates five simulated patients from a pool of 11. The player selects one patient, then the program calculates the patient's condition according to initial condition and selected treatment. Condition of the simulated patient may improve or deteriorate accordingly. Every two hours, the program display the data, requests the diagnosis and asks addition/change of treatment. The program then judges if diagnosis is correct. This process is repeated up to 48 hours. Finally a score and comments are displayed according to the performance of the patient and of the player. Students and young physicians used the original disk 312 times and more than 30 copies are distributed throughout the country. It is useful by itself as a self-teaching tool, but even more useful when combined with verbal teaching by instructors. (Key words: acid-base balance, ARDS, CAI, game, simulation)

(Suwa K: A computer program for studying blood gases in respiratory care. J Anesth 1: 155–161, 1987)

For studying blood gases and acid-base chemistry, a process is required to apply the knowledge obtained from textbooks to actual clinical situation. We have developed a computer program to enhance this process, which simulates a patient-physician interaction. It was originally designed to simulate a patient under anesthesia during surgery[1], but it was found so useful that we have developed another to apply it to ICU. We report here the elements of the program and the results of our use for a year.

Methods

1. Basic structure of the program

The basis of this program is to simulate a patient along the time-axis, to request to make diagnosis and choose some treatment. This is similar to the actual clinical set-up, in which we refer to measurements and patient's condition, make a diagnosis and choose some treatment. This program differ from other programs which simply calculate and/or make diagnoses of the acid-base chemistry. The rough flow-chart is shown in figure 1.

1-1. Simulation of patients (table 1)

The basic structure of the program is the simulation of physiology and pathophysiology of respiratory failure. They consist of following elements and parameters, most of which simulate the actual parameters.

a. metabolism: Basal oxygen consumption ($B\dot{V}O_2$) is calculated from age, sex, height and weight from Kleiber's formula[2]. In spontaneous ventilation, oxygen cost of breathing was added, which is an exponential function of minute ventilation and compliance. Therefore,

$$\dot{V}O_2 = B\dot{V}O_2 \times \exp(k\dot{V}_E)$$

The constant k was assumed to vary according to the patient's condition. The CO_2 production is calculated from the oxygen consumption with the assumed RQ of 0.8.

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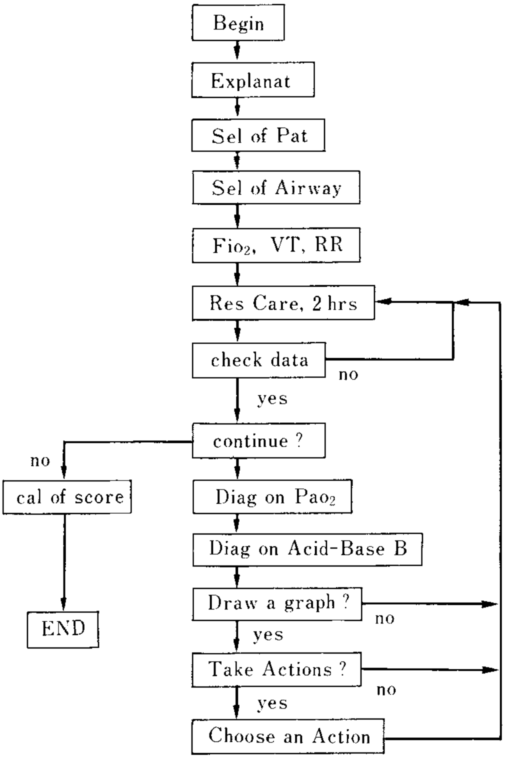

Fig. 1. A rough flow chart of the program

b. Ventilatory volume. In artificial ventilation, the player determines the tidal volume and the respiratory rate respectively. In spontaneous ventilation, the minute ventilation is assumed to depend upon Pao_2 and $Paco_2$[3]. The ventilatory response to O_2 is assumed to be hyperbolic and that to CO_2 is assumed to be exponential.

c. Alveolar ventilation and CO_2 output. Alveolar ventilation is calculated form the minute ventilation and the V_D/V_T ratio. Then the CO_2 output from the lung is calculated. The difference between the CO_2 production and the CO_2 output from the lung is either the accumulation or the depletion of the body CO_2 storage.

d. Exchange of CO_2 and the level of $Paco_2$. The body as a whole is assumed to consist of a single compartment and simplified form of CO_2 dissociation curve (logarithmic function) was assigned[4]. From the initial $Paco_2$, the whole body CO_2 is calculated. Adding or subtracting the CO_2 balance in the next one minute, $Paco_2$ a minute later is calculated.

e. Alveolar gas exchange. The gas exchange ratio (R) is assumed to be equal to the ratio of (CO_2 production/O_2 consumption). Knowledge of FIO_2 and $Paco_2$ enables to obtain PAo_2. Original Pao_2 is determined from the age and the degree of obesity. From Don's data[5,6], we obtained a regression equation of,

$$Pao_2 = 110 - 0.36 \times \text{age} - 0.26 \times \text{Weight/Height/Height}$$

The disability of the lung oxygenation was assigned and was multiplied to this value. The ratio of Pao_2/PAo_2 is taken to be the index of the lung oxygenating capability.

f. Acid-base chemistry. Base Excess (BE) is assigned randomly between +5 and −5 mEq/L. Knowledge of BE and $Paco_2$ enables us to obtain pH and HCO_3^-. We used an algorithm described by Kelman[7] as well as that of ourselves[4].

g. Effect of $NaHCO_3$ & acid administration. This changes the BE as well as CO_2 and bicarbonate exchange.

h. Effect of PEEP and Body position. Both PEEP and head-up position improves the ratio of Pao_2/PAo_2, but it was assumed that in obese patients the effect of PEEP is less and the effect of head-up position is more marked.

i. Oxygen-debt. Conceptually it is similar to its physiological counterpart. It is calculated as the difference between oxygen consumption and half of oxygen transport (Cao_2 × C.O./2). When it is negative (oxygen surplus), 10% of this surplus is accumulated as "Excess oxygen", indicating the general energy reserve.

j. A parameter of respiratory condition. This parameter has no physiological counterpart. It defines how good the lung or respiration is; namely the Pao_2/PAo_2, V_D/V_T, ventilatory response to O_2 and CO_2 and oxygen cost of breathing. At the start, it is 5 to ten steps away from normal. The way how this parameter changes is described in "Simulation" section.

1-2. Initial values

Initial values are divided into two groups, one determined by the player and the other

Table 1. Parameters & formulae used in this model

Metabolic:		
Bas O_2 consumpt	$B\dot{V}o_2$ per Kleiber	
O_2 consumption	$\dot{V}o_2 = B\dot{V}o_2 \times \exp(k\dot{V}_E)$	In spont vent, $\dot{V}o_2$ by vent work shall be added. It will be in exponential function.
CO_2 production	$RQ = 0.8$,	
	$\dot{V}co_2 = RQ \times \dot{V}o_2$	Calculated from Vo_2
Vent Cond	Art Vent: Set the VT & RR	
	Spon Vent:	Vent resp to O_2 & CO_2
	$\dot{V}_E = APaco_2 \times \exp(Paco_2 - 40)$	Combination of hyperbola
	$\times (b + c/(Pao_2 - d))$	(O_2) & Expon (CO_2)
Alveolar Ven &	$\dot{V}_A = \dot{V}_E (1 - V_D/V_T)$	Alv Ven equals to $\dot{V}_E$ less
CO_2 output	$\dot{V}co_2$ (exp.) $= Paco_2 \times VA/.863$	dead space ventilation.
CO_2 balance	$Cco_2 = Co(1 + Pco_2^k)$	A simplified CO_2-dissociat
	$\Delta Cco_2 = \dot{V}co_2$ (Prod)	curve urve
	$- \dot{V}co_2$ (expi)	
Alv gas exchan	$PAo_2 = PIo_2 - Paco_2 (FIo_2 + (1 - FIo_2)/R)$	Alveolar air equation
Pao_2	$Pao_2 = 110 - 0.36 \times age - 0.26W/H^2$	From actual data
Acid-base balance	Base Excess = 0	Random term is added.
	$pH = f(Paco_2, Pao_2, BE)$	KS + Kelman
PEEP & Body position	$Pao_2/PAo_2 = f$ (PEEP, Head-up deg)	This ratio varies with PEEP & head-up angle.
O_2-debt	$O_2debt = Co_2 \times CO/2 - \dot{V}o_2$	Arbitrary def of O_2debt.

determined by the program. The player determines the following variables.

1) Rank of the player. Choose from Student, Physician in training, Physician trained, Consultant Physician, and Professor. The higher the rank, the worse the initial respiratory condition, the more arbitrary and less logical the performance of the patient, and the more severe the scoring criteria.

2) Choice of airway management. Choose from Monitor (no treatment), Mask O_2, Endotrachal tube and Tracheostomy.

3) Choice of a patient. Five patients appear on the screen. They are randomly chosen from a pool of 11. Five of them have ARDS-type respiratory failure, while five others have acute-on-chronic failure. One patient is in failure due to neuromuscular disorder. Age, sex and body size are generated randomly.

4) Condition of ventilation. Choice of spontaneous or artificial. Artificial ventilation cannot be given via a face-mask or in "monitor" mode.

5) Selection of FIo_2. "Monitor" indicates the room-air. The maximum FIo_2 by a face-mask is less than 40%.

Other initial conditions are determined by the program. In acute respiratory failure, Pao_2/PAo_2 is low and V_D/V_T is high. Ventilatory response to CO_2 is low in chronic respiratory failure.

1-3. Simulation of the patient for 2 hour period

Now the blood gas is calculated in one minute interval. From the metabolic CO_2 production and the pulmonary CO_2 output, the amount of CO_2 in the body is calculated and $Paco_2$ is determined. The knowledge of BE enables the calculation of pH and HCO_3^-. This algorithm of calculating Pco_2, pH, BE and HCO_3^- is fairly accurate simulation of dynamic exchange of CO_2 and acid-base equilibrium. Furthermore, the BE is programed to increase automatically when the Pao_2 is low.

An unrealistic assumption is made that, when all of three parameters of Pao_2, $Paco_2$

Fig. 2. The message of the initial display

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Program for Blood Gases in Respiratory Care
Program for Blood Gases in Respiratory Care

Let's study Blood Gases in Respiratory Care by playing a game.
Duration of care is up to 48 hours.

Make every effort to keep the blood gas values within normal range.
(Pao2 80 & Paco2 40 mmHg in Acute Failure; 60 & 50 in Chronic Failure).

If the values are maintained in normal range, then the lung will heal.
If the values are grossly abnormal, then the lung will deteriorates.
You will be honored with ALMIGHTY, when the score is high in Professor rank.

No knowledge of computers is required.
Use only F-key, Y/N-keys & Numeral keys.
Do not hit a key twice or hit two keys.

I wish you a Good Luck!

Devised and Programmed by: Kunio Suwa, M.D.
                           Department of Anesthesia
                           University of Tokyo, Tokyo.
Hit any key
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and pH fall in normal ranges at the same time, the parameter of respiratory condition improves by one step in this two hour period. If one of the blood gas values is grossly abnormal, it deteriorates by one step.

1-4. Alarm program

If one of the blood gas values reach an extreme level, then the alarm program starts automatically. Unless appropriate action is taken, the patient deteriorates further, O_2debt increases more, and finally the death ensues. With appropriate action, the patient may escape from this condition. The possible actions are the same as those in "Action" program.

1-5. Death program

If O_2debt exceeds 100 ml/kg, the death ensues[8]. No resuscitation program is supplied.

1-6. Diagnosis program

After 2 hours of respiratory care, the program halts, displays the blood gas data and request the diagnosis, which are divided into oxygenation and CO_2 & acid-base chemistry. They are multiple choice pattern diagnosis, and the program keep requesting until the correct answer is chosen. This diagnostic step, together with the "Action" step, consists of the main part of the instruction.

1-7. Action program

According to the condition of the patient, the player may choose the following: change of airway, change of FI_{O_2}, change of ventilation, change of PEEP, administration of $NaHCO_3$ and of acid, and head-up tilt.

1-8. Graph program

The time-course of the blood gas values are displayed graphically.

1-9. Total time of respiratory care

These processes may be repeated up to 48 hour period, which means 24 times of diagnosis and treatment in one use of the program.

1-10. End of respiratory care and scoring

When eigher the time exceeded 48 hours or the player requested to end the study, the program stops the respiratory care and evaluates the results. Factors considered are,

1) whether the patient has improved and discharged from the ICU, remained in respiratory failure, or deteriorated and died,

2) how closely the blood gas values have been maintained to normal.

3) ratio of erroneous/correct diagnoses.

4) number of alarms

The scording is done in a manner of subtraction from the fullscore. The criteria of the score is 10 times as severe for Professor as for Student. Therefore the results which would earn 95 points in Student earns only 50 points in Professor.

II. The software and hardware

The actual program is written in BASIC language for NEC-PC-9800 series computer. If contains a little over 1000 computer lines, occupies 64K of memory, and consists of one main program and 60 subroutines. The keys actually used by the player are limited to function keys, numerical keys and "y/n" keys. All steps to the next screen display are virtually instantaneous. The initial version has produced the display all in Japanese, but we have subsequently written an English version. It has also been converted to run on an IBM-PC computer.

Many parameters of initial conditions are generated randomly and various random terms are added in the calculation, which helps to avoid exactly the same patient appearing and the performance being entirely predictable. The degree of this randomness is made greater as the rank of the player goes higher. A deliberate effort is made so that a program may generate abnormal values more often, which is what is required for the program of this nature.

For the rank of Student, numerical answers can be chosen from those already prepared. Reasonably good answers may be obtained, although a fine adjustment is not possible. From Residents above, the player is requested to enter actual numbers. A more accurate knowledge is required, but a finer adjustment is possible.

Results

For the last two years, this program, together with its earlier version, has been in use extensively in our department. Both students and physicians like it very much, and many have copied the earlier version. From a special data file prepared to record the actual use of this program, approximately 140 students and physicians used it 312 times for the last 20 months. The usage of "Professor" is high, ranking third to "Physician-in-training" and "Student" use, reflecting the fact that players prefer to jump to this rank rather than climbing up the ladder step by step (table 2). The obtained score ranges from zero to 100, but many low scores were obtained in "Professor" rank, indicating that players often challenged this rank prematurely. These data reflect only those recorded on author's own disk. More than 30 copies of this respiratory care version have been distributed throughout the country. A good number of copies of anesthesia version have also been distributed. We may estimate safely that this program has been in use at least several times more.

Table 2. Results of chosen ranks and obtained scores

scores	Students	Phy-in-tr	Phy-tr	Consul	Prof	Total
0	4	16	2	2	8	32
1–50	13	16	2	3	44	78
51–60	0	8	6	5	1	20
61–70	0	8	6	3	0	17
71–80	0	12	2	1	0	15
81–90	12	28	5	3	1	49
91–95	22	10	0	0	0	32
96–100	42	13	5	3	6	69
total	93	111	28	20	60	312

Discussion

This program is interesting and useful by itself as a self-teaching tool, but it is even more useful to students when combined with the verbal teaching by an instructor. Students have less opportunities to get an exposure to actual diagnoses and treatments in the clinical settings. Even if they have, many patients show normal values, and the students may not encounter abnormal situations. One such example is that they often had difficulties in "numerical" answers. While many students made correct diagnosis on acid-base abnormalities, they could rarely calculate the amount of $NaHCO_3$ or of acid correctly. The same was true as for the degree of PEEP. The author, as well as other instructors, felt that teaching is more efficient and proceeds more smoothly with the use of this program. The initial prediction that we can just hand such a program to students and tell them to self-teach has turned out to be in error. Teaching via computers and regular teaching method are complementary to, rather than mutually exclusive to, each other.

It took less than two months to write and debug the original program, but took almost a year to complete it, which was quite unexpected. As it turned out, the program had to be tested and re-tested many times on students and young physicians in order to make it really usable and palatable to them. This process was much slower and more time-consuming than the original development. It could not be done just by the hard work of a programmer's part. For completing it, the program needed to be used and discussed by students, and this is a very slow process. It was, of course, a very enjoyable and rewarding experience, however.

We may report here an example of this nature. At one time a student erroneously entered a huge amount of bicarbonate. At that time, a program of giving acid was not incorporated. He, however, corrected the condition of the "patient", by giving "negative" bicarbonate, which was beyond my expectation. The program was subsequently revised and acid administration is now possible.

A change from the anesthesia version to ICU version turned out to be more difficult and extensive than originally estimated. The main reason was that the logic applied in respiratory care in ICU differs considerably from that in anesthesia. There is yet another reason, however, that a new component have been incorporated in which the patient's condition either improves or deteriorates depending upon the diagnoses and treatments. For doing so, fairly extensive revision of the model was required as well as a good amount of programming. With this revision, however, it has become possible to see a patient quickly deteriorating into cardiac arrest in the face of inappropriate treatment, or to see a patient going back into a respiratory failure against a premature attempt of weaning from artificial ventilation or from oxygen administration. If the treatment is done correctly and the patient is maintained in good condition, his/her condition improves and be discharged from the ICU. This aspect is quite attractive as compared to the older version, which simply simulated the blood gas changes.

Graphical presentation of CO_2 and acid-base changes in such short time intervals are not common under real condition. Not only does it help students learning blood gases, but it helps them realize the dynamics of CO_2 and to predict the changes occurring next 2 hours. Visualization of CO_2 dynamics and acid-base chemistry in this manner may improve the actual care in the ICU.

We were informed recently of a program "Baby", developed by Edmunds et al. in Toronto[9]. While it deals with the circulatory condition, the approach is quite similar to ours; simulation of a single patient along the time-axis, element of a game, use of random variables and settings of difficulty level. Its graphics are far superior and more sophisticated, partly due to the computer used (Apple-McIntosh), but mainly due to the programming capability. We also became aware of a program "Arterial Blood Gases" by Hoffer et al.[10] We do not know whether it is similar to ours or it is of more didactic nature.

This program may be classified as one of CAI (computer aided instruction). Studying blood gases and acid-base problems in relation to respiratory care on time-axis is especially suitable to CAI.

This work was presented at the Computer Session, 7th Asian-Australasian Congress of Anesthesiologists, held in Hong Kong, September, 1986.

A copy of this program (English version: 5"-diskette and compatible with IBM-PC) may be purchased from Soft-Science, Inc: Shinjuku-NS-Building, 2-4-1 Nishi-Shinjuku, Shinjuku-ku, Tokyo, Japan. (Phone Tokyo 342-1471)

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