Johns Hopkins Hospital
Hemodynamic Monitoring Conference

Dynacath Patient Simulator Workshop

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The Critical Care Patient Simulator has been developed by the author for training, certification, modeling, and demonstrating problems in the management of critical care patients[1]. The simulator consists of an Apple Macintosh® computer and software, and a replica of a human torso designed to enable students to practice critical care medicine. The computer displays patient histories, laboratory results, treatment options, patient responses, and a real-time cardiac monitor. The torso apparatus is used to practice insertion of a hemodynamic monitoring catheter, while the cardiac monitor displays catheter pressure as the catheter is advanced into the heart, pulmonary artery and wedge position.

Workshop participants may develop procedural skills in performing cardiac catheterization, and cognitive skills in interpreting cardiac rhythms and hemodynamic data.

Special calculators in the program may be used to determine hemodynamic, respiratory, ventilatory, and renal function indices.

An short overview of authoring cases for the simulator is presented.

Trainee Operation [2]

Overview

The trainee begins a simulation by selecting a patient from the Cases folder and reviewing the initial history and physical examination information provided.

As in real life, trainees may order studies, select a management plan, seek consultation, or connect the patient to a cardiac monitor. Immediate feedback, or discussion is available for each management plan selected. Studies are performed by selecting from study alternatives programmed by the author. Similarly, a management plan is selected from choices provided by the author. Once a plan has been selected, all data change to conform with the intervention. Cardiac catheterization may be performed at any time by simply selecting the cardiac monitor from the computer menu, and introducing a catheter into the torso apparatus. The initial data presented (including both digital and analog display of waveforms), undergo real-time changes that correspond with the treatment given. This is made possible by the author's having previously entered the data as a consequence of the selected management.

Care is continued by reviewing progress notes and consultations, ordering additional studies, and selecting additional management alternatives. Continued care is possible because of automatic linking of previously authored modules. The care rendered may improve, worsen or cause no change in a patient's condition. Final management of the patient is dependent on the sequence of modules that occur, and may vary from one trainee to the next.

Suitable medical conditions for study include arrhythmias, cardiac tamponade, cardiomyopathies, congenital defects, constrictive pericarditis, fluid and electrolyte disturbances, myocardial infarctions and complications, post-operative conditions, pulmonary disorders, shock and valvular defects.

Potential users include medical and graduate students, residents, subspecialty trainees, hospital medical staff, nursing staff, and technicians.

Reviewing the History & Physical Examination

The simulation begins by selecting the **Open Chart** item under the **File** menu heading (Fig. 1), locating the Cases folder in the file dialog that appears, and opening the appropriate chart. A history and physical examination is displayed in a window on the Macintosh computer screen. You can scroll through the chart by selecting the controls on the right-hand side of the window.

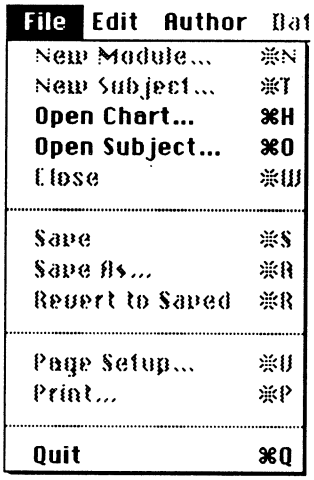

Fig. 1. **File** menu items.

Ordering Studies

Once the chart has been reviewed, you may select any of the bold-type items listed under the **Trainee** menu (Fig. 2). Items in gray-type can not be selected. Notice the extended menu for **Order Studies**. The gray-type items may become bold-type later or not at all, depending on what has been authored previously.

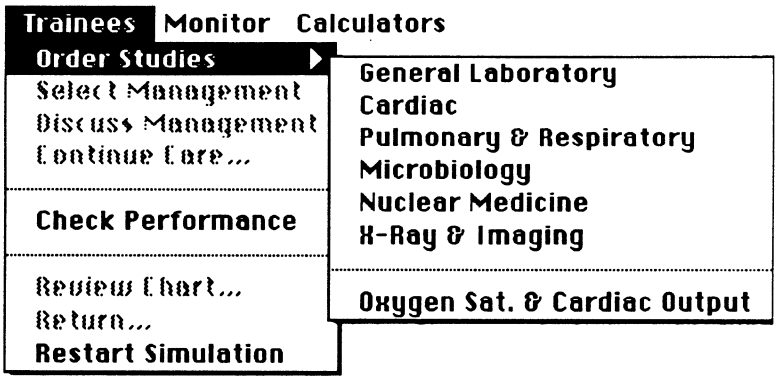

Fig. 2. **Trainees** menu items, and the extended **Order Studies** menu items. The **Oxygen Sat. & Cardiac Output** display may also be called directly from the torso apparatus console by pressing the **Special Studies** button when the cardiac monitor is being displayed. When done ordering studies, select **OK** on the display that appears.

The trainee may select from the study options, or proceed directly with a management plan after reviewing the presenting history and physical. Studies are ordered by selecting from the list of options provided in the dialog that appears (Fig. 3).

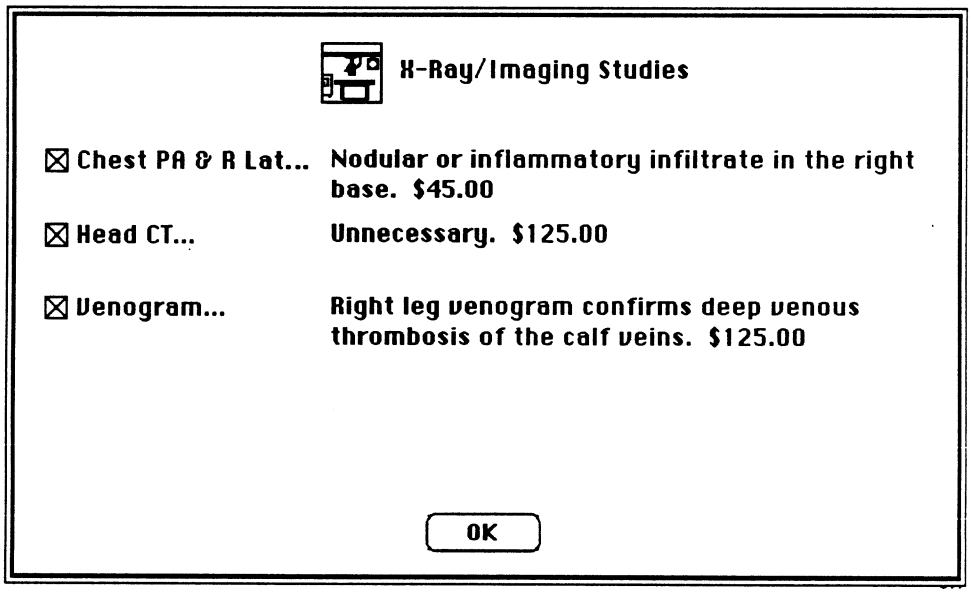

Fig. 3. A study is ordered by checking the box on the left-hand side of the display, and the result is displayed on the right-hand side. The system keeps score on the studies ordered, determines unnecessary or inappropriate orders and tabulates cost of care.

You may return to this display later to review the results or order additional studies. However, once you have selected a management plan, the study options and results may change. For example, an initial review of a chest x-ray may show congestive heart failure. After appropriate management a repeat film may show this has cleared. If inappropriate care is delivered, a repeat film may show significant worsening!

Using the Cardiac Monitor and Torso Apparatus

If appropriate, the trainee may connect the patient to a cardiac monitor by selecting **Show Cardiac Monitor** under the **Monitor** menu (Fig. 4).

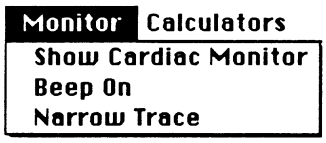

Fig. 4. The **Monitor** menu.

Show Cardiac Monitor changes to **Hide Cardiac Monitor**, and must be selected to remove the monitor display from the screen later. Placement of a pulmonary artery catheter should be done only when the cardiac monitor is showing. Selecting **Beep On** will make the display more realistic, and selecting **Narrow Trace** will provide a sharper waveform.

Once the monitor is showing (Fig. 5), the torso apparatus control switches may be used, and a pulmonary artery catheter may be inserted into the patient. Select **ECG** and/or **Arterial Line** on the apparatus control panel, and if data has been entered by the author, waveforms will appear on the cardiac monitor.

Most pulmonary artery catheters (ie. Swan-Ganz® catheter) will work with the torso apparatus.

Warning: Do not insert sharp needles, force insertion components, overly insert a metal guide wire, infuse fluids or inject fluids into the apparatus.

If you do not have a syringe available, or are unable to secure the catheter to the adaptor or port on the enclosure, you may instead simulate the process by selecting the **Balloon Inflated** or **Balloon Deflated** switches on the apparatus control panel. Do not use these switches if you are using an actual syringe. The indicators will read correctly by either method.

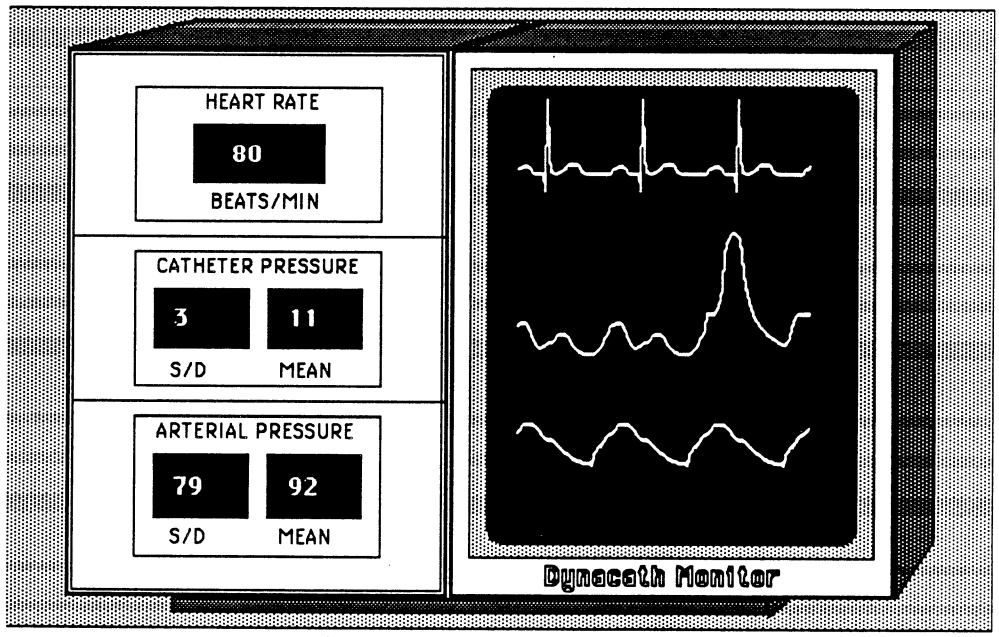

Fig. 5. Simulated cardiac monitor.

The **Clear** switch may be used after withdrawing the catheter if the catheter position and display appear out of sync. This problem may arise if the catheter is moved at times other than when the cardiac monitor display is showing. There is no harm in simply pulling the catheter out between cases, as the system will clear itself when a new case is started.

The **Special Studies** switch may be used to call up the **Oxygen Sat. & Cardiac Output** display while the cardiac monitor is showing.

Selecting a Management Plan

Four management plans are available at any given time, and these can be chosen by selecting the item **Select Management** under the **Trainees** menu (Fig. 6). Once a plan has been selected, all studies and the cardiac monitor display change based on the plan selected. For example, follow-up studies may be ordered, the ECG reviewed, or the patient may undergo right-heart catheterization.

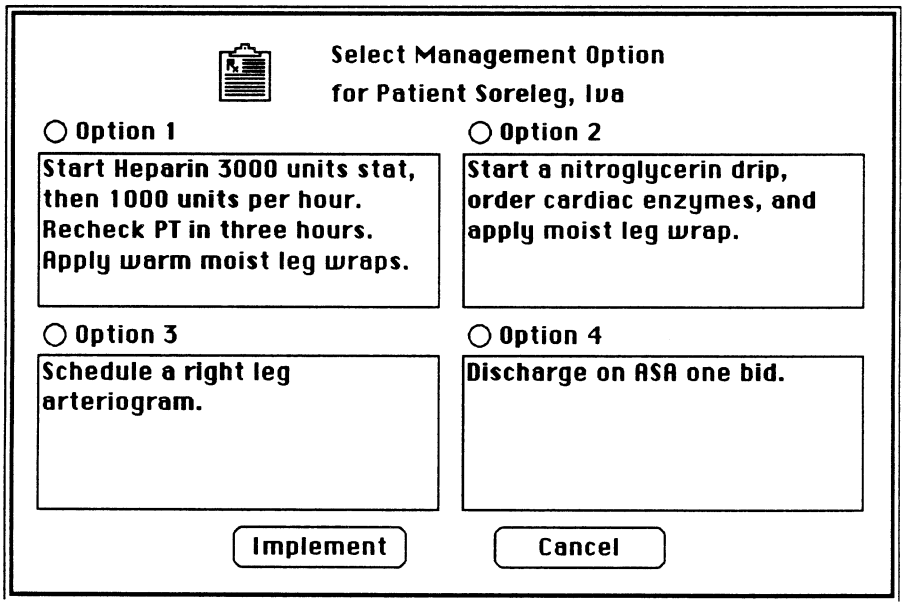

Fig. 6. One of four management plans may be selected at a time. After selecting the round button above an option, select **Implement**.

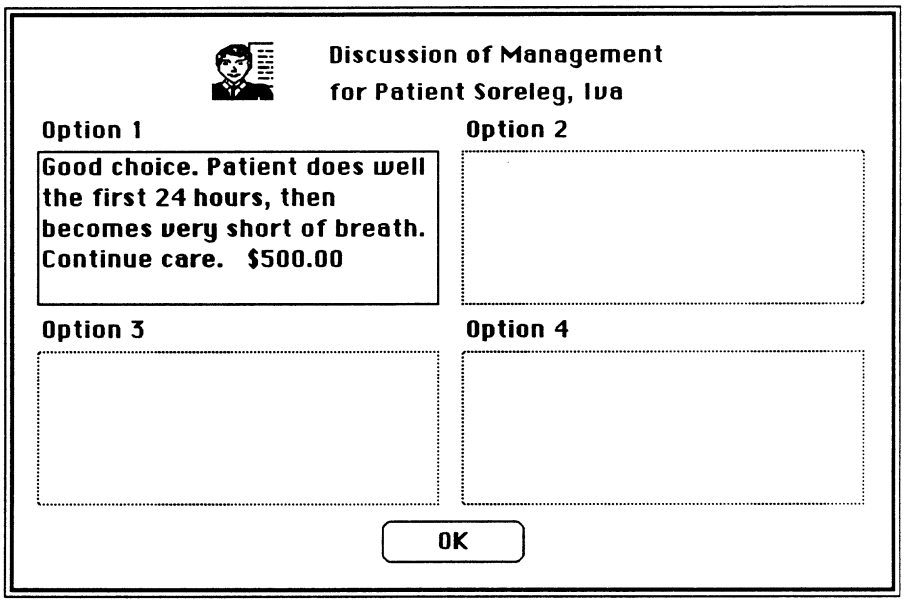

Fig. 7. Discussion, or immediate feedback is presented for each management plan.

Discussion

You may at any time select **Discuss Management** under the Trainees menu, and receive immediate feedback about your management choice (Fig. 7). You will need to consult this area before advancing further in the case.

It is possible to "change your mind" and select a different plan at this juncture. Your performance evaluation will take this into account however.

Continuing Care

If the **Continue Care** item is in bold-type, you may continue the patient's care by selecting this item. The patient's chart will automatically open with a progress note or consultation - dependent on the management plan you chose. You are now presented with new study options and results, as well as new management alternatives.

Time Traveling!

It is possible to go back in time and review old chart notes, studies, results and management options by selecting **Review Chart**. Each time you select this option, you move further back in time. To move forward in time select **Return**. Repeatedly selecting this item will bring you back to the present!

You may also select **Restart Simulation** to quickly prepare the case for the next trainee.

Performance Evaluation

Trainee performance is monitored for both cognitive skills in patient management and procedural skills at catheterization (Fig. 8). The former is accomplished by numerical score of

the care delivered, determination of the numbers of unnecessary and inappropriate studies or treatments, and cost analysis of the care delivered.

This concludes discussion of the method for trainee operation of a patient simulation.

Subject Review

Select **Open Subject** under the **File** menu and locate the Subject folder in the file selection dialog that appears. **Open** the folder, and select for review any topic that may

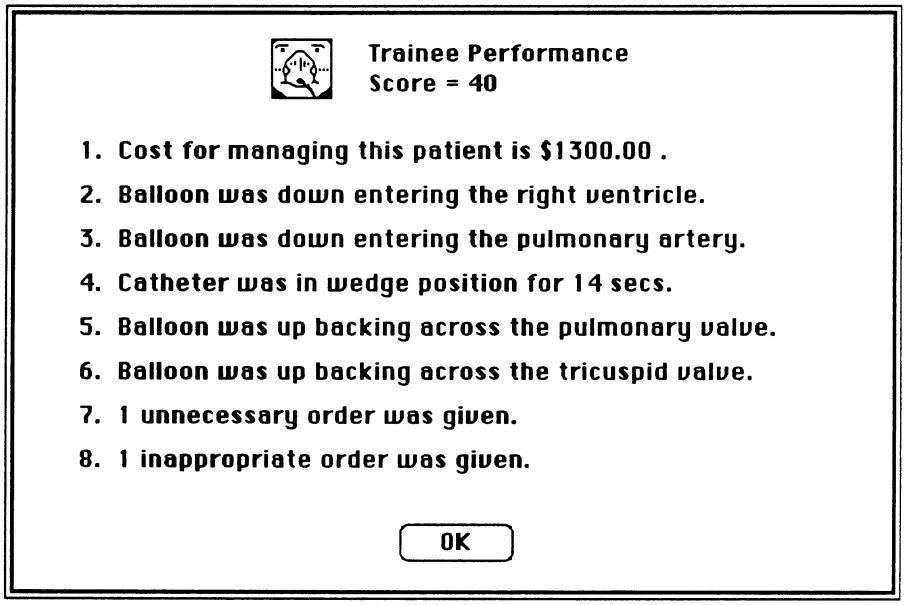

Fig. 8. The Trainee Performance display may be reviewed at any time while managing a patient, and results will be accumulative, or representative of the last catheterization performed.

be of interest. The subject text will appear in a window, and can be scrolled through by selecting the controls on the right-hand side of the display (Fig. 9).

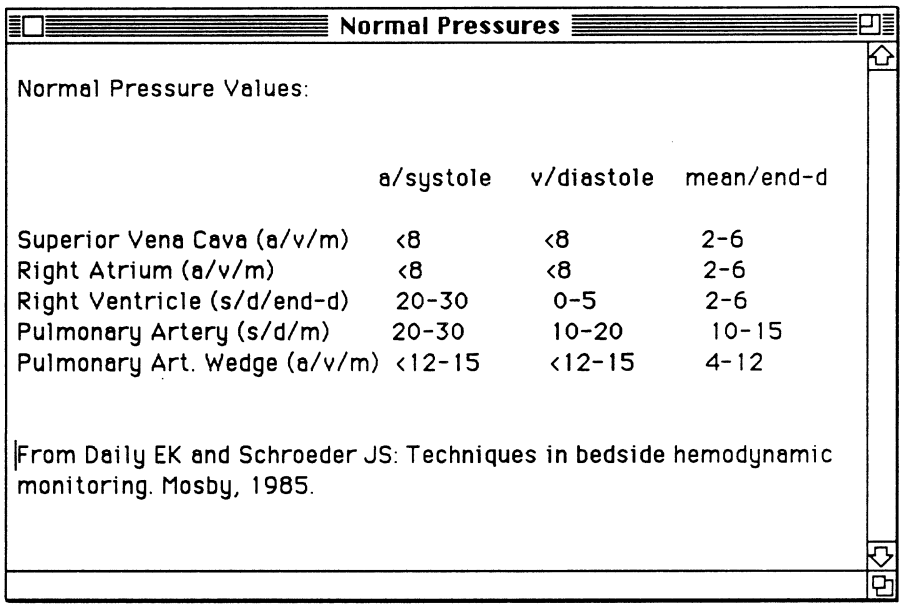

Fig. 9. Example subject document.

Calculator Operation

Overview

Included with Dynacath Critical Care Patient Simulator™ are four calculators for determining essential indices of cardiopulmonary and renal function.

Selection

Under the **Calculator** menu heading select the specific calculator desired (Fig. 10).

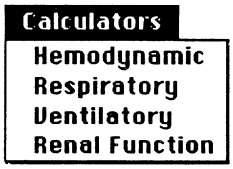

Fig. 10. **Calculator** menu items.

Hemodynamics Calculator

The Hemodynamics Calculator takes as input the patient's heart rate, blood pressure, pulmonary artery pressure, pulmonary artery wedge pressure, central venous pressure, cardiac output, height and weight (Fig. 11).

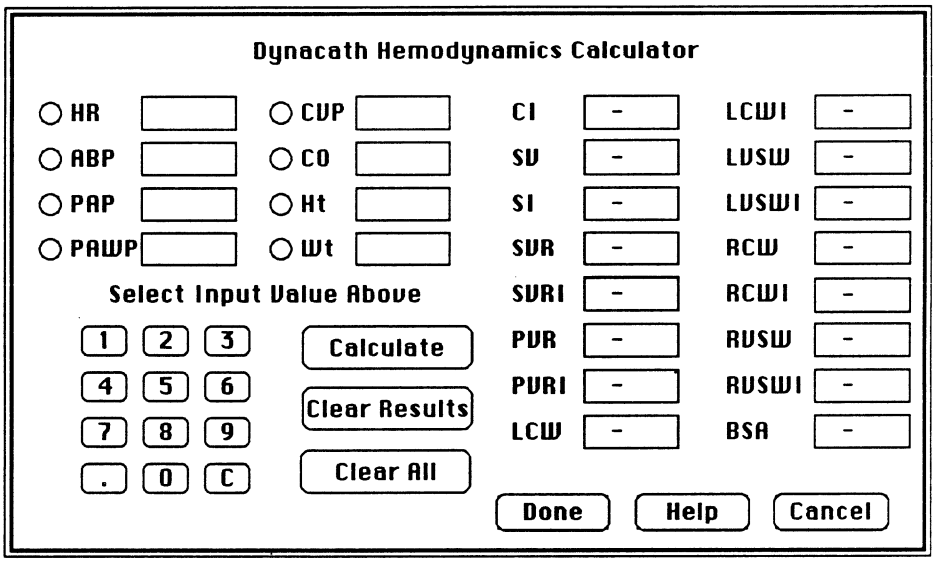

Fig. 11. Hemodynamics Calculator.

Once all values have been entered on the left-hand side of the display, selecting **Calculate** will force output values for the cardiac index, stroke volume and index, systemic vascular resistance and index, pulmonary vascular resistance and index, left cardiac work and index, left ventricular stroke work and index, right cardiac work and index, right ventricular stroke work and index, and body surface area.

To operate the Hemodynamics Calculator, perform the following steps:

1. Note the height and weight from the patient's history and physical. Determine the patient's arterial pressure, pulmonary artery pressure, and central venous pressure from the cardiac monitor while advancing a pulmonary artery catheter.

2. Select the small round radio button adjacent to each input value on the left- hand side of the display.

3. Enter the value by selecting digits (or decimal point) on the key pad in the lower left-hand corner of the display (or type on the computer keyboard). Select C to clear the entry if you wish, or simply re-select the radio button and again enter digits.

4. Once all the values are entered, select **Calculate** and observe the output values appear. You can go back and change any input parameter and recalculate the output values. This is an ideal way to observe the effect of changing any one input value by small or large amounts.

5. You may clear just the results by selecting **Clear Results** or the entire display by selecting **Clear All**.

6. Dismiss the display by selecting either **Done** or **Cancel**. The data will remain in the calculator until you remove it. If run from within a case, the data will remain until the case is completed.

7. Clicking on any input or output display rectangle will automatically bring up a help display with the appropriate full name, normal range, derivation and any other information previously entered by an author (12).

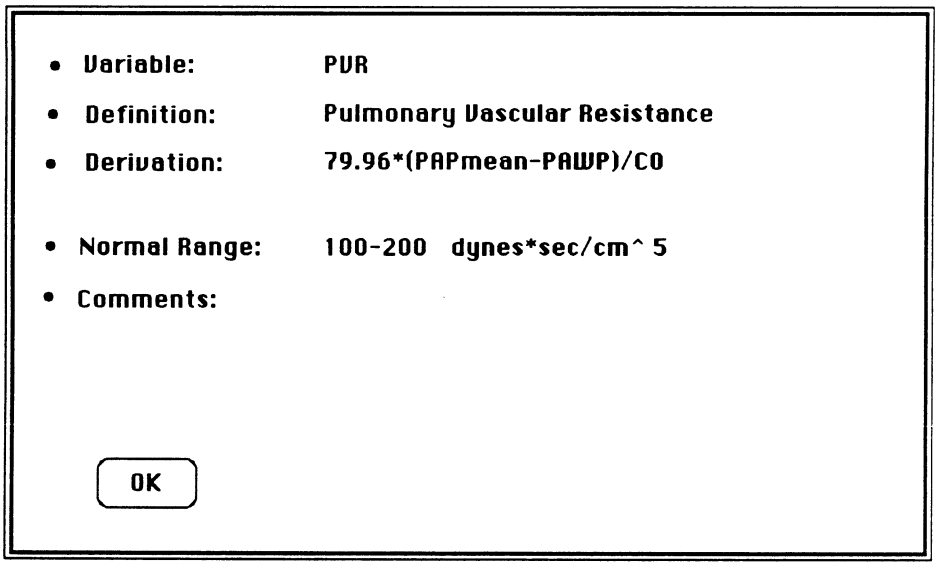

Fig. 12. Example of help display for pulmonary vascular resistance. The comment area is available for authors to convey additional information to trainees. Entry of text in the comment area is possible after entry of a proper access code under the **Author** menu heading.

Respiratory Calculator

The Respiratory Calculator takes as input the cardiac output, fraction of inspired oxygen, partial pressure of oxygen in arterial blood, partial pressure of carbon dioxide in arterial blood, percent arterial oxyhemoglobin saturation, venous partial pressure of oxygen, percent venous oxyhemoglobin saturation, hemoglobin, height, weight, and barometric pressure (Fig. 13).

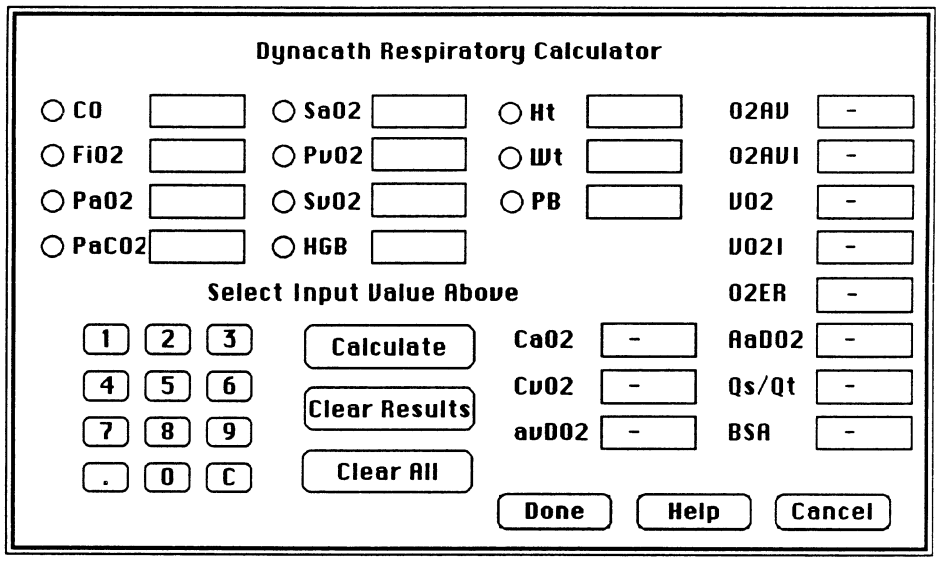

Fig. 13. Respiratory Calculator.

Calculated output data are arterial oxygen content, venous oxygen content, arteriovenous oxygen difference, oxygen availability and index, oxygen consumption and index, oxygen extraction ratio, alveolar-arterial oxygen difference, percent shunt, and body surface area.

Ventilatory Calculator

The Ventilatory Calculator takes as input the respiration rate, arterial partial pressure of carbon dioxide, tidal volume, peak inspiratory pressure, positive end-expiratory pressure, and pressure of expired carbon dioxide (Fig. 14).

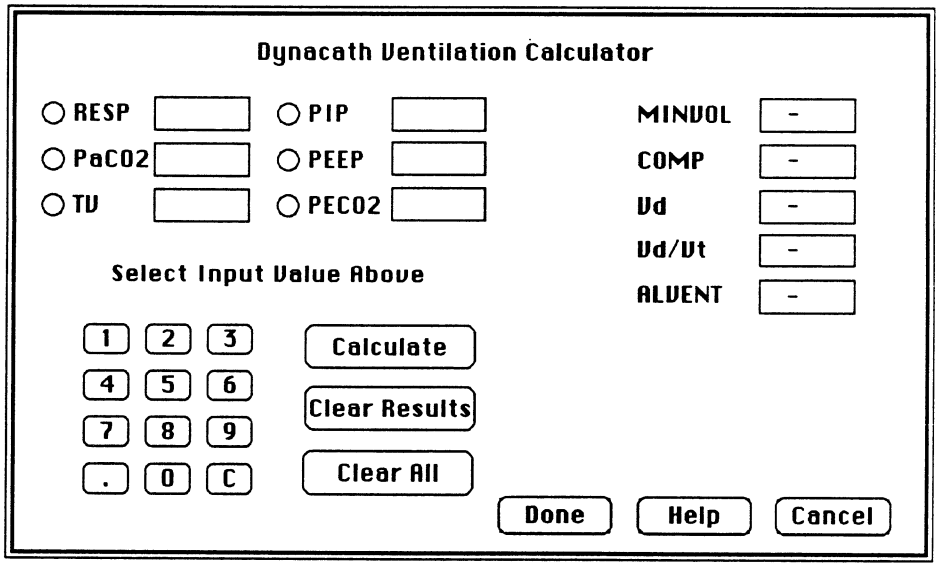

Fig. 14. Ventilatory Calculator.

Calculated output values are minute volume, compliance, dead space, dead space/tidal volume ratio and alveolar ventilation.

Renal Function Calculator

The Renal Function Calculator takes as input data the serum sodium, serum creatinine, plasma osmolarity, urine osmolarity, urine creatinine, urine sodium, urine potassium, urine volume, blood urea nitrogen, height and weight of the patient (Fig. 15).

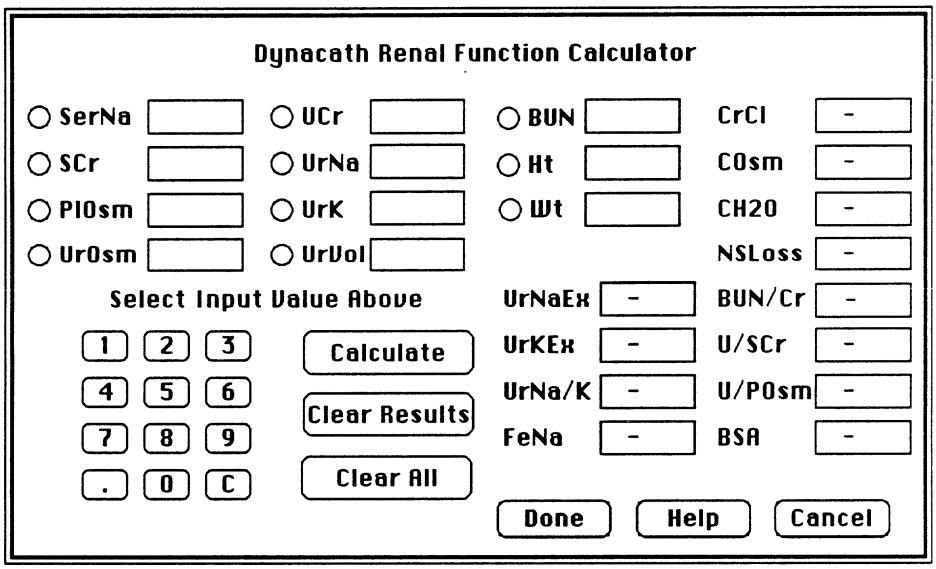

Fig. 15. Renal Function Calculator.

Calculated output data are urine sodium excretion, urine potassium excretion, urine sodium to potassium ratio, fractional excretion of sodium, creatinine clearance, osmolar clearance, free water clearance, nonsaline loss, blood urea nitrogen to creatinine ratio, urine serum creatinine ratio, urine plasma osmolarity ratio, and body surface area.

Author Operation

Overview

The Dynacath Critical Care Patient Simulator™ has no inherent knowledge of medical illness or physiologic processes. The "knowledge base" or computer database is derived entirely by authored material. The system provides both the hardware and software tools to allow an author to enter all data involved in the management problem.

The author creates a case by dividing the total management problem into individual operations, or "modules." A module is a group of data consisting of a history and physical exam (or subsequent progress note or consultation), study options and results, hemodynamic data, four potential management plans and appropriate discussion. Data is entered for the patient's initial condition, and for the consequence of each management plan. Histories, physicals, progress notes, and consultations are entered using standard word processing. Dialog boxes are used to enter study options and results, hemodynamic data, management plans and discussion.

Actual waveforms from the critical care unit or cardiac catheterization laboratory may be used by simply tracing one or more cycles on a digitizing tablet. The program allows an author to automatically adjust the rate and pressure of the waveforms once they have been entered, reducing the number of waveforms that need to be drawn. This is accomplished by numerical analysis of the drawn waveform, and application of mathematical tools unique to computer raster graphics presentation.

Part of one case may be shared with another-either directly or through a library of waveforms-shortening the time it takes to author a case.

Although many problems in medical management can be demonstrated with a single module, a case consisting of multiple modules allows the trainee to provide "continuing care" for the patient. After the first module, progress notes or consultations are presented rather than the history and physical. During the simulation, only those modules appropriate to the trainee's action are presented.

Authoring a case may take anywhere from an hour to several days, depending on the number of modules needed. The author must consider the consequences of each treatment option provided to the trainee, and enter conforming data.

An outline of the information necessary for authoring a single module is shown in Table 1.

Table 1. - **Outline of Information Needed for Authoring a Single Module in Construction of a Simulated Case.**

I. History and physical examination (initial module)
- A. Identify with a pseudonym (base name)
- B. Type appropriate information, or

Progress notes and consultations (subsequent modules)
- A. Identify with an identification number appended to the base name (eg. Smith, John[1..99])
- B. Type appropriate progress note or consultation

II. Hemodynamic data
- A. Enter rate & pressure data for the initial presentation and consequence of each management option
  1. Heart rate
  2. Catheter pressure readings (RA, RV, PA, Wedge)
  3. Arterial pressure (systolic and diastolic)
- B. Enter waveform data for the initial presentation and consequence of each management option (actual tracings may be used)
  1. Rhythm strip
  2. Hemodynamic monitoring catheter
  3. Arterial line
- C. Merge data (process waveforms to match rate and pressure)

III. Study options and results
- A. Enter studies for the initial presentation and consequence of each management option
  1. General laboratory
  2. Cardiac studies
  3. Pulmonary & respiratory studies
  4. Microbiology
  5. Nuclear medicine studies
  6. X-Ray & imaging studies

7. Oxygen saturation & cardiac output

B. Include reserved words with study results

1. "Unnecessary" and "inappropriate" synonyms
2. Performance score ({-100..100})
3. Cost of study or procedure ($n,nnn.nn)

IV. Management options

A-D. Enter up to four management plans

V. Discussion text

A. Enter up to four discussion replies to the management options above

B. Include reserved words with each discussion

1. Next module's identification number ([1..99])
   (This indicates to the system which module to automatically link once a given management option is selected)
2. "Unnecessary" and "inappropriate" synonyms
3. Performance score ({-100..100})
4. Cost of treatment ($n,nnn.nn)

Summary

The Critical Care Patient Simulator may be used for practicing placement of a pulmonary artery catheter and for obtaining experience in patient management. Instructors create a curriculum by authoring cases - complete with histories, study options and results, hemodynamic data and management options.

References

Saliterman SS: A computerized simulator for critical-care training: New technology for medical education. Mayo Clinic Proceedings 65:968-978, 1990

Saliterman SS: The Dynacath Critical Care & Hemodynamic Monitoring System User Manual. Minneapolis, Dynacath, 1992