Critical Care & Hemodynamic Monitoring Training System

Steven S. Saliterman

Vol. 1

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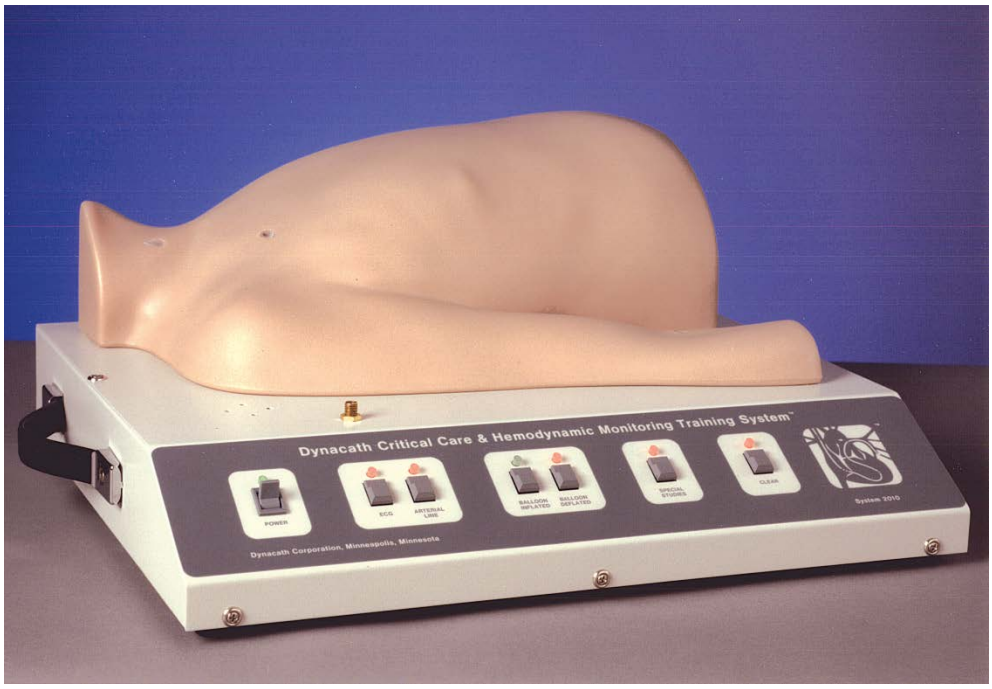

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Contents

Volume 1

Preface

Preface

The Critical Care & Hemodynamic Monitoring Training System was a training aid for physicians, medical students and nurses learning management of critically ill patients. The system included a means for practicing placement of a pulmonary artery catheter through the heart, with display of catheter and arterial waveforms, and electrocardiogram on a simulated cardiac monitor. The catheter balloon could be inflated to obtain wedge pressure readings.

Cases could be authored which provided a synopsis of a patient's medical history and studies. The student could then select various management options and observe the outcome over time. This included updated study reports and realtime changes on the cardiac monitor. Cost of care could also be tracked.

This was the first manikin interfaced to a computer for medical training, ushering in a new era in medical education (Rogers et al. 2001). The use of a mouse and graphical user interface, allowing interaction between the student, manikin and computer had not been done before.

Volume 1 contains various manuscripts, user manual, photographs, drawings, US patent, correspondence, presentations, feature articles and marketing brochures. Volume 2 contains the final version of the software source code.

Prototype A was a breadboard-only attempt to identify the position of a pulmonary artery catheter and inflation status of the balloon. The catheter was passed through a series of aluminum blocks each representing an anatomical location. The blocks contained a light emitting diode and phototransistor side-by-side, allowing for measurement of reflected light. The amount of reflected light could be correlated with the presence of the catheter and balloon state (inflated or deflated). Martin Rosenstein, a general surgeon, wrote a program in assembly language code for the Apple II computer to process the signals. The method however proved to be unsatisfactory.

Attention turned to producing a full sized prototype of the system, and the newly introduced Apple® Macintosh® computer in 1984 was chosen as the platform (having superior graphics compared to the IBM PC). Space was leased in the newly renovated Ford Centre in downtown Minneapolis for the development effort.

Design of prototype B, the production unit, and software development were all done by the author. Some components for the production unit were fabricated by local vendors based on the engineering drawings contained here. All assembly, including populating circuit boards was done at the Ford Centre facility.

The prototype fiberglass shell was cast from my plaster mold by Bob Johnson, a noted artisan in resin materials. In the prototype, position of the catheter was determined by having it turn a rubber roller, and this in-turn the shaft of an optical encoder.

The balloon state was determined by having the catheter pass through a tube the width of the inflated balloon, and measuring attenuation of a short sound burst down the tube (using a tiny speaker and microphone on either end of the tube).

The next effort was to design the production model. The acoustic balloon-state detection scheme was abandoned in favor of simply diverting the air into an internal pneumatic switch. The optical encoder quadrature output was decoded in hardware, and along with the pneumatic switch and front panel switch position, data was sent via a serial interface to the Macintosh computer. The state of the front panel indicators (with the exception of the power LED), was determined in software, and sent back to the apparatus to be displayed.

Software was written in Pascal and cross-compiled on a Lisa computer (The Lisa Workshop), as this was the only software development environment at the time for a Macintosh computer. Subsequently, the Macintosh Programmers Workshop (MPW), a source-level debugger called SADE (Symbolic Application Debugging Environment) and the "Inside Macintosh" publications became the Macintosh programming environment. The program consisted of over 25,000 lines of code.

A Kurta® tablet interface was added to assist in authoring cases for the system allowing incorporation of actual patient waveforms by tracing with a stylus. The authoring component was quite sophisticated, including a medical record, an ability to select different studies and interventions, and ultimately to see the effects in the simulation – including catheter measurements. There was even an ability to determine the cost of the care delivered. Several built-in software "calculators" allowed for rapid assessment of hemodynamic data. Two additional encoder inputs were included on the main circuit board for future sensing needs, such as catheter rotation. While separate software modules were tested to simulate x-ray display of the catheter moving through the heart, these were not included in the final system.

Apple Computer was helpful in providing access to its "evangelist" team and Developer Relations Group for consultation, and computers needed at various conferences and other showings of the system. They also provided an educational discount for their products to institutions acquiring the system.

The system received a patent (4,642,055) in 1987, and I was an invited participant in the 17th Annual Inventors Expo, sponsored by the United States Patent Office on February 12, 1989. The project was presented at the scientific session of the Mayo Medical School Alumni Society meeting on November 4, 1989 and published in the Mayo Clinic Proceedings (*Mayo Clinic Proc* 65:968-978, 1990). The system was ultimately acquired by eighteen medical institutions.

Three of the systems were set up annually at the Johns Hopkins Hospital “Hemodynamic Monitoring/Patient Care and Pulmonary Artery Catheterization” conference from 1991 to 1994 (chaired by Dr. James Schauble), and I was an invited lecturer each year.

Dynacath® was incorporated in Minnesota for accounting and tax purposes. Funding was possible by commitments from the institutions that acquired the system.

The software continued to operate on all Macintosh computers using the “classic” Mac OS software through System 7 (mid 1990s). Development was concluded when Apple made a major change in its operating system, and an entire rewrite of the software would have been required. Existing systems were supported for many years.

Steven S. Saliterman
2018

References

Rogers, P. L., H. Jacob, A. S. Rashwan, and M. R. Pinsky. 2001. 'Quantifying learning in medical students during a critical care medicine elective: A comparison of three evaluation instruments', *Critical Care Medicine*, 29: 1268-73.

Manuscripts

Special Article

A Computerized Simulator for Critical-Care Training: New Technology for Medical Education*

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A patient simulator has been developed for training, certification, modeling, and demonstrating problems in the management of critical-care patients. The Critical Care & Hemodynamic Monitoring Training System consists of a personal computer, 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; the cardiac monitor displays catheter pressure readings as the catheter is advanced into the heart and also pulmonary artery and wedge position. Special screen calculators in the program may be used to determine hemodynamic, respiratory, ventilatory, and renal function indices. In contrast to previously described simulators and computer oriented instructional programs, this system contains no inherent data base. Instead, authors build a library of informative cases by using the hardware and software tools provided. Individual "modules" of patient information are authored, and these are transparently linked as a student undertakes management of a patient. Although this system is a technologic achievement, determination of its usefulness as an instructional tool or certification aid must come from broader use and controlled studies.

The demand for proficiency among critical-care physicians and nurses has never been higher. In recent years, this demand has been reflected in the dramatic increase in the number of publications focused on critical-care medicine. Board certification has also been instituted to ensure uniformity in training and development of high-quality residency programs and to recognize those physicians who, through special education and testing in critical-care medicine, have substantiated competence in the field.[1] Recommendations for fellowship training in critical care, published in 1987 by the Society of Critical Care Medicine's Task Force on Guidelines, highlight the importance of an environment in which the trainee has sufficient critical-care responsibilities to develop both patient-care and procedural skills.[2] Similar concerns for training and certification in Canada have also been published.[3,4] Standards for educating nurses in critical care, developed during a 3-year period, are now being implemented.[5]

In certain professions, such as aviation and space flight, the need for simulating routine and adverse situations has long been recognized.

*This material was presented at the scientific session of the Mayo Medical School Alumni Society on Nov. 4, 1989.

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Although an airline pilot or an astronaut would not be expected to assimilate all the skills necessary for their jobs by actually experiencing the many potential disasters that await them, critical-care providers have traditionally depended on actual patient contact for much of their training.[6] Moreover, many providers who have not achieved certification face the same level of responsibility as those who have. The complexity of treatment modalities and the sophisticated technologies available to providers have strained our traditional educational programs. Although perceived as an important adjunct to medical training, advanced simulators in medical training have been introduced slowly.[7-9] In the future, simulators may play a crucial role in continuing education and the granting of privileges for performance of certain procedures.

Patient-management simulators have traditionally integrated various manikin components with computer display of important physiologic events. Some devices are impressive in their ability to duplicate bedside evaluation[10-13] or administration of anesthesia,[14-17] providing lifelike responses for the student. After a 4-year period of development, the system described herein was granted a patent in 1987 from the US Patent and Trademark Office.[18]

The system consists of software that operates on a Macintosh computer (Apple Computer, Inc., Cupertino, California), a portable peripheral unit including a replica of a human torso (Fig. 1), and various controls to display a real-time cardiac monitor on the computer (Fig. 2). Trainees can develop manual dexterity skills in performing cardiac catheterization and cognitive skills in interpreting cardiac rhythms and hemodynamic data.

The Critical Care & Hemodynamic Monitoring Training System (Dynacath Corporation, Minneapolis, Minnesota) contains no inherent data base. Instead, authors build a library of informative cases by using the hardware and software tools provided. Expansion and modification of the data base are limited only by the amount of computer storage available. This method promotes timeliness and quality of the instructional material by allowing incorporation of recent literature, tailoring of cases to specific audiences, and customizing for regional, social, or philosophical approaches to certain management problems.

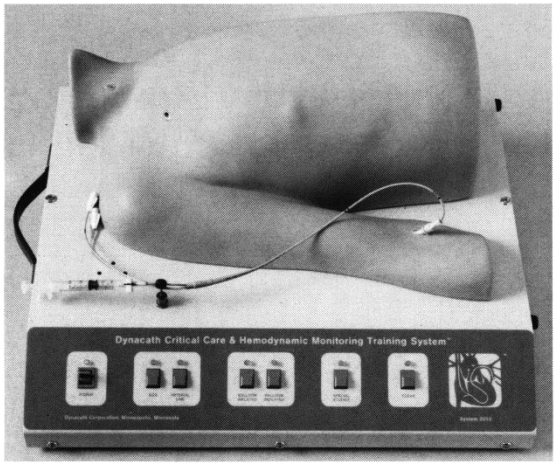

Fig. 1. Photograph of Critical Care & Hemodynamic Monitoring Training System. In this replica of a human torso, a catheter may be placed by using standard insertion components and advanced through cardiac chambers into wedge position. System monitors insertion technique, including improper use of the balloon, prolonged time in wedge position, and "overwedging" of catheter. Anatomic landmarks—such as distance to tricuspid valve—are controlled by software.

It is the only available system that allows simulation of complete catheterization of the right side of the heart, with real-time simulation of cardiac rhythms and arterial and catheter pressures. Suitable medical conditions for assessment include arrhythmias, cardiac tamponade, cardiomyopathies, congenital defects, constrictive pericarditis, fluid and electrolyte disturbances, myocardial infarctions and complications, postoperative conditions, pulmonary disorders, shock, and valvular defects.

The system is portable and may be carried by one person. The current cost of the system is less than $5,000, excluding the computer. The potential users include medical and graduate students, residents, subspecialty trainees, hospital medical staff, nursing personnel, and technicians.

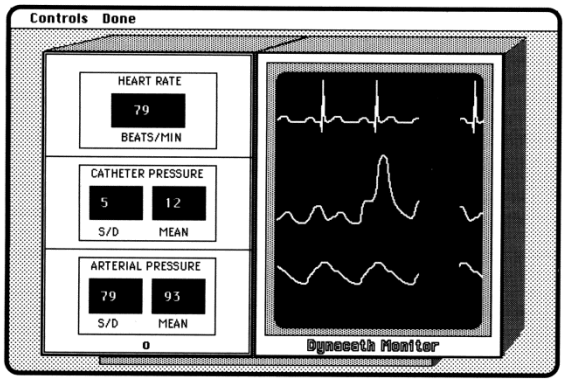

Fig. 2. Simulated cardiac monitor displays rhythm, catheter pressure, and arterial line pressure data. Systolic and diastolic values (*S*/*D*) are displayed alternately on left side of monitor, along with mean pressure. Catheter pressure readings show real-time changes as catheter is advanced through right atrium, right ventricle, pulmonary artery, and wedge position. "Overwedging" may be identified by increasing pressure values as catheter is advanced. A "beep" may be added to make the display more realistic. The probability of "missing" the heart—that is, crossing the chest or going down the inferior vena cava—is controlled by software.

MATERIAL AND METHODS

Construction.—The system consists of a simulated adult torso made of rigid polyethylene, with access ports for right-heart catheterization from the median basilic vein in the antecubital fossa, the subclavian vein, and the internal jugular vein. Catheterization is possible from the right side only. An internal guideway leads the catheter to precision-aligned rollers that rotate an optical encoder. The optical encoder provides information about catheter position and direction of motion to the computer. A three-way adapter is connected between the catheter and the balloon syringe for diverting air into a durable internal balloon. A sensor determines the status of balloon inflation, and this information is also provided to the computer. A single cable connects the torso apparatus to the computer's modem port, and power is provided through an Underwriters' Laboratories-approved power supply.

Software.—The software is written in Macintosh Programmers' Workshop Pascal and compiled into machine code for distribution. Source code modification is not possible by the system user, although suggestions for revisions from test sites have been regularly incorporated into the software.

Two levels of operation are available: a case input and development function for instructors (or "authors") and a simulation function for students (or "trainees"). A computer keyboard is unnecessary during simulations; selections are made by using the apparatus switches or by pointing the computer cursor—with a mouse or trackball—to suitable screen buttons and controls (Macintosh User Interface).

Author Operation.—The system has no inherent knowledge of medical illness or physiologic processes. The "knowledge base" or computer data base is derived entirely by authored material. The system provides both the hardware and the software tools to enable an author to enter all data involved in the management problem. A flowchart of the authoring operation is shown in Figure 3.

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 examination (or subsequent progress note or consultation), hemodynamic data, study options and results, four potential treatment plans, and appropriate discussion. Data are entered for the patient's initial condition and for the consequence of each treatment plan. Histories, physical examinations, progress notes, and consultations are entered by using standard word processing (Fig. 4). Dialog boxes (Macintosh User Interface) are used to enter hemodynamic data, study options and results, treatment plans, and discussion (Fig. 5). 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 (Fig. 6). The program enables an author to adjust the rate and pressure of the waveforms automatically once they have been entered; thus, the number of waveforms that need to be drawn is reduced. This procedure is accomplished by numerical analysis of the drawn waveform and application of mathematical tools unique to computer raster graphics presenta-

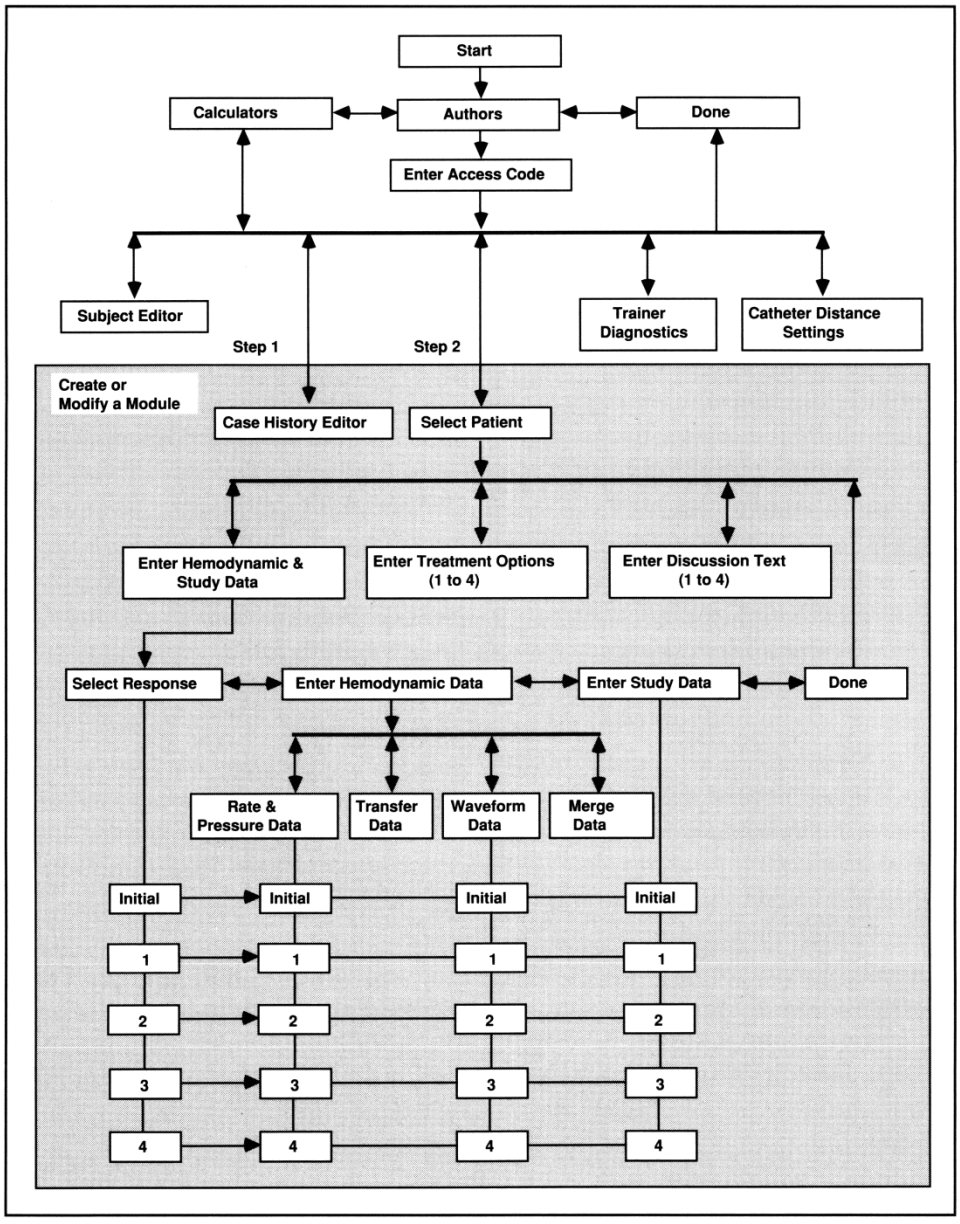

Fig. 3. Flowchart of program operation for authoring cases. Once a history and physical examination have been prepared and entered, all hemodynamic and study data, treatment options, and discussions are entered by using tools provided by the system. Management problems are divided into discrete modules, each containing either the history and physical examination or the progress notes and consultation, as well as treatments, discussions, and "response" data ("initial" data and data resulting from each treatment plan). Trainees do not see the modules but rather progress through the case just as they would in an actual patient-management situation. Modules automatically interconnect on the basis of treatment selected. By limiting treatment options to four per module, the author does not have an unwieldy amount of data; cases can be expanded later by adding more modules. Each management problem may end in a variety of ways, depending on the scenarios created by the author and the action taken by the trainee.

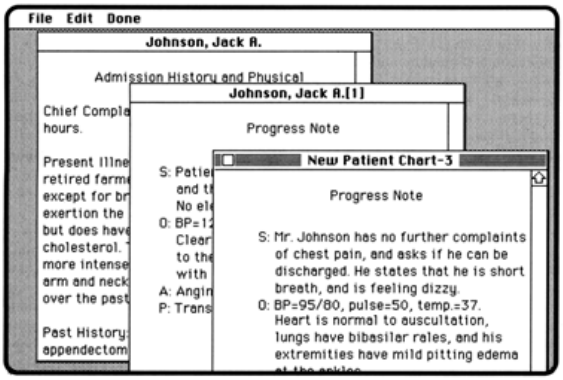

Fig. 4. Example of computer screen appearance when history and physical examination are entered. Multiple documents may be open at one time, including the initial history and physical examination, progress notes, and consultations. Editing features include "cutting and pasting" of text within or between documents. Because each document is saved by a patient pseudonym, memory is also reserved for storage of module-specific data. *BP* = blood pressure; *S* = subjective; *O* = objective; *A* = assessment; *P* = plan.

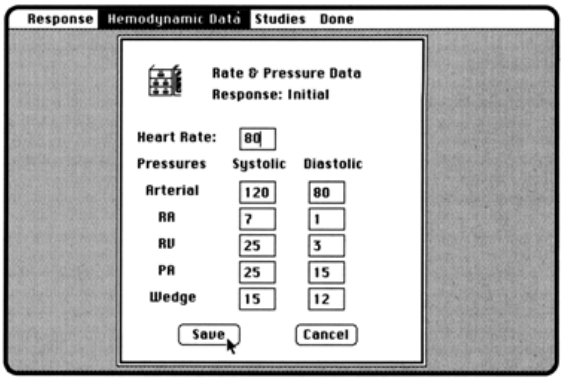

Fig. 5. Entry of module-specific data is by means of dialog boxes, such as example shown here for heart rate and hemodynamic values. Similar dialog boxes are used for entry of study options and results, treatment plans, and discussions. Computer cursor is moved to appropriate entry point above, and values are typed on computer keyboard. Default values (previously stored data) are shown when dialog box first appears. New data are incorporated into module by selecting "Save." *PA* = pulmonary artery; *RA* = right atrial; *RV* = right ventricular.

tion. Because part of one case may be shared with another—either directly or through a library of waveforms—the time needed to author a case can be shortened.

Although many problems in medical management can be demonstrated with a single module, a case consisting of multiple modules enables 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 examination. During the simulation, only those modules appropriate to the trainee's action are presented.

Authoring a case may take 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 the conforming data. An outline of the information necessary for authoring a single module is shown in Table 1.

Although having the latitude to allow the trainee to select any treatment at any time would be ideal, no available instructional system could predict the outcome. This range of options may be possible in the future by incorporating cardiovascular and other models. Authors may use models currently available to assist them in constructing cases.

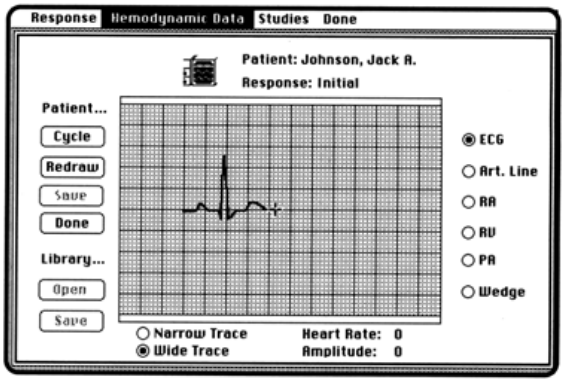

Fig. 6. One or more waveform cycles are either drawn freehand or traced on a digitizing tablet. Once entered, the waveform is automatically cycled, adjusted for rate and pressure, and positioned for proper display later on the cardiac monitor. Numerical analysis methods are used to merge the drawn waveforms with the previously entered heart rate and pressure data. *Art.* = arterial; *ECG* = electrocardiogram; *PA* = pulmonary artery; *RA* = right atrial; *RV* = right ventricular.

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 (for example, Smith, John[1...99])
   B. Type appropriate progress note or consultation

II. Hemodynamic data
   A. Enter rate and pressure data for the initial examination and consequence of each treatment option
      1. Heart rate
      2. Catheter pressure readings (right atrial, right ventricular, pulmonary artery, wedge)
      3. Arterial pressure (systolic and diastolic)
   B. Enter waveform data for the initial examination and consequence of each treatment 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 examination and consequence of each treatment option
      1. General laboratory
      2. Cardiac studies
      3. Pulmonary and respiratory studies
      4. Microbiology
      5. Nuclear medicine studies
      6. X-ray and imaging studies
      7. Additional
   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. Treatment options
   A-D. Enter up to four treatment plans

V. Discussion text
   A. Enter up to four discussion replies to the treatment 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 link automatically once a given treatment option is selected)
      2. "Unnecessary" and "inappropriate" synonyms
      3. Performance score ({-100...100})
      4. Cost of treatment ($n,nnn.nn)

*See "Performance Evaluation."

Trainee Operation.—The trainee begins a simulation by selecting a case from the library (a listing of cases is presented on the computer screen by selecting the appropriate menu item) and reviewing the information provided on the initial history and physical examination. A flowchart of the trainee operation is shown in Figure 7.

As in a real-life situation, students may order studies, select a treatment plan, seek consultation, or connect the patient to a cardiac monitor. Studies are performed by selecting from study

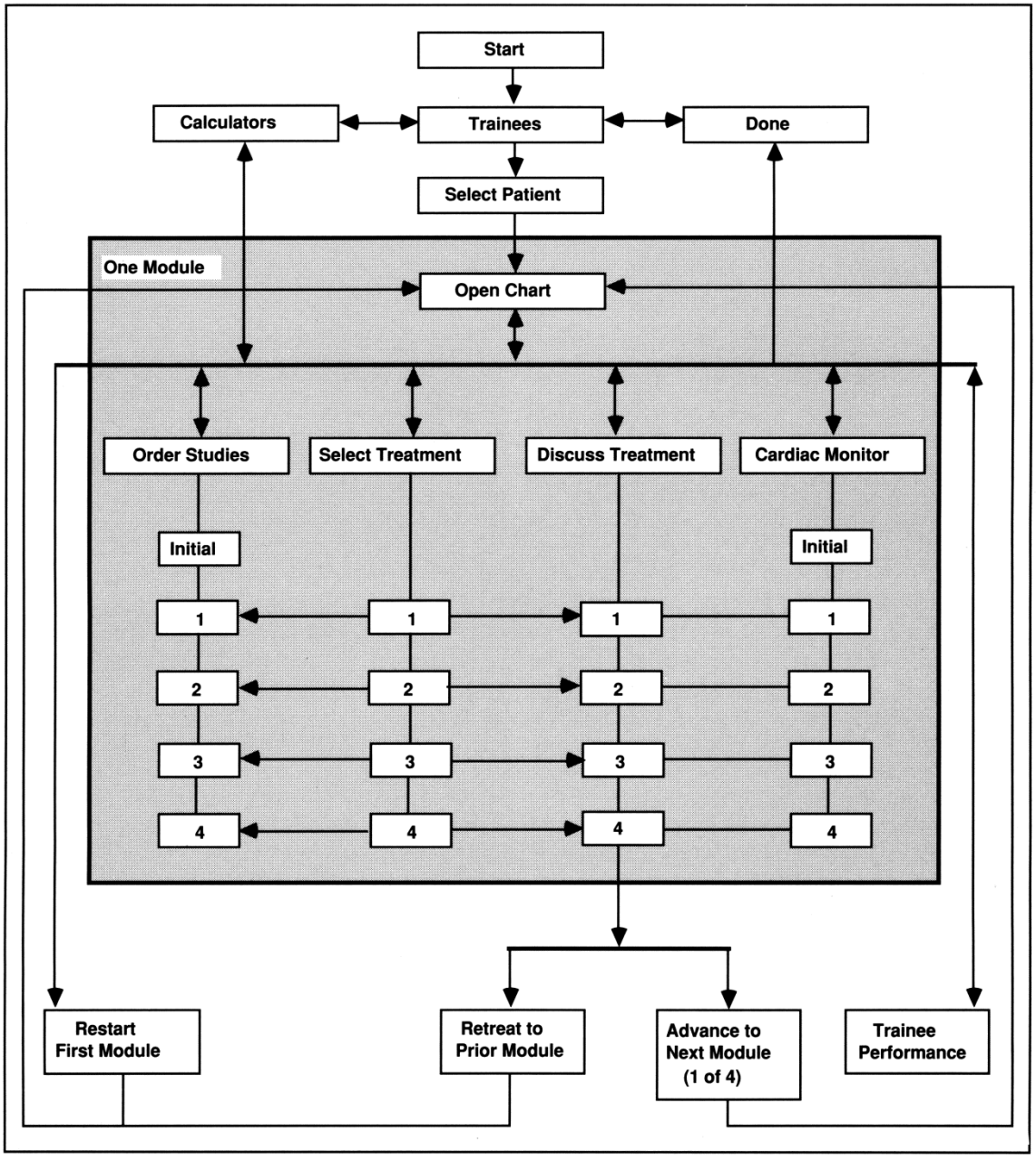

Fig. 7. Flowchart of program operation for trainee level. Once a patient has been selected and the history and physical examination have been reviewed, the trainee may elect to order studies, select a treatment plan, review discussion material, or connect the patient to the cardiac monitor. "Initial" data are presented if no treatment has been selected. After one of four treatment plans has been selected, ordering further studies or review of the cardiac monitor will reveal the consequences to the patient (numbered boxes). If appropriate, the trainee may—by selecting "Advance to Next Module"—review the chart again for progress notes or consultations and thereby continue management of the patient.

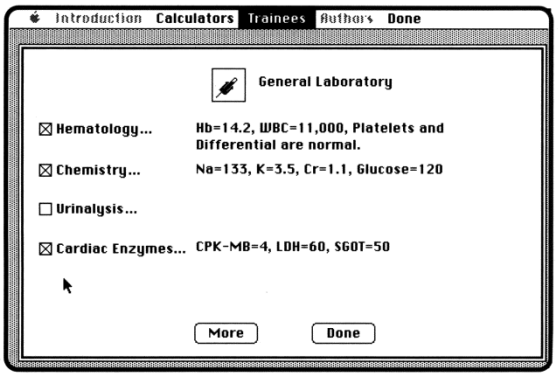

Fig. 8. Laboratory studies are ordered by checking an option from a list of studies made available by the author, as shown in example. Several categories of study are available, and most departments of a major referral center are included. *CPK-MB* = creatine kinase MB isoenzyme; *Cr* = creatinine; *Hb* = hemoglobin; *K* = potassium; *LDH* = lactate dehydrogenase; *Na* = sodium; *SGOT* = serum glutamic-oxaloacetic transaminase; *WBC* = white blood cells (leukocytes).

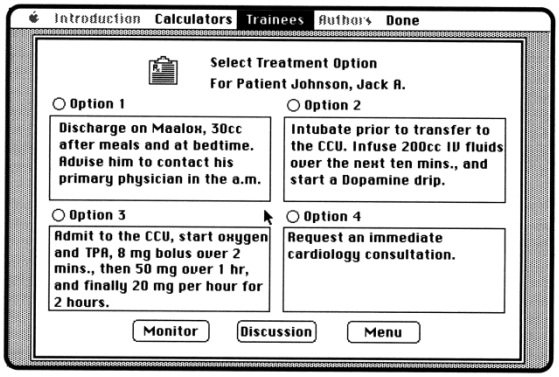

Fig. 9. Trainees may select from one of four treatment plans with each module. Once a treatment has been selected, further ordering of studies or review of the cardiac monitor will reveal the consequences to the patient. A trainee may select another treatment plan if the initial choice is less than favorable. The author determines which treatments (if any) will cause the case-management problem to progress beyond the current module. *CCU* = critical-care unit; *IV* = intravenous; *TPA* = tissue-type plasminogen activator.

alternatives programmed by the author (Fig. 8). Similarly, a treatment plan is selected from choices provided by the author (Fig. 9). Once a treatment plan has been chosen, all data change to conform with the intervention. Cardiac catheterization may be performed at any time simply by 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 provided. This process is made possible by the author's having previously entered the data as a consequence of the selected treatment.

Simulated care is continued by reviewing progress notes and consultations, ordering additional studies, and selecting additional treatment 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. The final management of the patient is dependent on the *sequence* of modules selected and may vary from one trainee to the next.

Performance Evaluation.—Trainee performance is monitored for both cognitive skills in patient management and procedural skills at catheterization (Fig. 10). The former is accomplished by assignment of a numerical score for the care delivered, determination of the numbers of unnecessary and inappropriate studies or treatments, and cost analysis of the care delivered.

The author assigns a point value (positive or negative) to each study and treatment; thus, evaluation is based on utilization and quality of care. In addition, because the author assigns a dollar amount to each study and treatment, the total cost for rendering the specified care can be determined.

Determination of unnecessary or inappropriate studies or treatments is accomplished by automatically scanning an author's text for reserved words. For example, if the trainee orders a lumbar puncture, the following authored response could appear:

> Patient refuses. Performing a lumbar puncture would be unsafe in light of the head computed tomographic findings. {-10} $125.00

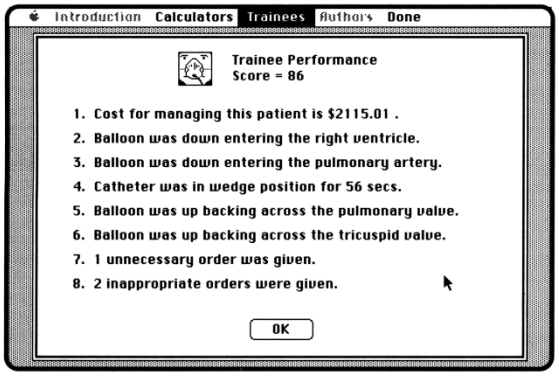

Fig. 10. Performance is assessed for both cognitive and manual dexterity skills. The system automatically processes authored information to identify unnecessary or inappropriate actions taken by the trainee.

In such a situation, the system would recognize the word "unsafe" and would increase the "inappropriate" score by one. In addition, selecting this test will decrease the trainee's "performance score" by 10 and increase the "cost of care" by $125.00.

Critical-Care Calculators.—Special screen calculators allow rapid determination of essential indices in critical-care management and thus are an important adjunct for selection of treatment or assessment of outcome. Subject areas include hemodynamic, respiratory, ventilatory, and renal function (Fig. 11). The trainee or author may use these calculators at any time. "What if..." analyses can be performed by simply changing one or more input variables and again selecting "Calculate" on the screen. These calculators are being tested for use as a separate tool in the critical-care unit. Several monitor manufacturers have incorporated similar calculator features into their own displays.

OBSERVATIONS

Each author must be responsible for the validity of the curriculum developed. This requirement is particularly important if the system is to be used for testing or certification purposes. Because no standard of care is purported by the system, authors must give the same attention to detail and accuracy of cases as they would a lecture or publication.

Once a case has been created, it should be observed in use to ensure its clarity, utility, and module-to-module consistency. To enter waveform data, instructors must have either (1) a complete understanding of the hematologic consequences of the disease or therapeutic intervention or (2) representative data (actual patient tracings) for direct entry into the case.

Before using the system, trainees should be oriented to the torso apparatus and Macintosh computer, as well as instructed in the proper technique for insertion of a catheter. Once this orientation has been completed, they may work independently with the system and may check their own performance at any time.

Once created, cases may be modified at any time or deleted entirely. Moreover, they may be exchanged with other system users by simply copying and exchanging disk media.

The initial impressions of specific users of this computerized system have been favorable. In particular, the ease of use by the true computer novice and the quick ability to program cases and monitor tracings into the equipment were considered important features.

DISCUSSION

Potential.—This system is not intended to replace actual patient contact but rather to prepare the trainee before encountering certain management problems. The trainee may be a medical student learning basic skills or an experienced cardiologist desiring to study problems rarely encountered. In addition, the system may be used to demonstrate models of unusual cardiovascular function, such as an artificial heart.

The system has been used with overhead projection of the computer display for conference presentation; thus, in effect, a physician or nurse can bring a "patient" to the conference by being able to present a real-time cardiac monitor. This system also enables the presenter to demonstrate the sequence of events in a patient during

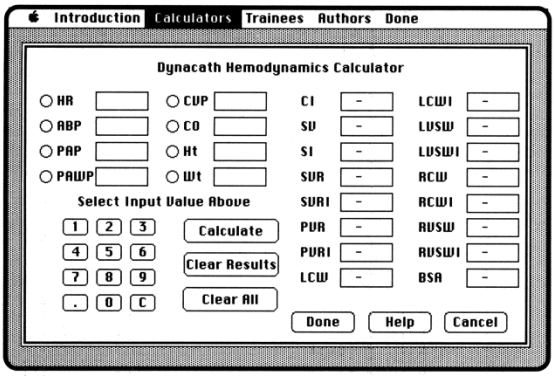

Fig. 11. Hemodynamics calculator is one of four calculators available in this system. Once all input values have been entered, selecting "Calculate" will cause immediate display of indices. Selecting any rectangular box brings up a display that contains the definition, derivation or formula, and comments. *ABP* = arterial blood pressure; *BSA* = body surface area; *CI* = cardiac index; *CO* = cardiac output; *CVP* = central venous pressure; *HR* = heart rate; *Ht* = height; *LCW* = left cardiac work; *LCWI* = left cardiac work index; *LVSW* = left ventricular stroke work; *LVSWI* = left ventricular stroke work index; *PAP* = pulmonary artery pressure; *PAWP* = pulmonary artery wedge pressure; *PVR* = pulmonary vascular resistance; *PVRI* = pulmonary vascular resistance index; *RCW* = right cardiac work; *RCWI* = right cardiac work index; *RVSW* = right ventricular stroke work; *RVSWI* = right ventricular stroke work index; *SI* = stroke index; *SV* = stroke volume; *SVR* = systemic vascular resistance; *SVRI* = systemic vascular resistance index; *Wt* = weight.

the hospital stay or to review problems as they exist for the patient.

Finally, this computerized simulator offers an alternative to animal-oriented workshops in catheter use and may lessen the need for experimental animals for this purpose.[19]

Limits.—This system is currently limited in its ability to simulate ventilator management, and the torso apparatus is not designed for placement of airways, chest tubes, or intra-aortic balloons or for performance of thoracentesis or pericardiocentesis.

A potential drawback of the system is the prospect of a poorly authored case becoming widely used; thereby, unacceptable procedures or methods may be learned. This risk can be reduced by peer review of authored cases, similar to the peer-review process for scientific manuscripts.

CONCLUSION

Although a computerized simulator for critical-care training is a technologic achievement, determination of the system as a useful instructional tool or certification aid must come from broader use and controlled studies. Investigators may wish to determine the system's usefulness in the following areas: (1) as a training, testing, certification, or modeling aid; (2) in evaluating utilization and quality of care delivery; and (3) in identifying discrimination patterns in patient care based on insurance, age, sex, religion, or race.

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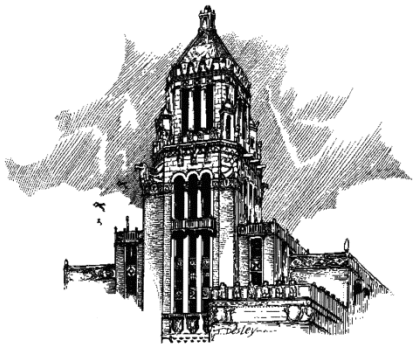

Johns Hopkins Hospital Hemodynamic Monitoring Conference
October 29, 1994

The hemodynamics of pulmonary and medical intensive care

STEVEN S. SALITERMAN, MD, FACP

Objectives: **To describe a) the physiology of oxygen delivery, b) the importance of hemodynamic monitoring in the medical intensive care unit, especially as it relates to pulmonary disease, c) methods for proper use of pulmonary artery catheters and interpretation of derived data and d) application of these principles to specific pulmonary diseases.**

Oxygen Transport: **Fundamental to interpreting and responding to changes in hemodynamic data is having an understanding of oxygen transport and consumption, Frank-Starling's law, chemical mediators, mixed venous oxygen tension, continuous venous oximetry, and acid-base balance.**

Hemodynamic Monitoring: **It is necessary to decide which patients will benefit from placement of a pulmonary artery catheter, select an insertion site and appropriate catheter, safely insert a catheter for measurement of cardiac, pulmonary artery and pulmonary artery occlusion pressure (wedge pressure), and interpret the resulting waveforms and pressure values. There are early and late complications of catheter placement that must be observed for.**

Pulmonary Considerations: **Patients with pulmonary disease may have marked changes in intrathoracic pressure, pulmonary vascular resistance, cardiac output, and oxygen delivery to the tissues. In respiratory failure right ventricular performance can not be predicted from the right ventricular ejection fraction, and is better correlated with the right ventricular end-diastolic volume index.**

Mechanical Ventilation: **An important adjunct to the treatment of critically ill patients, mechanical ventilation serves to improve oxygenation and reduce the work of breathing. Changes in intrathoracic pressure associated with the underlying pulmonary disease, PEEP, and type of ventilation all influence hemodynamic measurements. The most common and important hemodynamic effect of mechanical ventilation is to decrease cardiac output by decreasing the pressure gradient for venous return.**

Pharmacologic Intervention: **Medications useful in the treatment of critically ill patients have significant hemodynamic effects, including influencing myocardial contractility, vascular resistance, preload and afterload.**

Specific Disorders: **Pulmonary edema, chronic obstructive pulmonary disease, adult respiratory distress syndrome, pulmonary embolism, barotrauma and contusion are among the conditions often encountered, and provide a special challenge in obtaining, interpreting and responding to hemodynamic measurements.**

OXYGEN TRANSPORT

Adequate tissue oxygenation depends on hemoglobin concentration, the percentage of hemoglobin saturated with oxygen in arterial blood (SaO_2), cardiac output (CO), oxygen consumption (VO_2), the affinity of hemoglobin for oxygen (P50) and the distribution of perfusion.

Normal compensatory mechanisms are typically

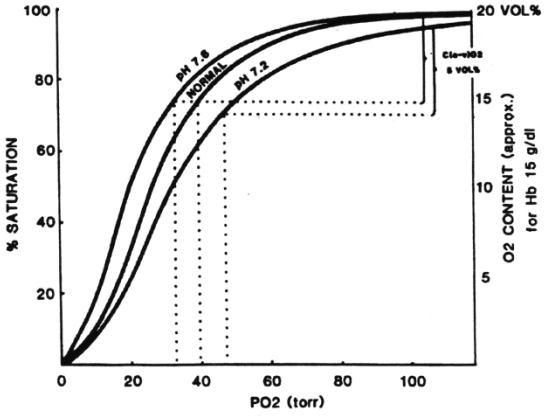

Figure 1. Oxygen dissociation curve [Snyder 1987].

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disturbed in critically ill patients, and shifts in the oxyhemoglobin dissociation curve (Fig. 1) such as from acidosis or alkalosis may profoundly impact oxygen content and delivery.

The curve may be shifted to the right with improved oxygen unloading (decrease in the affinity of hemoglobin for oxygen) at the tissue level by increased blood temperature, carbon dioxide, hydrogen ion concentration, 2,3-DPG, intercellular sodium, and hemoglobin concentration.

The curve may be shifted to the left by hypothermia, hypocarbia, alkalosis, anemia, and decreases in 2,3-DPG or sodium.

Although methods exist for approximating oxygen consumption in critically ill patients, they are technically difficult and may not give clue to individual organ metabolism. In summary, it is best simply to maximize oxygen transport to support the greater than normal metabolic rates.

Tissue oxygenation depends on both oxygen saturation and rate of flow:

$$TO_2 = CO \times CaO_2$$

TO_2 is oxygen transport, CO is cardiac output and CaO_2 is arterial oxygen content.

If cardiac output is severely depressed despite improvement in arterial oxygenation, oxygen transport may be worsened. It is necessary to consider all factors that contribute to oxygen supply and not rely solely on the level of arterial oxygen saturation improvement [Edwards 1993], [Snyder 1987].

Oxygen Consumption (VO_2)

The amount of oxygen utilized is normally determined by the body's energy requirements, and can be calculated from the Fick equation [Dantzker 1991]:

$$VO_2 = VI \times FIO_2 - VE \times FEO_2 = CO \times (CaO_2 - CvO_2)$$

VI and VE are the inspired and expired minute ventilations, FIO_2 and FEO_2 are the inspired and expired fractional concentrations of oxygen, CO is the cardiac output, and CaO_2 and CvO_2 are the arterial and mixed venous oxygen content.

In a steady state condition the amount of oxygen taken up by the tissues is equal to the amount taken up in the lung, so that $V0_2$ can be calculated from either the gas side of the system (Fig. 2), measuring the difference between the amount of oxygen in the inspired and mixed expired gas, or the blood side as the product of the cardiac output and the arterial-venous oxygen difference.

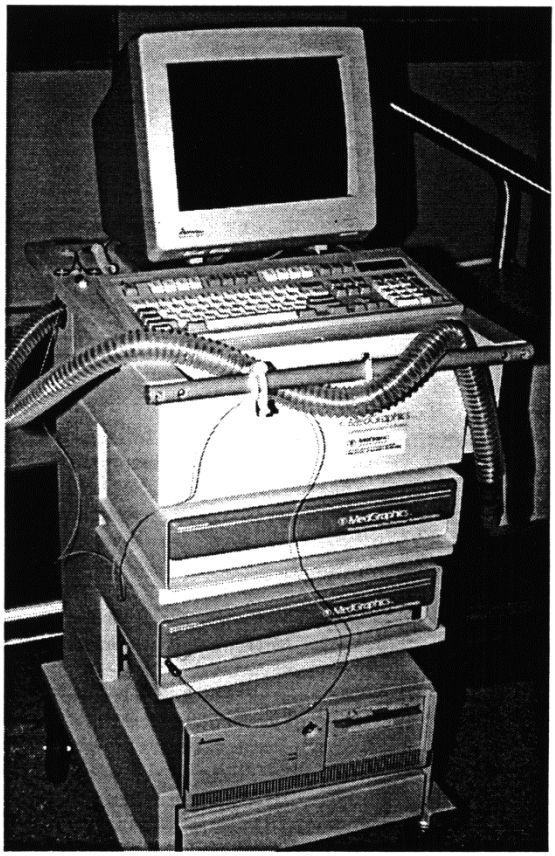

Figure 2. The MedGraphics Gas Exchange® system.

Frank-Starling's Law

Cardiac output is dependent on heart rate, intrinsic myocardial contractility, preload and afterload .

The Frank-Starling curve (Fig. 3) shows the relationship between left ventricular (LV) preload and stroke volume (SV). For a given heart rate, as venous return increases, preload increases, and the force of ventricular contraction increases, allowing the heart to empty to a nearly constant end-diastolic volume or increased stroke volume. This is Starling's law, and only cardiac myofibrils - not skeletal or smooth muscle - have the ability to increase their force of contraction as fiber length increases above resting length.

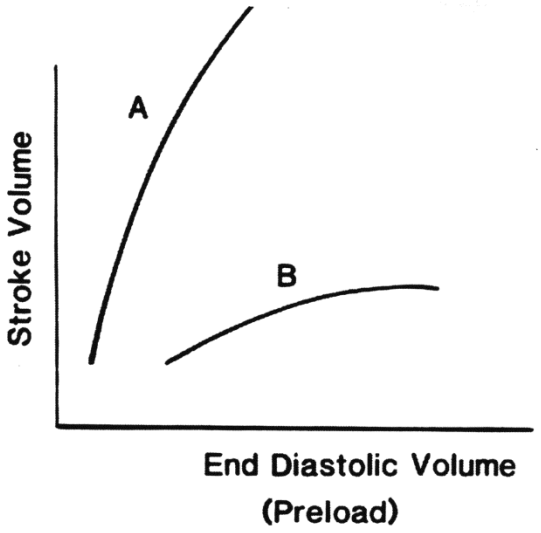

Figure 3. Frank-Starling Curve [Snyder 1987].

The ventricle described by curve A has a better performance than that described by curve B.

Pulmonary artery occlusive pressure (PAOP) is used as an estimate of end-diastolic pressure which in turn approximates LV preload [Goldberg 1987].

Prostaglandins, Prostacyclin, Thromboxane A2 and Leukotrienes

Prostaglandins and related substances come from the breakdown of tissue, and are involved in producing shock, fever, and pain.

Prostacyclin modulates vasoconstriction in the microvasculature and participates in the hyperemic response to hypoxia. It augments renal flow, sodium and water excretion, and modulates hemostasis. The balance between prostacyclin and TXA2 is critical to maintaining hemostasis, and imbalance may cause vasospasm, infarction, and angina.

The leukotrienes are potent mediators of coronary vasoconstriction and produce negative inotropic effects [Bruns 1987], [Gerrard 1987], [Zeid 1987].

Pulse Oximetry, Mixed Venous Oxygen Tension, Continuous Venous Oximetry

Pulse oximetry is commonly used for measuring arterial oxygen saturation (SaO2) (Fig. 4).

Figure 4. The Nellcor® Pulse Oximeter.

Mixed venous oxygen tension (PVO_2) may be the most reliable single physiologic indicator for monitoring the overall balance between oxygen supply and demand.

Mixed venous blood is a flow-weighted mixture of all blood that has traversed the systemic vascular beds and may best be sampled from the proximal pulmonary artery.

Marked venous hypoxemia (PVO_2 < 27 mmHg) and lactic acidosis is associated with high mortality.

Mixed venous oxygen tension does not indicate if a specific organ is under perfused or the distribution of perfusion. Another drawback is that in critically ill patients the central venous sample may not represent a true mixed venous sample.

Fiberoptic catheters for continuous analysis of blood oxygen saturation (SvO_2) has increased in popularity since first introduced in 1972 (Fig. 5). The SvO_2 reflects the overall balance between oxygen supply and demand. Calibration with a mixed venous sample and catheter position are important.

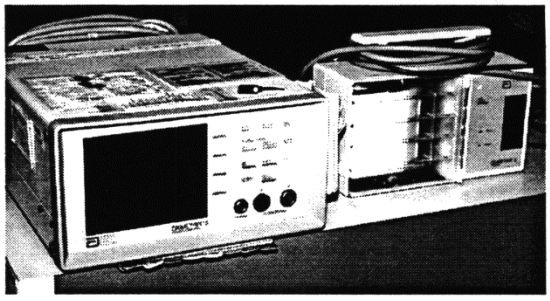

Figure 5. The Abbott Oximetrix® for measuring continous mixed venous oxygen saturation.

Table 1. Interpreting Arterial Blood Gases.

Condition	Findings	Cause
Respiratory Acidosis	**(PaC02 > 45) + (pH < 7.35)**	**Inadequate ventilation**
Metabolic Acidosis	**(PaC02 < 35) + (pH < 7.35)**	**H+ buildup**
Respiratory Alkalosis	**(PaC02 < 35) + (pH > 7.45)**	**Increased ventilation**
Metabolic Alkalosis	**(PaC02 > 45) + (pH > 7.45)**	**Volume depletion or low K+**

The normal range is 0.68-0.77. High values indicate an increase in delivery relative to consumption, and is associated with cirrhosis, sepsis, peripheral left-to-right shunting, cyanide toxicity, arterial hyperoxia or technical problems (calibration error, wedging of the catheter).

Low values may be associated with anemia, arterial oxygen desaturation, increased oxygen consumption or decreases in cardiac output. A rapidly falling $Sv0_2$ may proceed a major cardiovascular complication.

Interpreting arterial blood gases for acid-base balance is also important, and Table 1 allows for distinguishing respiratory from metabolic disorders [American Heart Association 1987].

[Martin 1992], [Nelson 1987], [Nelson 1992], [Snyder 1987], [Vincent 1992].

Echocardiography

Comprehensive cardiovascular ultrasound imaging can be used to determine hemodynamics, including gradient, pressure, flow and valve area.

Since 1987 transesophageal echocardiography has been considered a routine extension of the precordial or transthoracic echocardiographic examination.

Superior results are obtained in prosthetic heart valves, mitral regurgitation, critical illness following infarct or trauma, endocarditis, cardiac tumors, thrombosis and masses, congenital heart disease and aortic disease [Seward 1991].

HEMODYNAMIC MONITORING

The pulmonary artery catheter allows measurement of right atrial, right ventricular, pulmonary artery, occlusion (wedge) pressure, and cardiac output. Taken together with blood pressure, arterial and mixed venous oxygen content, the clinician can properly evaluate cardiopulmonary function, and through repeated measurements be able to monitor the patient's progress and response to therapeutic interventions.

Guidelines for catheter use and clinical competence in hemodynamic monitoring have been published [American Society of Anesthesiologists 1993], [Expert Panel 1991], [Friesinger 1990], [Naylor 1993], [Society of Critical Care Medicine 1992], [Young 1990].

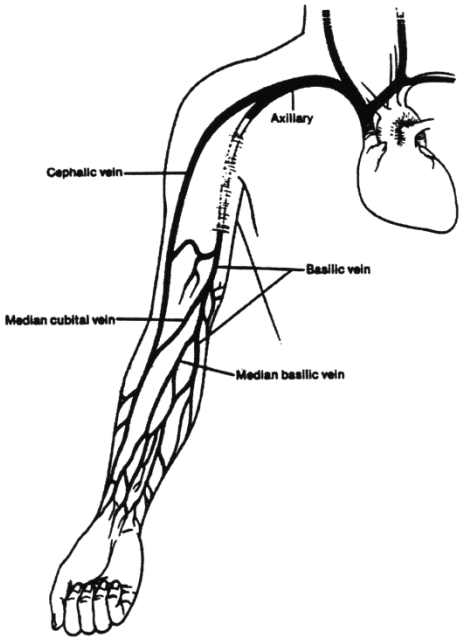

Figure 5. Anatomy of the arm veins [Daily 1989].

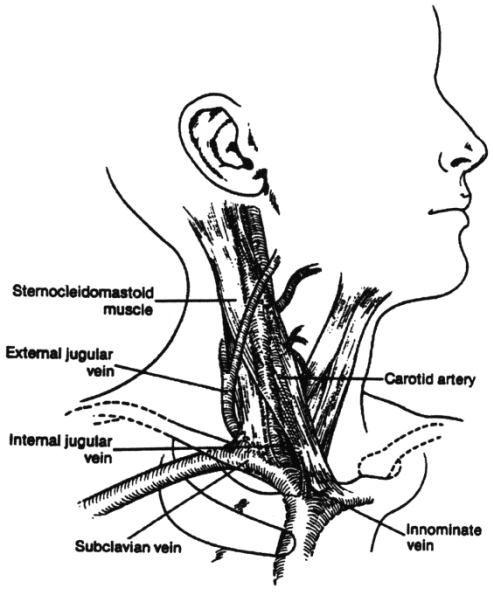

Figure 6. Anatomy of the Subclavian and Jugular Veins [Daily 1989].

Insertion Technique

Common sites for catheter insertion include the medial basilic vein (Fig. 5), internal jugular vein and subclavian vein (Fig. 6). Femoral vein catheterization has also been shown to be safe and effective.

A ready-made tray, such as the Arrow® Percutaneous Sheath Introducer Kit speeds the process of venous access and catheter placement.

The site (Fig. 7) is first cleansed and draped, and then using an 18 Ga. x 2.5 catheter assembly, the vein is located. A plastic sheath remains in place, while an inner metal needle is removed. A 0.035 inch spring wire is inserted through the sheath, and then the sheath is also removed.

A vessel dilator is pre-placed through a detachable hemostasis valve and larger flexible sheath, and the combination assembly is slid down the wire into the vein. The wire and dilator are removed, and an intravenous solution is connected to the side-port of the valve.

A pulmonary artery catheter, such as a Swan - Ganz® type is removed from its container and the balloon inspected after inflation for symmetry. Enough air should be used to recess the tip of the catheter. The air is passively deflated and the catheter is wiped clean with saline.

The catheter is placed through the contamination

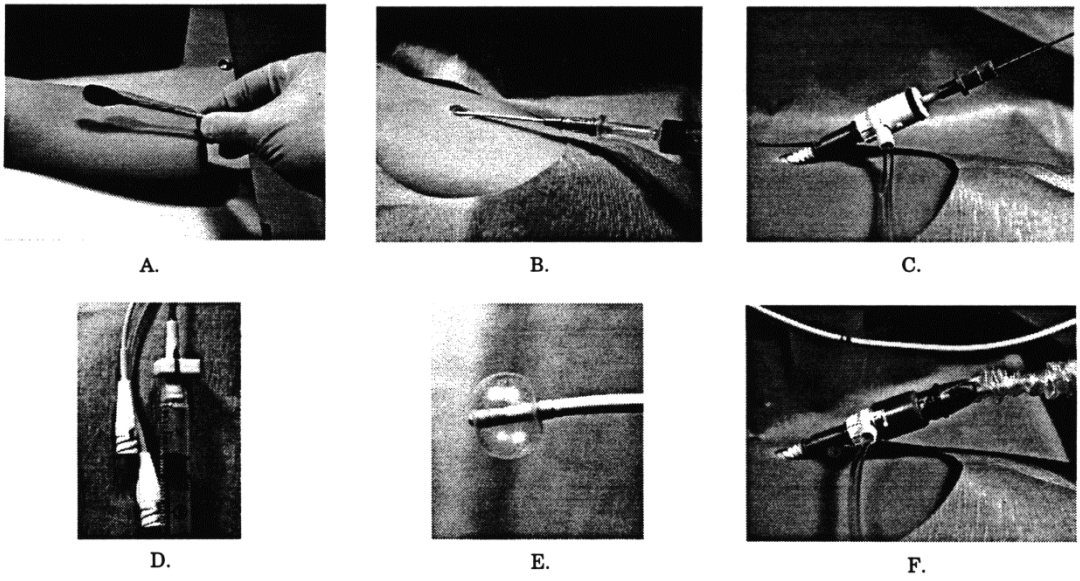

Figure 7. Catheter insertion: a) skin preparation, b) vein location and placement of a plastic sheath, c) advancement of a larger sheath, hemostasis valve and vein dilator down the spring wire, d) use of a safety syringe, e) testing for balloon function and f) placement of the pulmonary artery catheter and contamination shield.

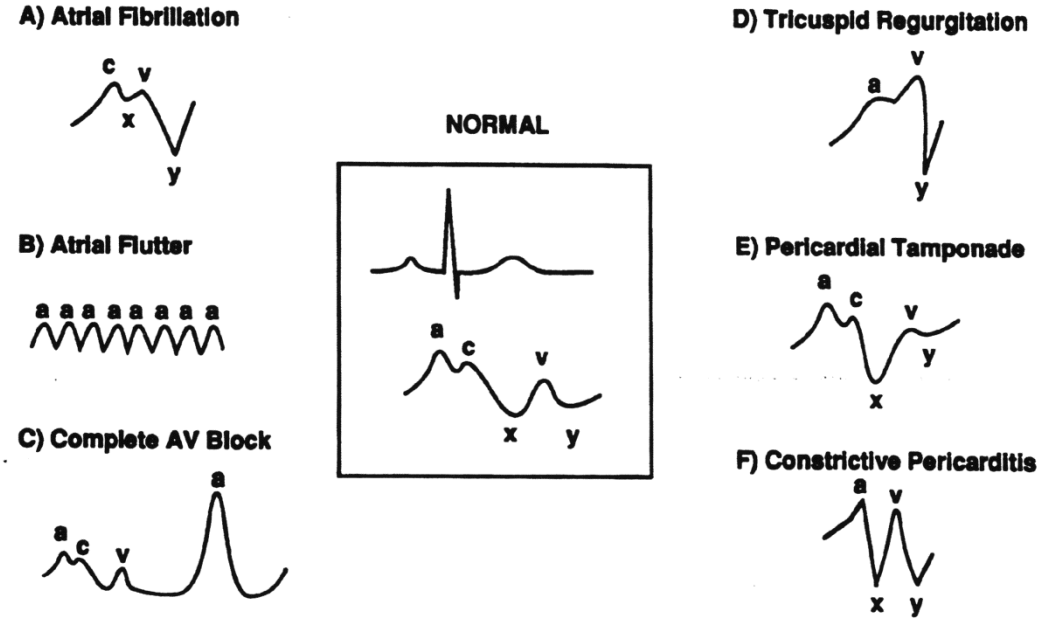

Figure 8. Representative right atrial pressure waveforms [Civetta 1992].

shield first, then slid into the hemostasis valve. The manometer is connected so that waveforms can be interpreted as the catheter is advanced.

The balloon should not be inflated until in the superior vena cava or right atrium. Advance until a pulmonary artery occlusive pressure reading is obtained, then deflate the balloon and pull it back into the pulmonary artery.

The hemostasis plug should be sutured to the skin and dressed. The contamination shield is unfolded providing a margin of safety for intermittently re-advancing the catheter and checking the pulmonary occlusive pressure reading.

Hemodynamic Pressure Measurement and Tracings

The *a* wave is due to atrial systole and follows the P wave of the electrocardiogram (Fig. 8). The *c* wave occurs with tricuspid valve closure. The *x* descent is due to a combination of atrial relaxation and the downward displacement of the atrioventricular junction during the early part of ventricular systole. The *v* wave corresponds to the flow of blood into the atria against a closed tricuspid valve during the late part of ventricular systole. The *y* descent results from the rapid flow of blood from the atria into the ventricles following opening of the mitral and tricuspid valves. Additional examples of waveforms are shown in Figs. 9-14.

The *a* wave is absent in patients with atrial fibrillation (A).

Flutter *a* waves are observed in patients with atrial flutter (B).

Large *a* waves ("Cannon *a* waves") occur when the atria contract while the atrioventricular valves are closed during ventricular systole. These may be regular in junctional rhythm or irregular when atrioventricular dissociation accompanies premature ventricular beats, ventricular tachycardia or complete heart block (C).

With tricuspid insufficiency, the right atrial *v* wave becomes prominent, the *x* descent is obliterated, and the *y* descent is steep (D).

Pericardial tamponade causes elevation and equalization of the right atrial, pulmonary artery diastolic, and wedge pressure tracings. The *x* descent on the right atrial pressure tracing is preserved; however the *y* descent is damped or absent due to restricted early ventricular filling (E).

Constrictive pericarditis also causes elevation and equalization of diastolic pressures. The *a* and *v* waves are followed by prominent *x* and *y* descents, resulting in a typical "M" waveform. Unlike in tamponade, the

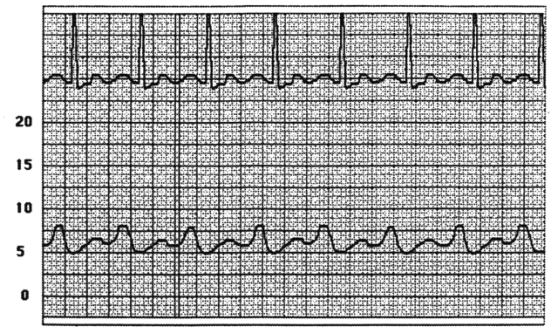

Figure 9. Normal right atrial pressure. *All tracings are from the Dynacath Critical Care Patient Simulator™.*

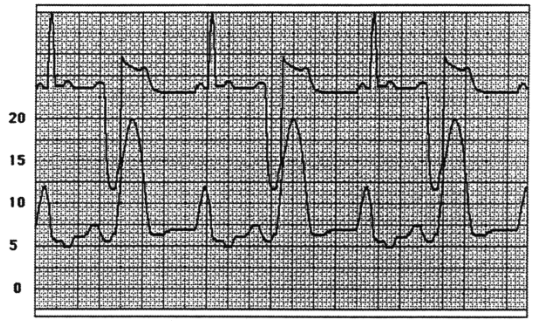

Figure 12. Ventricular bigeminy. Note the Cannon *a* wave with each premature ventricular contraction.

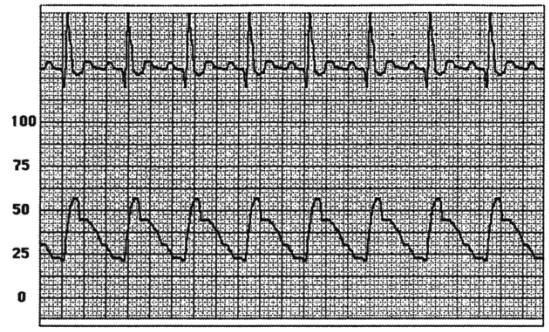

Figure 10. Normal pulmonary artery pressure.

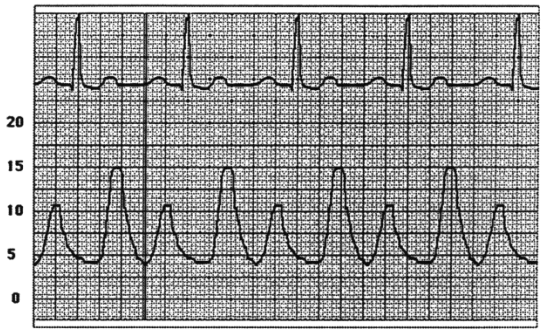

Figure 13. Tricuspid insufficiency. Typically the large *v* wave occurs early in diastole.

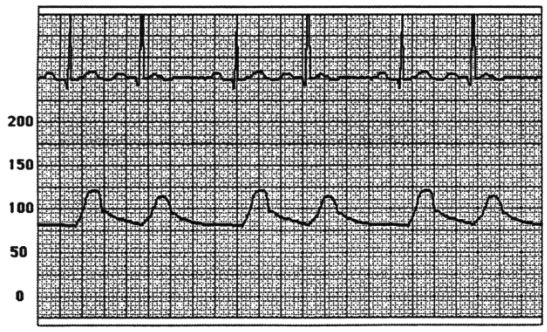

Figure 11. Premature atrial contractions. Note the arterial pressure variation with shorter filling time.

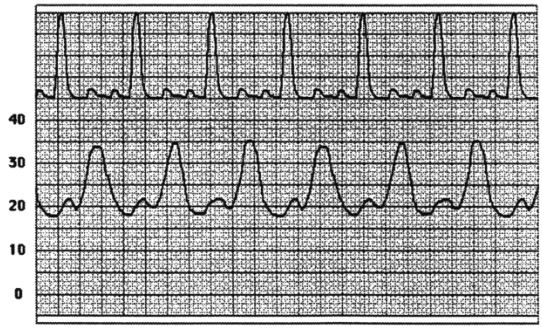

Figure 14. Mitral insufficiency. Typically the large *v* wave occurs late in diastole.

y descent is prominent because there is no restriction of early ventricular filling (F).

In acute mitral insufficiency, a large *v* wave may be present in the pulmonary artery wedge tracing. This has been attributed to the regurgitant blood flow across the incompetent mitral valve into a relatively noncompliant left atrium. The *v* wave may mimic the pulmonary artery waveform and be misinterpreted as the catheter being in the pulmonary artery position. Compare with the ECG. The peak of the *v* wave occurs after the T wave (the peak of the pulmonary artery systole occurs within the T wave). Mitral obstruction, congestive heart failure and VSD may also have large v waves.

With right ventricular failure, the right ventricular end-diastolic pressure may be so high that during catheter insertion the right ventricular waveform may resemble the pulmonary artery tracing.

In hypovolemic shock, extremely low right ventricular and pulmonary artery pressures may be observed.

[Ahrens 1991], [Astiz 1993], [Bach 1992], [Berlauk 1991], [Biga 1991], [Bridges 1993], [Cobean 1992], [Connors 1992], [Cope 1992], [Ermakov 1992], [Ferraris 1992], [Findling 1994], [Hamilton-Farrell 1990], [Her 1993], [Iberti 1992], [Masood 1989], [Nolan 1992], [Ornato 1993], [Pagliarello 1993], [Roth 1992], [Shively 1991], [Shoemaker 1990], [Sola 1993], [Spodick 1989], [Steingrub 1991], [Tuchschmidt 1994], [Tuman 1989], [Vine 1991], [Weed 1991], [West 1992], [Yelderman 1992], [Zion 1990].

Complications of Hemodynamic Monitoring

Complications of central venous and pulmonary artery cannulation include the following:

1. Immediate Complications:
   a. Multiple puncture
   b. Pneumo/hemo/hydro/chylothorax-mediastinum
   c. Arterial puncture - hematoma or bleeding
   d. Air embolism
   e. Cardiac arrhythmias
   f. Catheter malposition
   g. Catheter knotting
   i. Subcutaneous and mediastinal emphysema
   j. Tracheal puncture-laceration

2. Late Complications:
   a. Pulmonary artery rupture
   b. Pulmonary infarction
   c. Catheter-related sepsis
   d. Balloon rupture
   e. Endocardial or valvular damage
   f. Venous thrombosis
   g. Infection
   h. Nerve injury
   i. Cerebrovascular compromise
   j. Cardiac perforation and tamponade
   j. Arteriovenous fistula
   k. Thrombocytopenia

[Allyn 1989], [Baraka 1991], [Bernardin 1994], [Duong 1993], [Feng 1990], [Gotchall 1989], [Guillaume 1990], [Hagley 1992], [Keusch 1989], [Kirton 1992], [McLellan 1989], [Mermel 1991], [Mermel 1993], [Mermel 1994], [Moorthy 1991], [Raad 1993], [Smart 1990], [Soding 1994], [Unger 1990], [Venus 1992], [Westenskow 1993].

Is Hemodynamic Monitoring of Value?

Inadequate training in pulmonary artery catheter placement and interpretation may account for the diversity of opinion as to the benefits of invasive monitoring [Iberti 1990]. In addition, physician assessment of the effect of right heart catheterization on treatment decisions and patient outcomes has been challenged [Ontario Intensive Care Study Group 1992]. There may also be interobserver variability in the interpretation of tracings [Komedina 1991]. For the present, it is believed that properly obtained data may direct the physician toward the most appropriate therapy, and improve patient outcome.

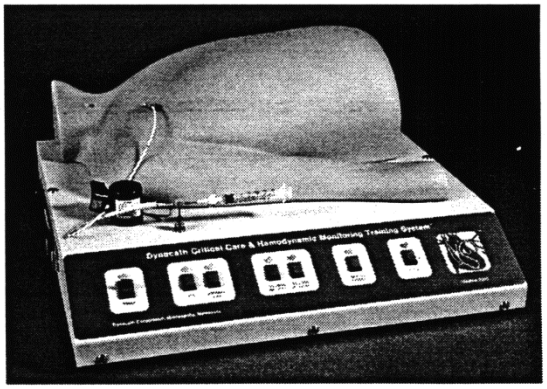

Figure 15. The Dynacath Critical Care Patient Simulator™.

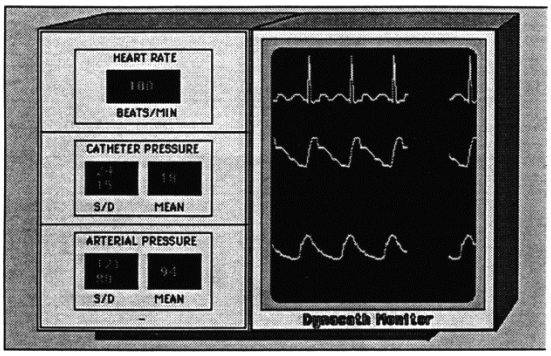

Figure 16. Apple Macintosh® Computer display of a cardiac monitor, with simulated patient data from the Critical Care Patient Simulator™.

Improved Training

The Critical Care Patient Simulator (Figs. 15-16) may be used to practice pulmonary artery catheter placement, interpret waveforms and integrate simulated hemodynamic data with case scenarios [Saliterman 1990]. This system also allows a trainee to order studies, select management plans and observe the hemodynamic consequences of therapeutic intervention.

PULMONARY CONSIDERATIONS

Ventilation/Perfusion

The physiology of ventilation and perfusion is helpful in understanding changes that occur with pulmonary disease. The determinants of local ventilation are local compliance, local airway resistance, and local change in transepithelial pressure. Compliance in normal lungs depends on relative alveolar volume (gravity dependent). Normally ventilation of the lung base is greater. In low lung volumes the proportion of gas delivered to upper lung units is greater. Airway resistance is dependent on edema, interstitial elasticity, bronchospasm, and obstruction (collapse or mucous).

Flow is diminished in the nondependent lung by gravity and compression of the alveolar vessels if PAOP is increased. Because of interstitial pressure, flow is decreased in the most dependent lung [Snyder 1987].

Pulmonary Vascular Resistance

Pulmonary vascular resistance (PVR) may be calculated by the following:

(PAP - PAOP)/ CO x 80
(normal 100-250 dynes•sec•cm-5)

The following may be associated with increased PVR [Fromm 1987]:

1. Primary Pulmonary Hypertension.
2. Vasoconstriction caused by hypoxemia and aci dosis.
3. Pulmonary obstructive processes - severe COPD or PE.

Right Atrial Pressure

Patients with pulmonary disease frequently have marked swings in intrathoracic pressure, and hemodynamic pressure measurements parallel these changes. There may be excessive fall in pressures during spontaneous inspiration.

The RA pressure may be normal in mild pulmonary disease or moderately elevated in severe disease.

Elevated RA pressures resulting from pulmonary disease denote increased right-heart dysfunction caused by increased pulmonary vascular resistance (PVR) or afterload. The a wave of the RA waveform becomes more dominant.

Wide swings in the RA pressure may occur with the respiratory cycle, and it is important to obtain a mean RA pressure at end-expiration over three to four cycles [Daily 1989].

Right Ventricular Function

The right ventricle is essential to cardiopulmonary function. Failure of the right ventricle is the inability to maintain adequate distribution of blood flow to ventilated lung segments [Nelson 1993].

In acute respiratory failure, the right ventricular ejection fraction does not reflect right ventricular performance [Her 1993]. There may be a severe reduction in right ventricular ejection fraction while the right ventricle continues to generate sufficient pressure for pulmonary perfusion.

This is because the ejection fraction is dependent on the afterload, and afterload may change dramatically in patients with acute respiratory failure. An

increase in pulmonary vascular resistance increases the afterload of the right ventricle.

The right ventricular end-systolic pressure volume relationship may be a clinically useful tool to assess right ventricular contractile function.

Right ventricular end-diastolic volume index is calculated as the stroke volume index (cardiac index/heart rate) divided by ejection fraction. This correlates better with cardiac output than do either the central venous pressure or pulmonary artery occlusion pressure.

A low value predicts that volume loading will likely increase the cardiac index in critically ill patients. A high value (>140 ml/m^2) implies that volume loading will be unlikely to improve cardiac index [Diebel 1992].

These values are less likely to be affected by positive end-expiration pressure (PEEP) than pressure-based variables [Eddy 1993], [Cheatham 1993].

Right ventricular end-diastolic volume may be measured using the Baxter Explorer System® pulmonary artery catheter.

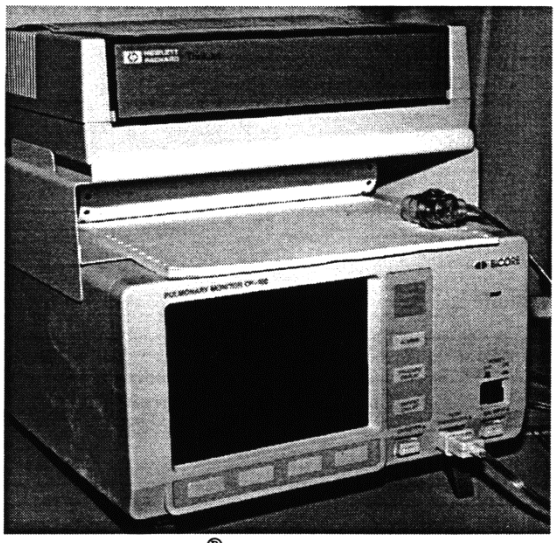

Figure 17. The Bicore® Esophageal Manometer system.

Pulmonary Artery Pressure

The PAP change depends on the degree of change of PVR and/or CO.

Pressure = Flow x Resistance

Increased PVR may be offset initially by decreased flow ("low cardiac output pattern"). More typically in the critical care patient the PVR will be sufficiently high to cause the PAP to be high.

Normally PA end-diastolic pressure (PAEDP) equals the PAOP or LAP, and reflects the LVP at end-diastole. This allows following the PAEDP rather than obtaining the PAOP pressure.

In pulmonary disease with increased PVR, the PAP may become elevated while the PAOP or LAP is low. There are two reasons for this:

1. When the balloon is inflated, flow stops in the pulmonary capillary, and measured pressure is a reflection of the LAP.
2. Marked reduction of lung compliance in pulmonary disease often prevents the transmission of increased pleural fluid pressure to the pulmonary microvasculature.

An increase in PVR is the major limiting factor in CO in patients with pulmonary disease. The arteriovenous oxygen difference is abnormally wide.

The SvO2 is frequently lower than normal as a result of increased oxygen extraction as a compensation to decreased oxygen delivery.

In general, because of the wide swings in intrathoracic pressure, accurate hemodynamic pressure readings can be measured by obtaining an end-expiratory pressure reading and averaging over three-four respiratory cycles. This may require use of a paper write-out rather than the scope display.

Esophageal Pressure (Pes) Monitoring

Esophageal pressure monitoring allows measurement of fluctuations in global intrathoracic pressure (Fig. 17). Pes allows estimation of the force generated during all patient-initiated breaths (spontaneous or mechanically ventilated), and allows partitioning of lung and chest wall components. Knowledge of the Pes helps interpret PAOP pressure during PEEP. Changes in Pes can be used to determine the work of breathing.

A thin esophageal catheter (about 2mm in size) with a long balloon is inflated, passed into the stomach, and then withdrawn until negative pressure deflections are observed during spontaneous inspiratory efforts. The balloon is withdrawn another 10 cm, and its final position tested by occluding the airway and measuring deflections in PAOP and Pes. These should closely approximate one another [Marini 1989].

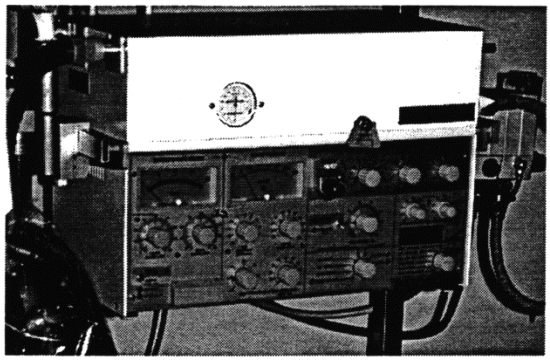

Figure 18. The Siemens Servo Ventilator.

MECHANICAL VENTILATION

Mechanical ventilation is used to improve oxygenation, treat alveolar hypoventilation and reduce the work of breathing (Fig. 18). Normally only 5% of total oxygen consumption goes to the work of breathing. In respiratory distress this can increases to as much as 50%. Muscle fatigue, observed by tachypnea, recruiting of accessory muscles, paradoxical muscle motion, discoordination and finally respiratory failure, may be relieved by mechanical ventilation.

The heart, existing in the thorax, is a pressure chamber within a pressure chamber. Therefore changes within the thorax (intrathoracic pressure - ITP) will affect the pressure gradient for blood returning to the chest (venous return), and leaving the chest (left ventricular output).

Whereas ITP falls with spontaneous inspiration, it rises with positive pressure ventilation (Fig. 19).

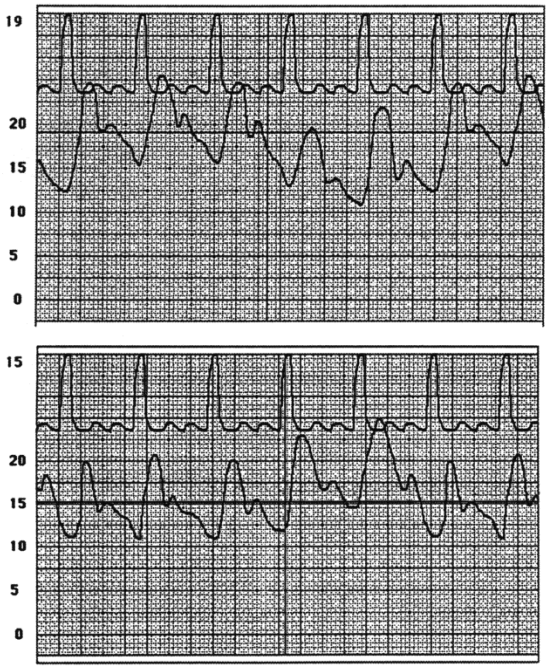

Figure 19. End-expiration occurs about the middle of each tracing above. The upper strip shows normal pulmonary artery pressure with spontaneous inspiration. The negative ITP produces a negative swing in the tracing. The lower strip shows a positive swing from increased ITP associated with mechanical ventilation.

Mode of Ventilation

Common modes of ventilation include assist control (ACV), synchronized intermittent mandatory (SIMV) and pressure support (PSV). Hemodynamic and oxygen transport pararmeters in patients on these various forms of ventilation have been studied [Sternberg 1994].

SIMV and PSV are commonly used for weaning. The PSV augments the patient's spontaneous breaths with a preset positive pressure delivered by the ventilator. The patient controls the respiratory rate, inspiratory flow and time. It reduces the ventilatory work done by the patient and improves the breathing pattern and patient's comfort.

All three modes increase intrathoracic pressure (ITP), lower venous return and lessen cardiac output. During the spontaneous breaths in SIMV the ITP is lower, and cardiac output (CO) increases. By allowing lower peak and mean airway pressures throughout the respiratory cycle SIMV marginally improves the cardiac index (CI) over ACV.

There is a slightly higher CI, oxygen transport and oxygen consumption on SIMV and PSV. It is felt that SIMV and PSV when used for 30 minutes can provide adequate ventilation with lower airway pressure and possibly less adverse effects on hemodynamic and tissue oxygenation parameters compared with ACV.

Positive Pressure Ventilation

Continuous positive airway pressure (CPAP) provides positive expiratory and inspiratory pressure in spontaneous breathing. When applied to pressure breathing it is referred to as positive end-expiratory

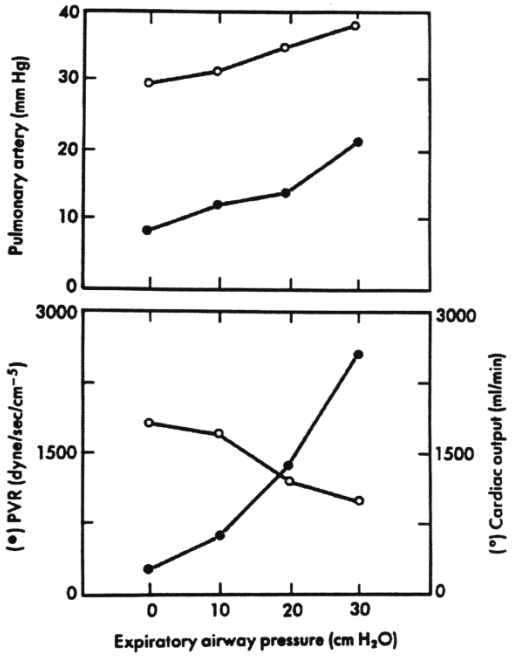

Figure 20. Changes in pulmonary artery pressure (PA), pulmonary vascular resistance (PVR) and cardiac output (CO) with increases in positive end-expiratory pressure (PEEP) (Daily 1989).

pressure (PEEP). Acute respiratory failure is often associated with a decrease in functional reserve capacity (FRC), and CPAP or PEEP may help decrease PVR (expanding collapsed areas) - improving venous return and LV filling.

As PEEP is increased, PVR and PAP increase, while CO decreases (Fig. 20).

Estimating Transmural Pressure

Since hemodynamic measurements obtained with mechanical ventilation are altered by increases in intrathoracic pressure, attempts may be made to estimate transmural pressure. Turning off the respirator for measurement can be dangerous. Distal esophageal balloons or inserting a catheter in the pleural space can allow determination of pleural pressure, but is not widely done.

Mean intrathoracic pressure is normally -3 mmHg. The true transmural pressures therefore would really be the measured pressure minus the estimated intrapleural pressure.

PAOP - Pleural Pressure = Transmural PAOP
(eg. 8 mmHg - (-3 mmHg) = 11 mmHg)

Normally this small and constant factor can be ignored in patients not mechanically ventilated. The extent to which the intrapleural pressure is increased depends on the mode of ventilation.

PEEP therapy increase intrapleural pressure only about 1/3 of the applied airway pressure because critical care patients usually have lungs that stiff and non-compliant. Effects or PEEP can be ascertained by measurement of the PAOP when PEEP is momentarily discontinued for suctioning.

Responding to the Effects of Mechanical Ventilation

Hemodynamic monitoring is helpful in patients receiving mechanical ventilation to achieve a satisfactory balance between the beneficial effect of increased oxygenation and the deleterious effects of decreased cardiac output.

When low blood pressure and cardiac output is due to decreased venous return, consider administering fluids, elevating the legs, pressure suit, minimizing increases in ITP by decreasing inspiratory time, decreasing tidal volume (Vt) or using the minimum amount of PEEP.

Volume loading may be beneficial if the right ventricular end-diastolic volume index is low.

A low CO with normal or high transmural PAOP or LAP may be secondary to LV dysfunction - such as can occur from hypoxemia - and further fluids would be adverse. An inotropic agent, such as dopamine, dobutamine, and epinephrine may be necessary to improve contractility.

The left ventricular function curve compares LV performance (either CO or stroke volume) as a function of LV filling pressure (LVEDP or PAOP) (Fig. 21). As the LVEDP increases, CO increases (Frank-Starling law). Increases in PAOP over 20 mmHg usually produce little or no improvement in CO. The "A" arrow and curve reflects a shift to a higher ventricular function curve and stroke volume without a change in preload, as seen with positive inotropic therapy. The "B" arrow reflects a shift to a higher ventricular function curve and stroke volume at a lower preload - as occurs with vasodilator therapy. The "C" curve reflects a shift to a lower preload and stoke volume while remaining on the same ventricular function curve, as occurs with diuretic therapy.

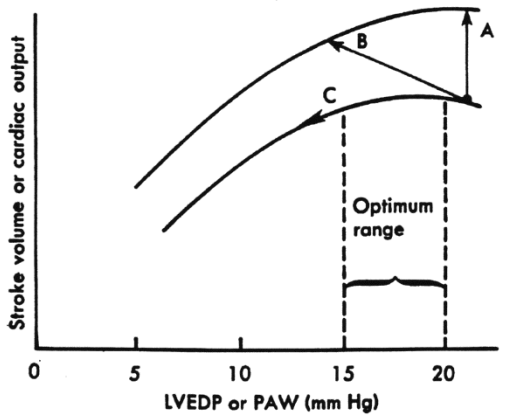

Figure 21. Left ventricular function curves, showing improvement with a) positive inotropic agents, b) vasodilators and c) diuretics (Daily 1989).

As CO falls reflex vasoconstriction (to maintain perfusing BP) increases SVR, afterload. and hence further reduces CO. Vasodilating agents or afterload-reducing agents such as nitroprusside or nitroglycerin. Indications are low CO, normal to high PAOP LAP with high SVR.

Clinical Application

When cardiac function is normal, venous return is the primary determinant of cardiac output. Increases in RAP induced by positive pressure ventilation will decrease cardiac output by increasing back pressure to venous blood flow.

A decrease in venous return will especially be pronounced in hypovolemic states (hemorrhage, dehydration), or when vasomotor tone is decreased (sepsis, spinal shock, autonomic blockage).

A decrease in venous return induced by positive pressure breathing may be responsible for cardiovascular collapse seen in some patients immediately after endotracheal intubation and "bagging" for acute respiratory failure.

Hemodynamic measurements may not be accurate in these patients - the PAOP may not accurately reflect LV filling when hyperinflation or high levels of PEEP (>12 cm H_2O). In such settings other parameters of cardiac output should be monitored such as cardiac output, mixed venous oxygen saturation, arterial-venous oxygen differences and urine output.

Sudden rises in PAP (hyperinflation, high PEEP, PE, hypoxic pulmonary vasoconstriction) can induce cor pulmonale. Venous return goes down, and the dilated RV impinges on the LV, decreasing compliance and filling, and further decreasing cardiac output. Countermeasures include bronchodilators, minimum inspiratory time ratio, minimum PEEP, and in most cases, fluid administration to increase RV filling pressure.

[Ahrens 1991], [Daily 1989], [Ishizawa 1989], [Lookinland 1989], [Pery 1991], [Pinsky 1987], [Poelaert 1991]

PHARMACOLOGIC INTERVENTION

Norepinephrine

Norepinephrine is a potent alpha receptor agonist which causes arterial and venous vasoconstriction, and beta-1-agonist which increases myocardial contractility. It increases BP because of increased SVR, and may not improve or worsen CO. It is a useful temporizing measure in hemodynamically significant hypotension refractory to other sympathomimetic amines. Usual does is 2-12 mcg/min.

Dopamine

Dopamine in low doses (1-2 mcg/k/min) produces vasodilation of renal, mesenteric and cerebral arteries. AT medium doses of 2-10 mcg/kg/min there is enhanced cardiac output and only a modest increase in SVR. At doses above 20 mcg/kg/min alpha-adrenergic effects predominate with constriction of vasculature and increases SVR much like norepinephrine, Dopamine is useful when there is hemodynamically significant hypotension in the absence of hypovolemia. Combined with vasodilators, such as nitroprusside, effects similar to dobutamine are achieved - that is improved myocardial contractility with reduced preload and improved cardiac output.

Dobutamine

Dobutamine is a potent inotropic agent that stimulates beta-1 and alpha-adrenergic receptors in myocardium. Its minor stimulation of peripheral alpha receptors is antagonized by more potent beta-2 stimulation, and mild vasodilation may occur. It does not produce renal or mesenteric vasodilation via dopaminergic receptors, improves balance between oxygen supply and demand and does not induce

arrhythmias. It is useful in the treatment of pulmonary congestion and low cardiac output or in the hypotensive patients in whom vasodilators cannot be used because of intolerance to lower pressures. It is the treatment of choice along with volume loading in patients with hemodynamically significant right ventricular infarction. Usual doses is 2.5-20 mcg/kg/min.

Isoproterenol

Isoproterenol is a beta-adrenergic inotropic and chronotropic medication which increase cardiac output in spite of peripheral vasodilation, venous pooling and reduction in mean blood pressure. It increase myocardial oxygen requirements and worsens ischemia. It is useful for hemodynamically significant atropine refractory bradycardia. It can cause serious arrhythmias. Usual dose is 2 mcg/min.

Digitalis

Digitalis is used to increase myocardial contraction and control ventricular response to atrial fibrillation and flutter. It has little role in the management of acute congestive heart failure.

Sodium Nitroprusside

Sodium nitroprusside is a potent peripheral vasodilator with effects on both arterial and venous smooth muscle. It is useful in the emergency treatment of hypertension and heart failure by reducing blood pressure and preload (via decreased peripheral vascular resistance from increased venous capacitance). May be useful when heart failure and pulmonary congestion is acutely or poorly controlled by diuretic therapy. It is the treatment of choice for hypertensive emergencies, and is easily titratable. Usual starting dose is 0.5 mcg/kg/min titrated to desired endpoint.

Nitroglycerin

Nitroglycerin relaxes smooth muscle, relieves angina, reduces LV filling pressure and SVR, decreases oxygen requirements and has the net effect of increasing cardiac output. It is useful in the emergency treatment of congestive heart failure, especially in patients with ischemic heart disease. Tolerance may develop, and intermittent dosing with nitrate-free periods may be beneficial. Usual dose is 10-20 mcg/min.

Propranolol

Propranolol is a nonselective agent which attenuates the effects of circulating catecholamines by blocking their ability to bind to beta receptors. It has both cardiac and pulmonary effects. Its primary emergency indication is for control of recurrent ventricular tachycardia, recurrent ventricular fibrillation and/or supraventricular arrhythmias refractory to other therapy. Adverse effects include precipitation of hypotension, CHF and bronchospasm.

Furosemide

Furosemide inhibits the reabsorption of sodium and chloride in the ascending loop of Henle. In patients with pulmonary edema during myocardial infarction, intravenous furosemide exerts direct venodilating effects that reduce venous return, and thus central pressure. These effects may be observed even more than that of diuresis. Usual dose is 20-40 mg IV up to 2.0 mg/kg total.

[American Heart Association 1987]

SPECIFIC PULMONARY DISORDERS

Pulmonary Edema

Hydrostatic and oncotic pressure gradients, in conjunction with barrier characteristics of alveolar epithelium, favor retention of fluid within the interstitial space (Fig. 22).

Pulmonary edema is often caused by a combination of increased intravascular pressure and increased capillary permeability. The latter the predominant cause of edema in sepsis or ARDS.

In severe LV failure, intrathoracic blood volume increases, and pulmonary edema may form. This occurs primarily because of increased pressure, but also in part from capillary leak. This decreases pulmonary compliance and gas exchange. Vasodilators, inotropic agents and diuretics, as well as addition of positive pressure breathing (including CPAP) may be necessary. This will decrease intrathoracic blood volume by decreasing venous return, and may improve cardiac performance by increasing ITP [Mecca 1992].

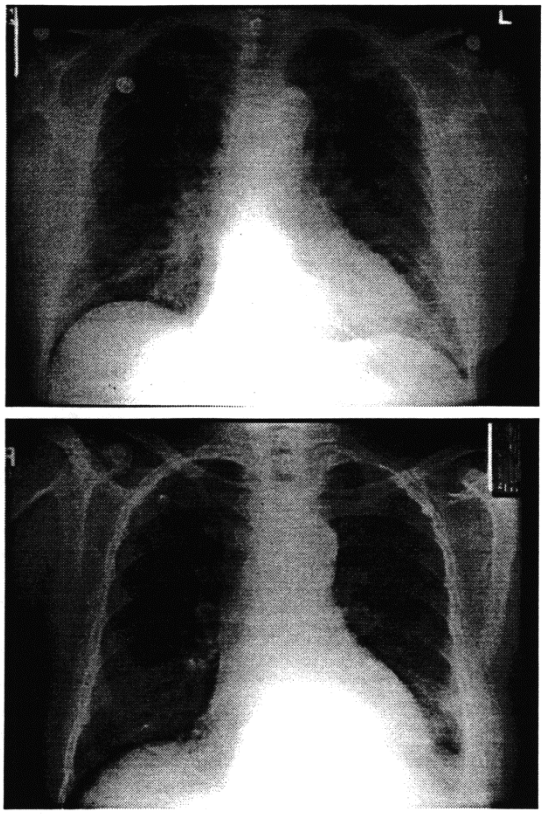

Figure 22. Pulmonary edema before treatment is shown in the upper film, and following diuresis in the lower film.

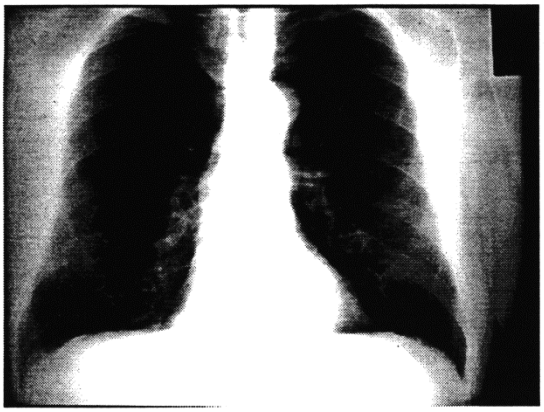

Figure 23. Chronic obstructive pulmonary disease (COPD). Note the hyperlucent lung fields, and flattened diaphragms.

Chronic Obstructive Pulmonary Disease

Chronic obstructive pulmonary disease (COPD) includes chronic bronchitis, emphysema, asthma, bronchiectasis and cystic fibrosis.

Emphysema is characterized by abnormal enlargement of the airspaces distal to the terminal and respiratory bronchioles. There are destructive changes of the alveolar walls and capillary membranes. The chest x-ray often shows flattening of the diaphragms (Fig. 23).

Acute respiratory failure is associated with alveolar hypoventilation and elevation of the arterial partial pressure of carbon dioxide ($PaCO_2$). Patients with acute respiratory failure superimposed on chronic respiratory failure can be distinguished from patients with chronic respiratory failure alone by decreased arterial pH and slightly higher than normal sodium bicarbonate. In chronic respiratory failure the kidneys retain bicarbonate resulting in a low normal arterial pH, increased bicarbonate and decreased serum sodium chloride.

COPD is characterized by impaired gas exchange from ventilation/perfusion inequalities.

Exaggerated increases in intrathoracic pressure (> 20 mmHg) or alveolar pressure during expiration may be transmitted to the pulmonary microvasculature in COPD.

COPD patients with large chests may have inaccurate zero calibration of the transducer.

[Cicale 1992]

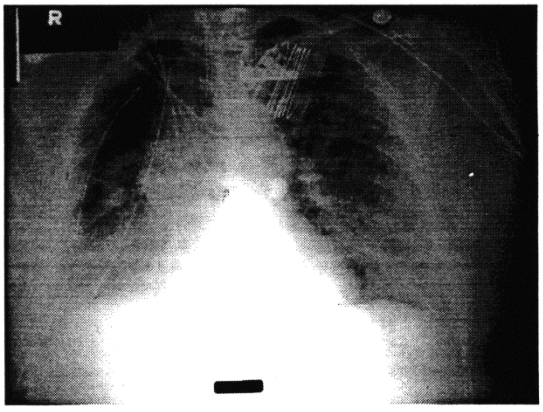

Figure 24. Adult respiratory distress syndrome (ARDS) following coronary artery bypass.

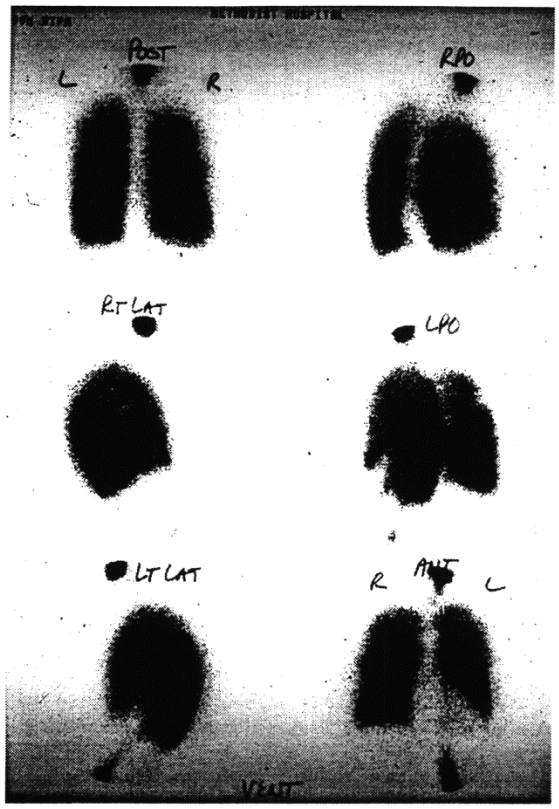

Figure 25. Normal ventilation scan.

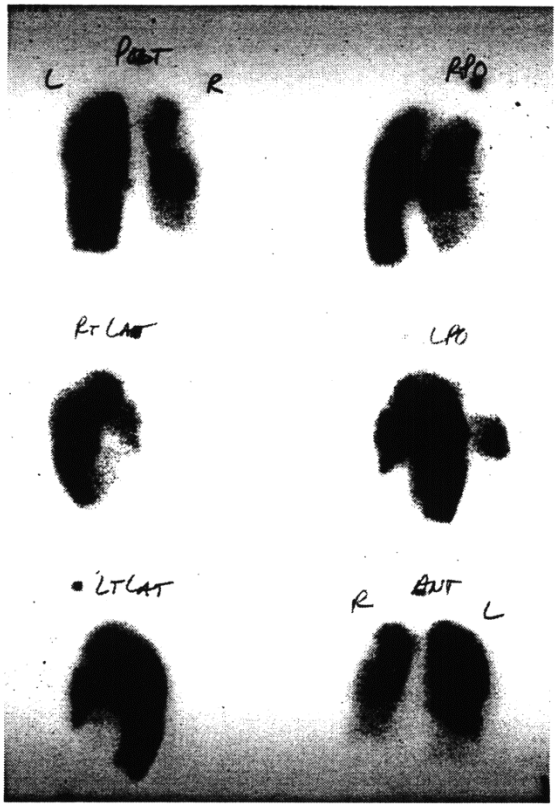

Figure 26. Abnormal perfusion scan, showing mismatched defects when compared to the prior ventilation scan.

Adult Respiratory Distress Syndrome

Adult Respiratory Distress Syndrome [ARDS] is characterized by dyspnea, hypoxemia, diffuse bilateral pulmonary infiltrates and stiff lung. It is caused by diffuse lung injury that leads to increase in extravascular lung water (Fig. 24), usually occurs in patients with no previous lung disease and has an estimated mortality as high as 50% in some studies. Aspiration of gastric contents and sepsis are highly associated with ARDS. Other causes include shock, trauma, toxic gases, drug ingestion, metabolic (uremia, Diabetic ketoacidosis), pancreatitis, CAB, multiple transfusions, DIC, and eclampsia.

Interstitial and alveolar edema, fibrosis and surfactant abnormalities lead to reduced lung compliance (reduced functional residual capacity).

Treatment of the underlying etiology is important, because there is no way to stop the capillary leak and fibrosis.

PEEP is the most effective support therapy. It should be titrated in increments of 2 to 3 cm H20 every 15 mins. with reassessment of arterial oxygen tension, shunt fraction and oxygen transport.

Some volume expansion may be necessary to compensate for reduction in cardiac output associated with positive pressure ventilation or PEEP. If hemodynamic performance is acceptable, judicious diuresis may help decrease lung water. Excessive diuresis can be hazardous. Choice of fluid replacement is controversial - crystalloid (albumin) is acceptable [Taylor 1992].

Pulmonary Embolism

Pulmonary embolism presenting symptoms include sudden onset of dyspnea, tachycardia, tachypnea, pleuritic chest pain, cough, fever, fatigue and apprehension.

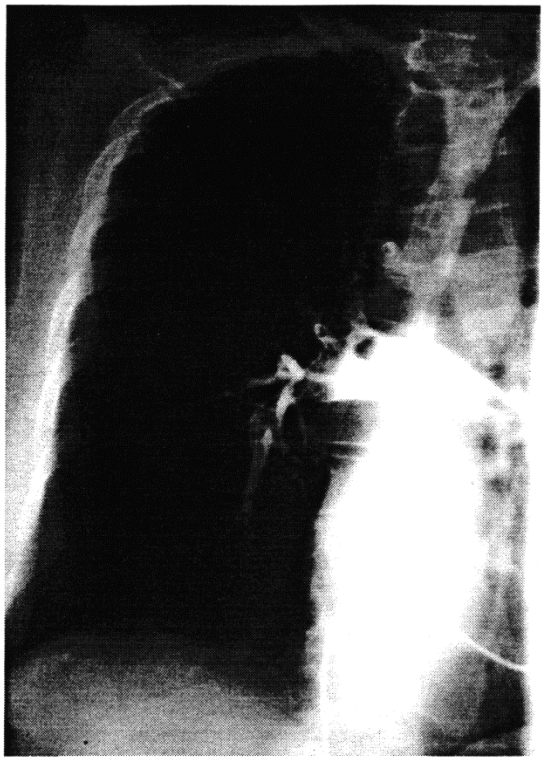

Figure 27. Angiogram showing segmental pulmonary artery occlusions, consistant with pulmonary embolism.

Acute cor pulmonale findings include right ventricular tap, augmented split pulmonic closure sound, right ventricular S3 gallop, distended neck veins, pulsus paradoxus (exaggerated fall in BP with inspiration), and Kussmaul's sign (paradoxic distention of neck veins with inspiration).

Arterial blood gases show hypoxemia with respiratory alkalosis.

Ventilation and perfusion scans (Figs. 25-26) are the best means of non-invasive diagnosis. Pulmonary angiography may be necessary to diagnose in patients with severe COPD (Fig. 27).

Treatment includes Heparin, oxygen, and in patients with massive embolism, isoproterenol may increase cardiac output and reduce pulmonary hypertension. If there is systemic hypotension, fluids and norepinephrine may be helpful. Morphine sulfate is useful in reducing pain and apprehension [Mandeep 1992].

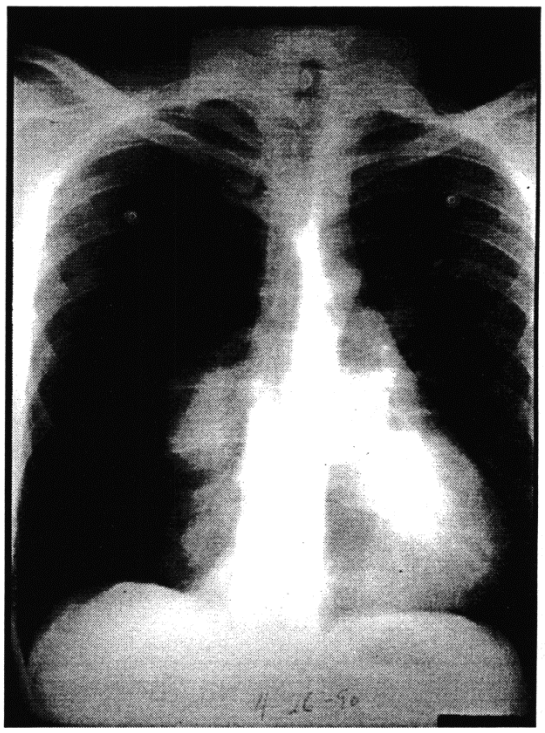

Figure 28. Spontaneous tension pneumothorax.

Barotrauma

Barotrauma is a complication of traumatic thoracic injury and therapeutic interventions. This includes pneumothorax, pulmonary interstitial emphysema, subcutaneous emphysema, pneumomediastinum. pneumopericardium, pneumoperitioneum and venous or arterial air embolization.

Pneumothorax is accompanied by hypoxemia resulting from increased intrapulmonary shunting, and reduction of cardiac output can occur if tension pneumothorax occurs. Decreased ventilation leads to hypercapnea and respiratory acidemia. Treat with chest tube is findings significant.

Tension pneumothorax findings include tachypnea/dyspnea, cyanosis, decreased blood pressure/cardiac output, hyperresonance to percussion ipsilateral side, and asymmetric chest movement with ventilation (Figs. 28-29).

Subclavian puncture and mechanical ventilation can cause pneumothorax. Incidence of this problem can be reduced by minimizing the number of mechanically delivered breaths, peak inspiratory pres-

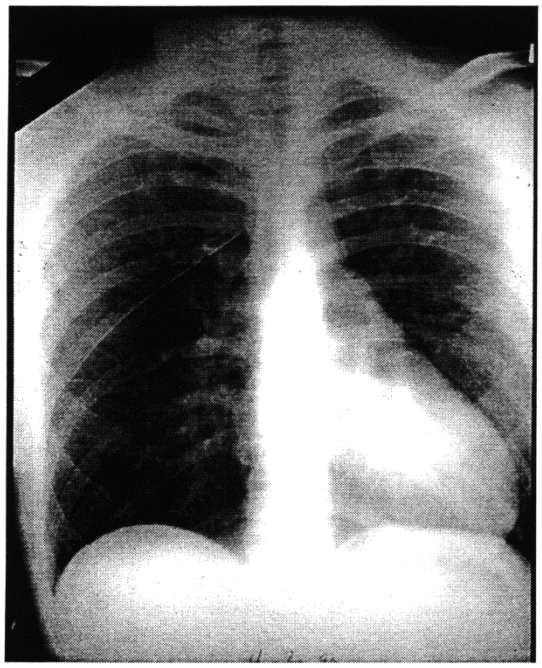

Figure 29. Pneumothorax treated with chest tube placement.

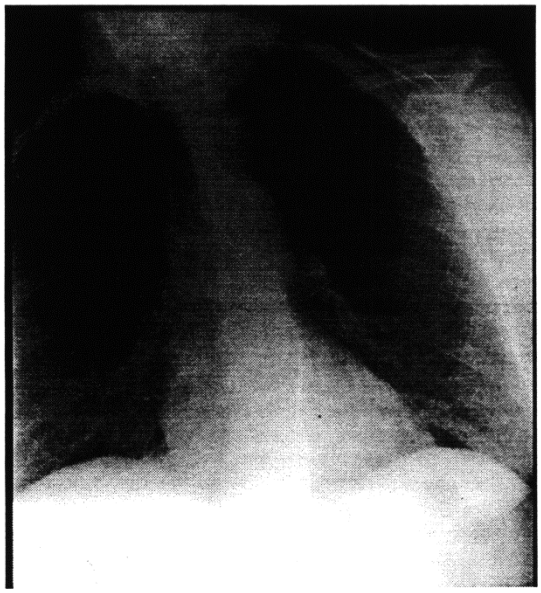

Figure 30. Contusion with development of a fluffy infiltrate in the right hemithorax.

sures, avoiding high PEEP/CPAP and maintaining intravascular volume [Brown 1992].

Contusion

Contusion may be determined by a pulmonary infiltrate appearing 24 to 48 hours after rib fracture or flail chest, or may appear more subtle, such as progressive hypoxia without rib fracture or flail chest (Fig. 30). Hematomas often develop, or in severe cases, they may evolve into ARDS. Oxygen and CPAP may be helpful in mild cases, and in severe cases, fluids and crystalloids may be helpful. Management should be similar to ARDS above [Mecca 1992].

SUMMARY

- It is necessary to consider all factors that contribute to oxygen saturation and not rely solely on the level of arterial oxygen saturation improvement.

- Mixed venous oxygen tension and continuous venous oximetry are important for judging the overall balance between oxygen supply and demand.

- Properly obtained hemodynamic data may direct the physician toward the most appropriate therapy, and improve patient outcome.

- Because of wide-swings in intrathoracic pressure, accurate hemodynamic pressure readings can be measured by obtaining an end-expiratory pressure reading and averaging over three or four respiratory cycles. This may require use of a strip chart recorder.

- In respiratory failure right ventricular performance can not be predicted from the right ventricular ejection fraction, and is better correlated with the right ventricular end-diastolic volume index.

- Mechanical ventilation is used to improve oxygenation, treat alveolar hypoventilation and reduce the work of breathing.

- The most common and important hemodynamic effect of mechanical ventilation is to decrease cardiac output by decreasing the pressure gradient for venous return.

- Estimating transmural pressure can be helpful in interpreting hemodynamic data in patients receiving mechanical ventilation.

• Hemodynamic monitoring in patients receiving mechanical ventilation is helpful in achieving a satisfactory balance between the beneficial effect of increased oxygenation and the deleterious effects of decreased cardiac output.

• Certain pulmonary disorders, like ARDS, especially if accompanied by severe left ventricular failure, require frequent assessment of hemodynamic and other data for proper guidance of therapy.

• Immediate and late complications of central venous and pulmonary artery cannulation should be monitored for.

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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.

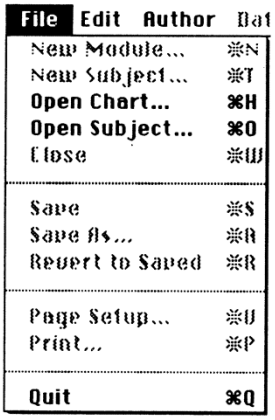

Fig. 1. **File** menu items.

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.

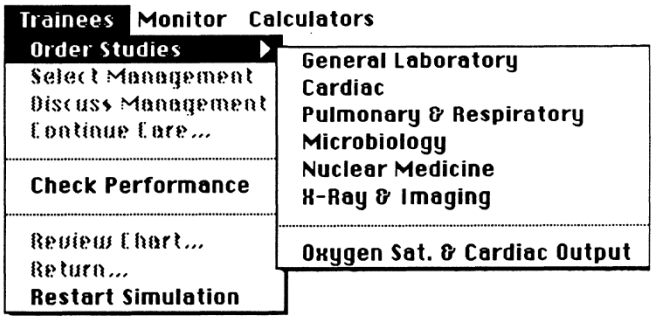

Fig. 2. **Trainees** menu items, and the extended **Order Studies** menu items. The **Oxygen Sat. & Cardiac Output** display may also be called directly from the torso apparatus console by pressing the **Special Studies** button when the cardiac monitor is being displayed. When done ordering studies,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

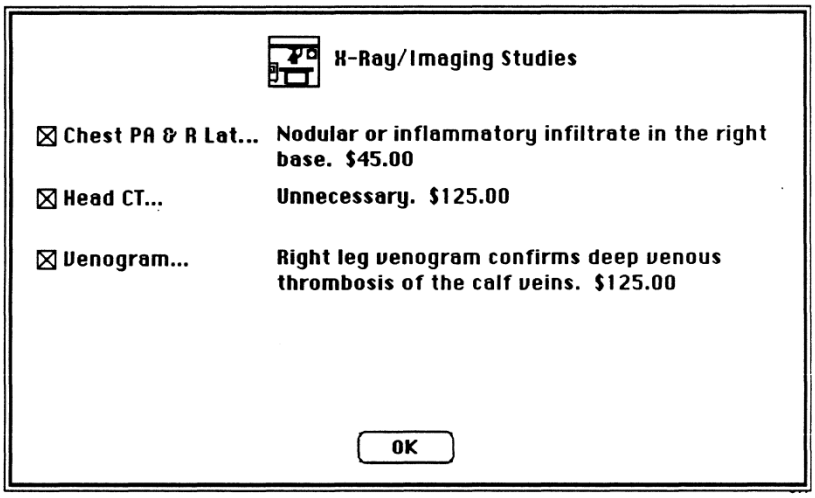

Fig. 3. A study is ordered by checking the box on the left-hand side of the display, and the result is displayed on the right-hand side. The system keeps score on the studies ordered, determines unnecessary or inappropriate orders and tabulates cost of care.

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).

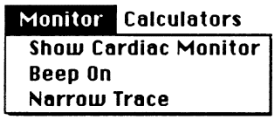

Fig. 4. The **Monitor** menu.

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.

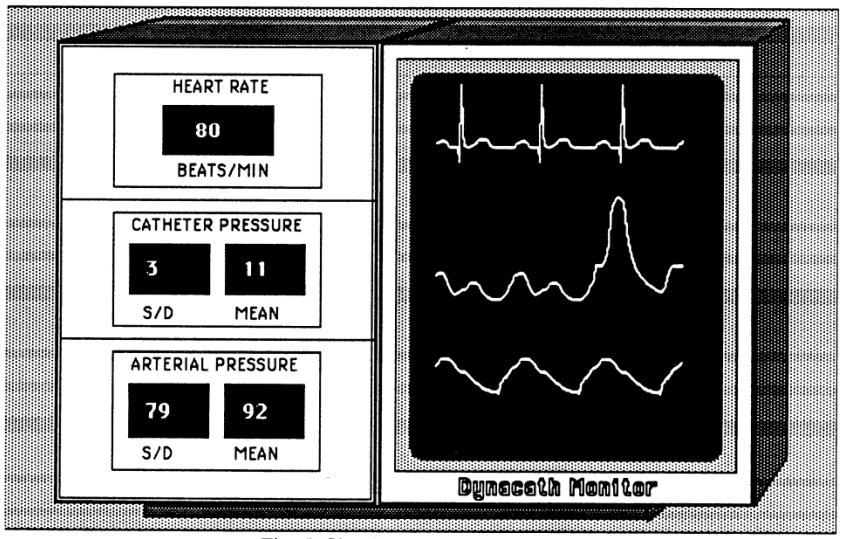

Fig. 5. Simulated cardiac monitor.

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.

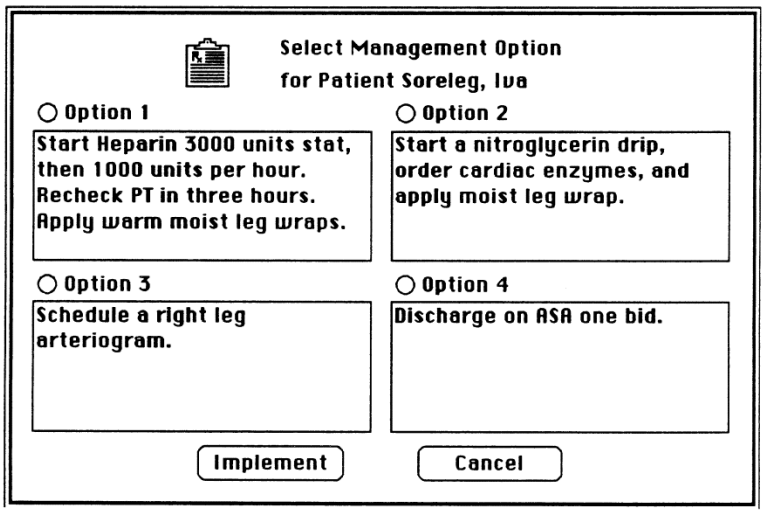

Fig. 6. One of four management plans may be selected at a time. After selecting the round button above an option, select **Implement**.

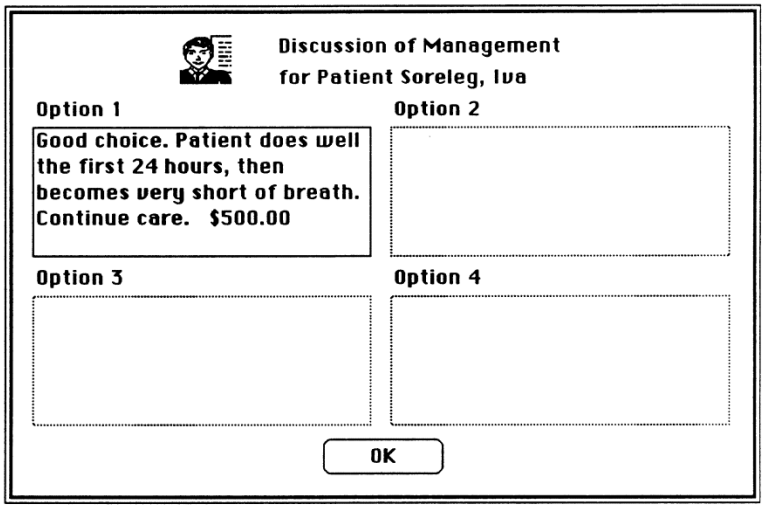

Fig. 7. Discussion, or immediate feedback is presented for each management plan.

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

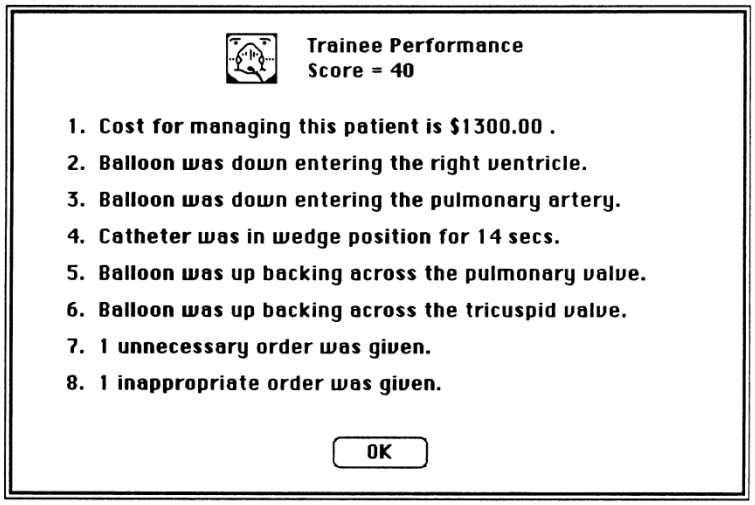

Fig. 8. The Trainee Performance display may be reviewed at any time while managing a patient, and results will be accumulative, or representative of the last catheterization performed.

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).

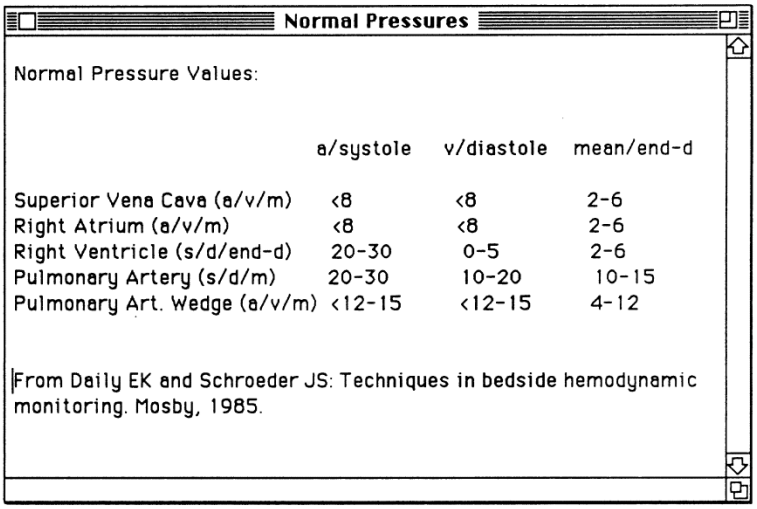

Fig. 9. Example subject document.

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).

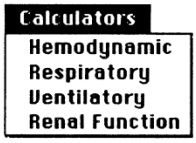

Fig. 10. **Calculator** menu items.

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).

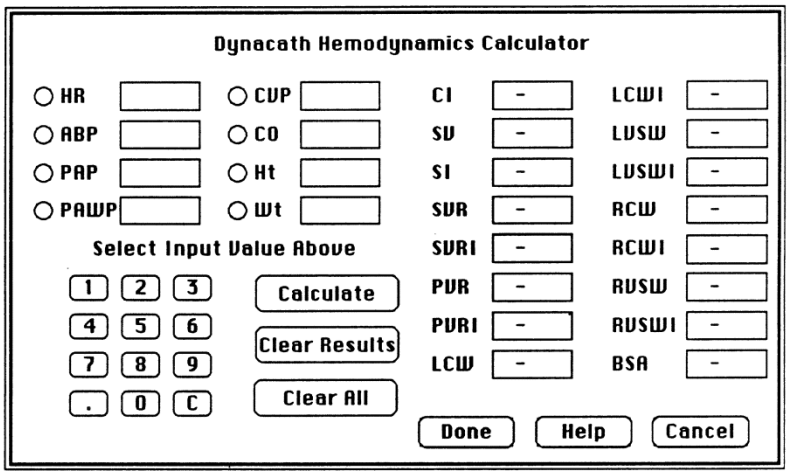

Fig. 11. Hemodynamics Calculator.

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).

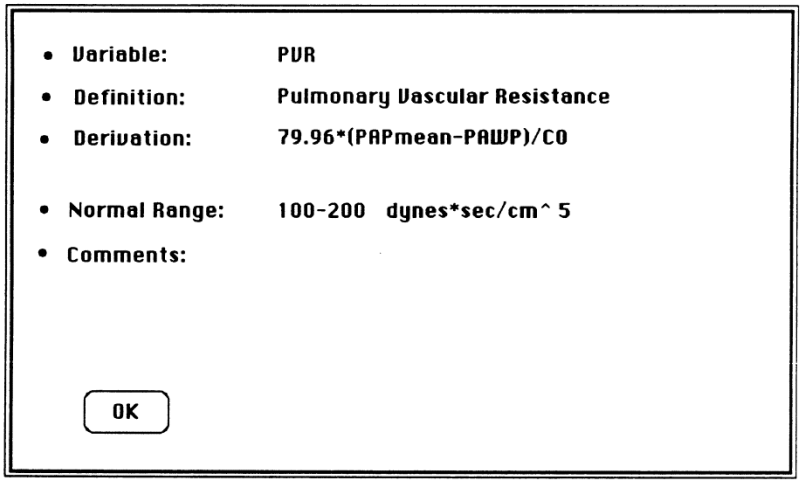

Fig. 12. Example of help display for pulmonary vascular resistance. The comment area is available for authors to convey additional information to trainees. Entry of text in the comment area is possible after entry of a proper access code under the **Author** menu heading.

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).

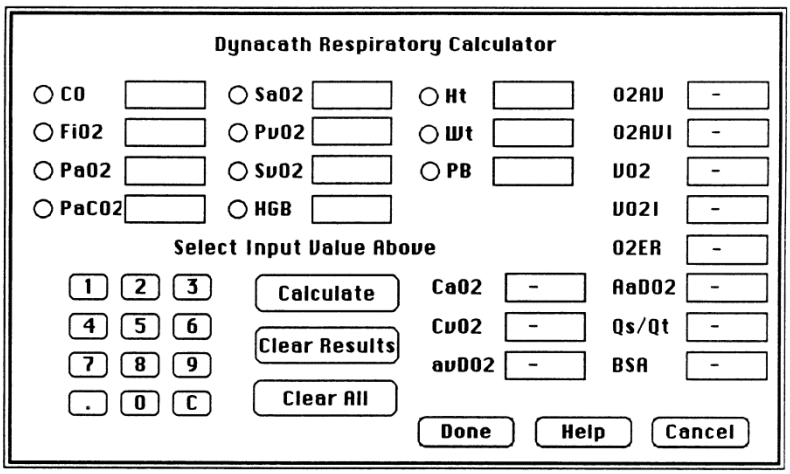

Fig. 13. Respiratory Calculator.

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).

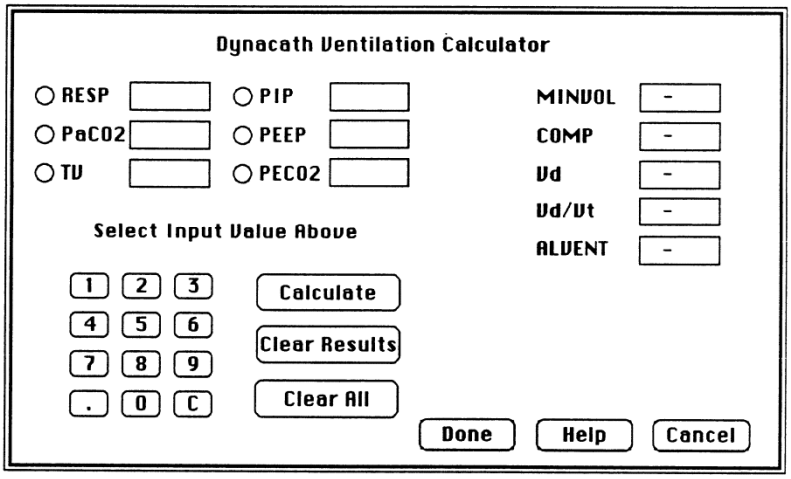

Fig. 14. Ventilatory Calculator.

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).

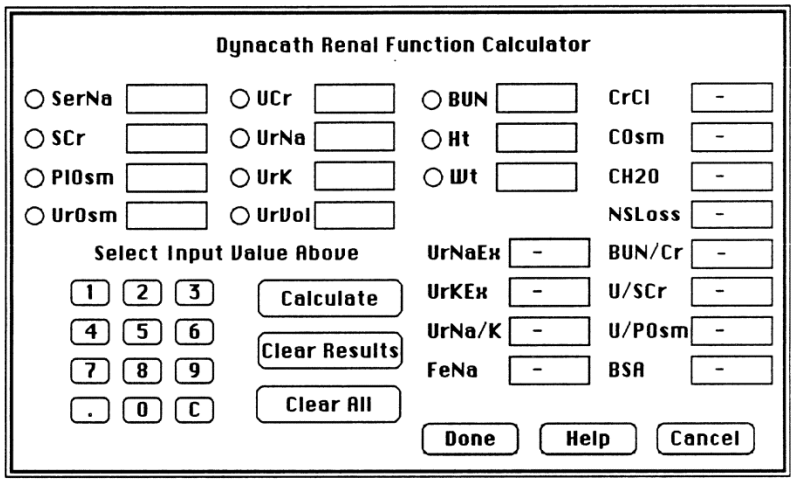

Fig. 15. Renal Function Calculator.

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

Methodist Hospital Grand Rounds
January 20, 1995

Evaluation of the Dyspneic Patient

STEVEN S. SALITERMAN, MD, FACP

Objectives: **To define dyspnea and to describe a) mechanisms and causes for dyspnea, b) current classification schemes, and c) evaluation and management of the dyspneic patient.**

The dyspneic patient often presents with a complaint of "breathlessness" or "shortness of breath" with activity - a subjective description of uncomfortable breathing.

Although various classification schemes have been devised for dyspnea, it is sometimes difficult from the history and examination, as well as preliminary screening studies to accurately diagnose why symptoms are occurring.

Disorders of several different organ systems, including the lung, pleura, airway, heart, pericardium, neuromuscular system, and vasculature may cause dyspnea. Moreover, anemia, metabolic disorders and psychogenic causes must be considered.

A systematic approach to evaluation and management is essential.

DYSPNEA

Strict interpretation: disordered(*dys-*) breathing (*-pnea*).

Conceptually: "It is a difficult, labored, uncomfortable breathing, although it is not painful in the usual sense of the word. It is subjective and, like pain, it involves both perception of the sensation by the patient, and his reaction to the sensation [Comroe 1966]."

Factors that can mediate reactions to dyspnea include cultural background, environment, life experiences and psycological states [McCord 1992]. Adaptation to dyspnea depends on the individual, and while some patients may simply modify there activity level to minimize dyspnea, others become so decompensated they require evaluation in an emergency room setting.

Mechanism

The sensation of dyspnea arises from afferent impulses from various sensory receptors and higher centers (Table 1.) A detailed review of causes and mechanisms at the receptor level has been published [Nisell 1991].

Classification

Classifications for the rating of dyspnea or breathlessness include the following [Borg 1982, Mahler 1987]:

1. Medical Research Council scale, which uses a five point intensity rating (Table 2).

2. Oxygen-Cost Diagram, which is a vertical 100-mm line that represents graded activity levels.

3. Baseline Dyspnea Index, which uses three categories based on functional impairment, magnitude of task, and magnitude of effort.

4. American Thoracic Society questionnaire for rating breathlessness [Altose 1985].

Several other instruments for classifying dyspnea have been described [McCord 1992]. Unexplained chest pain with accompanying breathlessness has also been explored [Bass 1991]. Measurement of dyspnea with exercise may also be useful [Mahler 1992].

Causes

Approximately two thirds of patients will have a pulmonary or cardiac cause for their dyspnea. Most causes for dyspnea are summarized in Table 3.

APPROACHES TO EVALUATION

Commonly one of three unsatisfactory approaches to dyspnea is taken by the clinician [Pratter 1991].

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Table 1. Receptors Hypothesized to Contribute to Dyspnea [Gillespie 1994].

Mechanoreceptors (vagal afferent)	Aortic bodies
Lung	Central medullary chemoreceptors
Stretch receptors	
J receptors	Central nervous system
Respiratory muscles	Efferent signals to respiratory muscles
Muscle spindle (intercostal)	
Golgi tendon organ (diaphragm)	Vasovagal receptors
Airway (irritant receptors)	Right atrial Mechanoreceptors
	Left atrial Mechanoreceptors
Chemoreceptors	Pulmonary artery baroreceptors
Carotid bodies	Right ventricular strain receptors

The first is "intuitive" or making a diagnosis without objective data - e.g. assuming because a patient is a smoker they must have COPD as a cause for their dyspnea; the second "search and destroy" or pursing one potential cause exhaustively before moving on to the next potential cause - e.g. proceeding with exhaustive cardiovascular studies before obtaining simple spirometry; and three, "hunt and peck" or evaluating and treating for one disorder after another in the hope of stumbling upon the correct diagnosis.

Because dyspnea is a subjective reporting by the patient or family, or simply an observation by the clinician or nurse during evaluation for other problems, a systematic approach must be taken to evaluating and managing. Dyspnea often is a presenting problem for primary care physicians (both pediatric and adult), emergency physicians, subspecialists in allergy, cardiology, endocrinology, intensive care, and thoracic disease, as well as several surgical specialties.

Table 2. Medical Research Council 5 Point Scale [Borg, 1982, Mahler 1987].

0	Not troubled with breathlessness except during strenuous exercise.
1	Troubled by shortness of breath when hurrying on the level or walking up a slight hill.
2	Because of breathlessness, walks slower on the level than other people of the same age, or must stop for breath when walk ing at own pace on the level.
3	Stops for breath after walking about 100 yards or after walking a few minutes on the level.
4	Too breathless to leave the house or breathless when dressing or undressing.

ASSESSMENT OF PATIENTS WITH DYSPNEA

The following initial evaluation is essential:

1. Determine specific activities that cause breathlessness.

2. Document exposures (i.e. workplace, farm, hobbies, animals and birds).

3. Review medications (think about drug-induced pulmonary conditions).

4. Inquire about past medical diseases, trauma, and surgery.

5. Comprehensive cardiopulmonary examination.

6. Screening studies, including electrocardiogram, chest x-ray, hemoglobin concentration, thyroid function and spirometry.

If the above is unrevealing for a cause of dyspnea, more specific testing is required to diagnose obstructive or restrictive airway disease, pulmonary hypertension, pulmonary emboli, mitral and aortic valve disease, pericardial effusion or tamponade, pericarditis, and ventricular dysfunction (Table 4).

Asthma is commonly a cause for dyspnea especially in those patients whose cause for dyspnea remains unexplained after history, physical examination,

Table 3. Causes for Dyspnea [Gillespie 1994].

Pulmonary	Abdominal distention	Systemic neuromuscular disorders
Airway	Chest wall injury	
Asthma	Effusion	Cardiac
Bronchiolitis obliterans	Fibrothorax	Arrhythmia
Chronic bronchitus	Kyphoscoliosis	CAD
Laryngeal disease	Pleural mass	Intracardiac shunt
Tracheal stenosis	Pnemothorax	Left ventricular failure
Tracheomalacia		Myxoma
	Vascular	Pericardial disease
Parenchymal	Pulmonary hypertension	Valvular disease
Acute alveolitis	Thromboembolic disease	
Drug-induced conditions	Vasculitis	Other
Emphysema	Veno-occlusive disease	Anemia
Lymphangitic carcinomatosis		Deconditioning
Metastatic disease	Neuromuscular	Gastroesophageal reflux
Pneumonitis	CNS disorders	Hyperthyroidism or hypothyroidism
Pulmonary edema	Myopathy and neuropathy	Metabolic acidosis
Pulmonary fibrosis	Phrenic nerve and diaphragmatic disorders	Psychogenic
Pleural or chest wall	Spinal cord disorders	

chest x-ray and spirometry. Pharmacologic bronchoprovocation challenge (BPC) is useful in identifying these patients [Pratter 1991].

Pratter reported on one hundred consecutive patients referred to a pulmonary disease clinic [Pratter 1989]. Causes included asthma (25%), interstitial lung disease (12%), COPD (12%), cardiomyopathy (9%), upper airway disease (7%), deconditioning (4%), GER (4%), psychogenic (4%), extrapulmonary (3%) and other (5%).

Depaso reported on seventy-two patients who were referred by other physicians (over a seven year period) for dyspnea greater than one month duration, unexplained by history, physical examination, chest roentgenogram and spirometry [Depaso 1991]. Frequency of individual causes are shown in Table 5.

A definite cause for dyspnea was found in 58 patients (81%), and no answer was found in 14 patients (19%). Dyspnea was due to pulmonary disease in 36%, cardiac disease in 14% and extrathoracic

Table 4. Specific Testing for Unexplained Dyspnea [Gillespie 1994].

Pulmonary	Cardiac
Flow-volume curves	Echocardiography
Total lung capacity	
Carbon monoxide diffusing capacity of the lungs	Additional Procedures for Difficult Cases
Oximetry or arterial blood gasses during exercise	Cardiopulmonary exercise testing
Bronchoprovocation testing	Monitoring of cardiac rhythm
Maximal inspiratory and expiratory respiratory pressures	Radionuclide cardiac studies
	Right or left heart catheterization
Vascular	Pulmonary angiography
Ventilation-perfusion lung scanning	High-resolution computed tomographic scanning of the chest
Venous studies of the legs	Lung biopsy
	Monitoring of esophageal pH (24 hour study)

Table 5. Causes for Chronic Dyspnea in 72 Specialty-Referred Patients [Depaso 1991].

Respiratory disease	
Airway obstruction	
Asthma/reactive airway disease (n=12)	
Endobronchial malignancy (n=1)	
Extrathoracic upper airway obstruction (n=1)	
Parenchyma	
Interstitial lung disease (n=2)	
Bullous disease (n=2)	
Chronic lower resp. bacterial infection (n=1)	
Pulmonary vascular	
Pulmonary embolism (n=3)	
Primary pulmonary hypertension (n=1)	
Respiratory muscle weakness	
Myasthenia gravis (n=1)	
Lower motor neuron disease (n=1)	
Chest wall	
Pectus deformity (n=1)	
Cardiac Disease	
Myocardial	
CAD (n=4)	
Cardiomyopathy (n=2)	
Conduction	
Arrhythmias (n=2)	
Intracardiac shunt (n=1)	
Constrictive pericarditis (n=1)	
Central Nervous System	
Hyperventilation Syndrome (n=14)	
Thyroid Disease	
Thyrotoxicosis (n=1)	
Myxedema (n=1)	
Kidney	
Metabolic acidosis (n=1)	
Gastrointestinal reflux (n=3)	
Deconditioning (n=2)	
Unexplained (n=14)	

disease in 4%.

Their conclusions were as follows:

1. Most but not all patients will have a recognizable disease to explain their dyspnea.

2. The disease spectrum is extensive resulting in a very broad differential diagnosis.

3. Neither the duration nor severity of dyspnea provided diagnostic insight.

4. Age younger than 40 years, intermittent dyspnea, and normal alveolar-arterial oxygen pressure difference (P[A-a]])O2 at rest breathing room air was strongly predictive of bronchial hyperactivity or hyperventilation.

5. With the exception of BPC, the diagnostic yield of any single non-invasive test was poor because of the large number of diagnosis seen in these patients.

6. All patients approaching diagnosis of "unexplained" or hyperventilation should have a BPC test.

7. Patients with a P(A-a)O2 <= 20 mm Hg are very unlikely to have occult pulmonary parenchymal or pulmonary vascular disease to explain their dyspnea.

ACUTE DYSPNEA CONSIDERATIONS

Acute dyspnea usually represents a sudden event that leads to pathophysiologic disturbances at rest. These include acute asthma, allergic reactions, upper airway obstruction, pneumothorax, pulmonary edema, pulmonary embolism, myocardial infarction, pericarditis, pericardial effusion, and sudden chamber wall or valvular injury following infarction.

These patients may be at acute risk and require prompt evaluation of oxygenation, supplemental oxygen support (and ventilation if necessary), as well as determination and correction of the underlying cause.

Oxygen Transport

Adequate tissue oxygenation depends on hemoglobin concentration, the percentage of hemoglobin saturated with oxygen in arterial blood (SaO2), cardiac output (CO), oxygen consumption (VO2), the affinity of hemoglobin for oxygen (P50) and the distribution of perfusion.

Normal compensatory mechanisms are typically disturbed in critically ill patients, and shifts in the oxyhemoglobin dissociation curve (Fig. 1) such as from acidosis or alkalosis may profoundly impact oxygen content and delivery.

The curve may be shifted to the right with improved oxygen unloading (decrease in the affinity of hemoglobin for oxygen) at the tissue level by

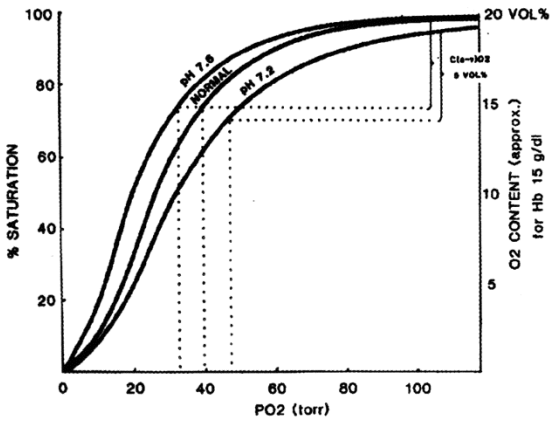

Figure 1. Oxygen dissociation curve [Snyder 1987].

increased blood temperature, carbon dioxide, hydrogen ion concentration, 2,3-DPG, intercellular sodium, and hemoglobin concentration.

The curve may be shifted to the left by hypothermia, hypocarbia, alkalosis, anemia, and decreases in 2,3-DPG or sodium.

Although methods exist for approximating oxygen consumption in critically ill patients, they are technically difficult and may not give clue to individual organ metabolism. In summary, it is best simply to maximize oxygen transport to support the greater than normal metabolic rates.

Tissue oxygenation depends on both oxygen saturation and rate of flow:

$$DO_2 = CO \times CaO_2 \times 10 \text{ (ml/min)}$$

DO_2 is oxygen delivery, CO is cardiac output and CaO_2 is arterial oxygen content.

If cardiac output is severely depressed despite improvement in arterial oxygenation, oxygen transport may be worsened. It is necessary to consider all factors that contribute to oxygen supply and not rely solely on the level of arterial oxygen saturation improvement [Edwards 1993], [Snyder 1987].

Oxygen Consumption (VO_2)

The amount of oxygen utilized is normally determined by the body's energy requirements, and can be calculated from the Fick equation [Dantzker 1991]:

$$VO_2 = VI \times FIO_2 - VE \times FEO_2$$
$$= CO \times (CaO_2 - CvO_2) \times 10$$

VI and VE are the inspired and expired minute ventilations, FIO_2 and FEO_2 are the inspired and expired fractional concentrations of oxygen, CO is the cardiac output, and CaO_2 and CvO_2 are the arterial and mixed venous oxygen content.

In a steady state condition the amount of oxygen taken up by the tissues is equal to the amount taken up in the lung, so that VO_2 can be calculated from either the gas side of the system, measuring the difference between the amount of oxygen in the inspired and mixed expired gas, or the blood side as the product of the cardiac output and the arterial-venous oxygen difference.

Pulse Oximetry, Mixed Venous Oxygen Tension, Continuous Venous Oximetry

Pulse oximetry is commonly used for measuring arterial oxygen saturation (SaO_2) (Fig. 2).

It is based on the principle that oxyhemoglobin and reduced hemoglobin have different light absorbance characteristics.

Drawbacks include false-high readings when high carboxyhemoglobin or methemoglobin. Other false readings with jaundice, skin color, nail polish, shock and severe hypoxia.

Mixed venous oxygen tension (PVO_2) may be the most reliable single physiologic indicator for monitoring the overall balance between oxygen supply and demand.

Mixed venous blood is a flow-weighted mixture of all blood that has traversed the systemic vascular beds and may best be sampled from the proximal pulmonary artery.

Marked venous hypoxemia (PVO_2 < 27 mmHg) and lactic acidosis is associated with high mortality.

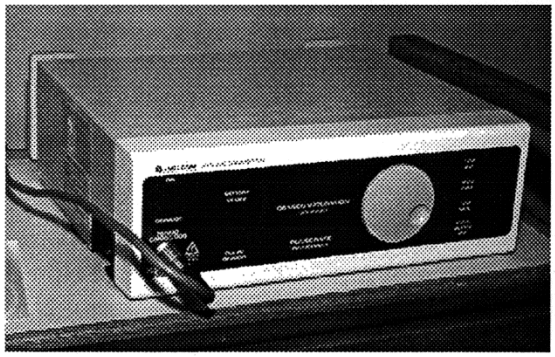

Figure 2. The Nellcor® Pulse Oximeter.

Table 6. Interpreting Arterial Blood Gases.

Condition	Findings	Cause
Respiratory Acidosis	(PaC02 > 45) + (pH < 7.35)	Inadequate ventilation
Metabolic Acidosis	(PaC02 < 35) + (pH < 7.35)	H+ buildup
Respiratory Alkalosis	(PaC02 < 35) + (pH > 7.45)	Increased ventilation
Metabolic Alkalosis	(PaC02 > 45) + (pH > 7.45)	Volume depletion or low K+

Mixed venous oxygen tension does not indicate if a specific organ is under perfused or the distribution of perfusion. Another drawback is that in critically ill patients the central venous sample may not represent a true mixed venous sample.

Fiberoptic catheters for continuous analysis of blood oxygen saturation (SvO_2) has increased in popularity since first introduced in 1972 (Fig. 3). The SvO_2 reflects the overall balance between oxygen supply and demand. Calibration with a mixed venous sample and catheter position are important.

The normal range is 0.68-0.77. High values indicate an increase in delivery relative to consumption, and is associated with cirrhosis, sepsis, peripheral left-to-right shunting, cyanide toxicity, arterial hyperoxia or technical problems (calibration error, wedging of the catheter).

Low values may be associated with anemia, arterial oxygen desaturation, increased oxygen consumption or decreases in cardiac output. A rapidly falling Sv02 may proceed a major cardiovascular complication.

Interpreting arterial blood gases for acid-base balance is also important, and Table 6 allows for distinguishing respiratory from metabolic disorders [American Heart Association 1987].

[Martin 1992], [Nelson 1987], [Nelson 1992], [Snyder 1987], [Vincent 1992].

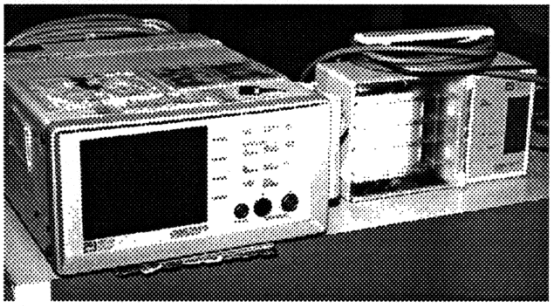

Figure 3. The Abbott Oximetrix® for measuring continuous mixed venous oxygen saturation.

TREATMENT OF DYSPNEA

Foremost in treatment of the acute or chronic dyspneic patient is correction of the underlying cause. Recognition and intervention in acute dyspnea may be life saving, while treatment of chronic dyspnea may improve quality of life.

An excellent review of evaluation and treatment of dyspnea in elderly patients has been published [Silvestri 1993].

Tobin reviews use of brochodilator therapy, diazepam in COPD patients, opiates, oxygen therapy and sitting near an open window or fan in care of dyspneic patients [Tobin 1990].

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User Manual

The Dynacath Critical Care & Hemodynamic Monitoring Training System

User Manual for Model 2010

with Installation & Startup Guide
and Author Workbook

Dynacath Corporation
Minneapolis, Minnesota

Table of Contents

Chapter 1: Introduction

Chapter 2: Author Operation

Chapter 3: Trainee Operation

Color Software Version 2.5
Manual Revision: 6/1/93

Chapter 4: Calculator Operation

Chapter 5: Entering Waveforms

Chapter 6: Airway Pressure

Chapter 7: Author Workbook

Agreement

Introduction 1

Overview

The Dynacath Critical Care Patient Simulator™ has been developed for training, certification, modeling, and demonstrating problems in the management of critical care patients. 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.

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

In contrast to previously described simulators and computer oriented instructional programs, this system contains no inherent database. Instead, authors build a library of informative cases by using hardware and software tools provided. Individual "modules" of patient information are authored, and these are transparently linked together as a student undertakes management of a patient.

Designed to be educational for both instructors ("authors") and students ("trainees") alike, the simulator should provide years of service, and will grow more valuable as your instructional curriculum develops.

Trainees may develop manual dexterity skills in performing cardiac catheterization, and cognitive skills in interpreting cardiac rhythms and hemo-

dynamic data.

Authors build a library of informative cases by using hardware and software tools provided. Expansion and modification of the database is limited only by the amount of computer storage media available. This method promotes timeliness and quality of the instructional material by allowing incorporation of recent literature, tailoring of cases to specific audiences and customizing for regional, social or philosophical approaches to certain management problems.

Suitable medical conditions for presentation 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.

Hardware

The system consists of an adult torso made of rigid polyethylene, with access ports for right-heart catheterization from the medial basilic vein in the antecubital fossa, the subclavian vein, and the internal jugular vein. Catheterization is possible from the right side only. An internal guideway leads the catheter to precision aligned rollers that rotate an optical encoder. The optical encoder provides catheter position and direction of motion information to the computer. A three-way adaptor is connected between the catheter and balloon syringe, diverting air into a durable internal balloon. A sensor determines the balloon inflation status, and this information is also provided to the computer. A single cable connects the torso apparatus to the computer's modem port, and power is provided through a UL-approved power supply.

Software

The software is written in Macintosh Programmers Workshop (MPW) Pascal®, and compiled into machine code for distribution. Two levels of operation are available: a case input and development function for authors, and a simulation function for trainees. A computer keyboard is not necessary during simulations; selections are made using the apparatus switches or by pointing the computer cursor - with a mouse or trackball - to suitable screen buttons and controls (Macintosh User Interface).

Installation & Startup Guide

Unpacking

Inspect all shipping cartons for damage prior to opening, and report any visible damage to your carrier immediately.

You should have received from Dynacath the simulator torso apparatus, attachments, manual and software. A digitizing tablet is offered as an option for direct entry of existing waveforms into instructional cases.

Save the original shipping carton in the event that is necessary to return the torso apparatus.

Setup

Static may damage the simulator as well as the computer, and should be minimized. Discharge mats can significantly reduce this hazard. The torso apparatus should be placed to the left of the computer to allow access to the catheter insertion sites.

WARNING: The torso apparatus should not be left standing on end, and should be mounted on a stable , flat surface for use.

Macintosh Computer

Version 2.52 of the Dynacath software requires an Apple Macintosh computer with a color display, minimum size of twelve inches. The computer should have at least 4 megabytes of RAM and a 40 megabyte harddrive. System 7.1 or later is preferable.

"Help balloons" provide for immediate direction as to the function of each menu item as you use the program. System 7.1 allows you to easily turn the balloons off or on.

The software is not copy protected and you are encouraged to make a backup copy for storage in a safe place, or for remote authoring.

System 7.1 allows multiple applications (programs) to be running at the same time. It is recommended that you close all other applications to prevent accidental loss of data and interference with the cardiac monitor display.

Some INIT files in the System folder may interfer with operation of the program. Start or restart the computer by simultaneously holding down the shift key until the "Welcome" display and "Extensions off" phrase appear. Alternatively, you may remove selected INITS from the system extensions folder in advance, and then restart normally.

The program is compatible with Capture® (a program by Mainstay for

capturing screen images for archiving or publication purposes).

CAUTION: Do not use screen savers (ie. After Dark®) or terminal programs (ie. AppleShare®) while using the Dynacath software. Turn extensions off or remove from the System extensions folder.

Connections

The torso apparatus has two connectors on the back, one for power and the other for interfacing to the Macintosh computer. With the power off, connect the wall-mount power supply to the torso apparatus, and the interconnecting cable to the modem port of the Macintosh. The printer port may be optionally used, but requires that you disconnect AppleTalk by selecting **Chooser** under the **Apple** menu, and making AppleTalk "inactive." If you are using a digitizing tablet, this should be connected to the Apple ADB port.

WARNING: All connections must be completed with the power off to all hardware.

Catheters

Most pulmonary artery catheters (ie. Swan-Ganz® catheter) will work with the torso apparatus. An old sterilized catheter will work fine, regardless of the condition of the balloon. Cleanly cut the small catheter extension (midway) going to the syringe hub, and insert the provided three-way adaptor in-line. The catheter should attach to the blocked end of the adaptor, and the syringe hub to the open end of the adaptor. The assembly is then firmly attached to the port on top of the torso apparatus enclosure (Fig. 1-1). The syringe and air control on the hub may be used normally, and the air is diverted into a durable balloon located inside the apparatus. The system electronically senses the state of the balloon, and this is incorporated into the performance evaluation of the trainee.

A little silicone high vacuum grease should be placed on the port threads from time to time to allow easy attachment and removal of the adaptor.

Standard catheter insertion components may be used. It helps to coat these lightly (wipe down) with a silicon spray commonly used with training manikins. It is unnecessary to "penetrate" the torso because access ports are already present. (There are less expensive training models generally available for vein locating and actual needle insertion practice.) It is recommended that you file down the sharp end of any needles included in the catheter insertion kit.

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

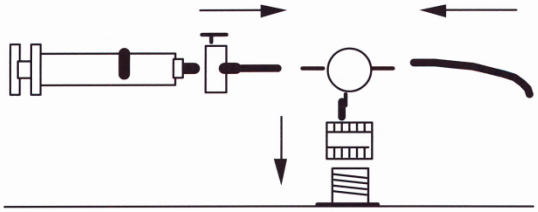

Fig. 1-1. The catheter is cut mid-way along the syringe/hub extension (usually a red tubing), and the syringe side is connected to the open end of the three-way adaptor. The catheter side is connected to the blocked end of the adaptor. When the syringe is used, air is diverted into the apparatus balloon instead of the catheter balloon.

CAUTION: Be sure to deflate the balloon prior to removing the adaptor from its mounting, or air will be trapped inside the balloon. This will lock the indicator in the "Balloon Inflated" position, and the manual controls will be inoperative.

Getting Started

In addition to reviewing this manual, familiarize yourself with operation of the computer, and follow the directions that come with the digitizing tablet. (Authors will need to configure the digitizing tablet for their computer, including setting the scale to match the Waveform Editor grid display with actual strip-chart paper.) Turn on the power to the computer, torso apparatus and digitizing tablet prior to inserting the software diskette. Once loaded into the computer, a window should appear with a heart icon for the program, as well as folders for Cases, Waveforms and Subjects that you author. These files should be copied to the hard drive by simply dragging the icons to your hard drive window. Do not rename the folders or locate them in new folders away from the program, or they will not be properly accessed during operation.

To begin, double-click on the heart icon, and follow the directions in the dialog that appears (Fig. 1-2). The simulator will automatically configure itself, and you should see all indicator lights on the torso apparatus going off except for the **Power** and **Balloon Deflated** lights.

WARNING: Do not turn the torso apparatus power off when the simulator software is running. The interuption in the communication link may cause the computer display to freeze, and data to be lost. If this occurs, simple turn the computer off and restart.

You are now ready to author cases or manage simulated patients. If you are using System 7.0, you can select **Show Balloons** under the **Balloon** menu

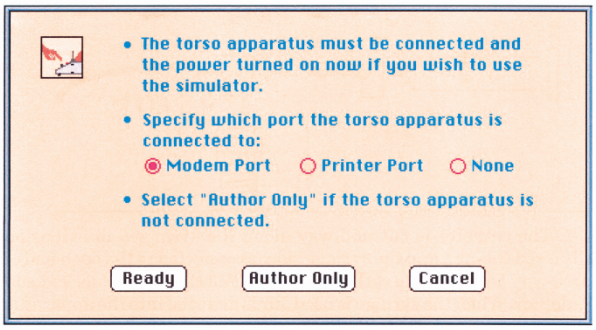

Fig. 1-2. Begin by selecting **Ready**. If you have not yet turned on the power to the torso apparatus, you may do so at this time. Select **Cancel** and turn off the computer and torso apparatus if you need to complete or correct connections. The modem port is selected by default. If you prefer the printer port, be sure to disconnect AppleTalk, and then select **Printer Port** above. You may author cases without the torso apparatus connected. Proceed by selecting **Author Only**.

heading. When you move the cursor over menu headings or items, a "help balloon" appears, and tells you exactly what the selection does. Once you feel comfortable with operation of the software, select **Hide Balloons**.

Problems

Please feel free to call or write with problems or suggestions. The Dynacath Critical Care Patient Simulator™ has evolved to its present form because of helpful recommendations from users. If you encounter difficulty with the software, record carefully the steps you took that led to the problem. If you have problems with the hardware, first try testing with the **System Diagnostics** display (Chapter 2, Author Operation), and then make a record of all apparent malfunctions.

Special educational discount pricing has been established because of the need to encourage authoring of cases. The demonstration cases provided are just that - *demonstration cases*, and not a curriculum. They were written to show you the potential of the Simulator.

For supplimental reading see Saliterman SS: A computerized simulator for critical care training: new technology for medical education. Mayo Clinic Proceedings 65:968-978, 1990.

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Author Operation 2

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 2-1, and is explained in the discussion that follows.

Table 2-1. **- 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)

Entering the History & Physical Examination

Familiarize yourself with the menu headings across the top of the screen (Fig. 2-1), and the menu items for each heading. Only those items in bold type can be selected - those in gray type may be selected at other times.

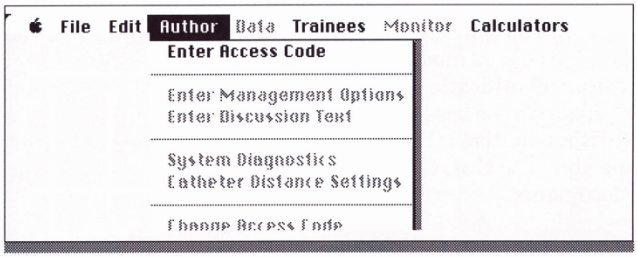


Fig. 2-1. Menu headings and menu items for **Author** are shown.

Selecting **Enter Access Code** will bring up a dialog box for you to type your unique code for authoring cases (Fig. 2-2). This is required for developing new cases and modifying previously authored cases.

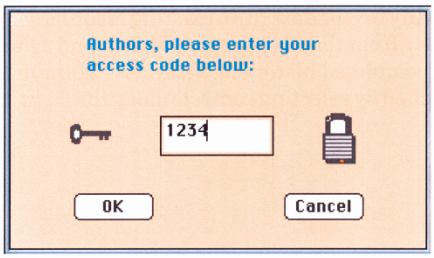


Fig. 2-2. Enter "1234" unless you have previously changed your access code. Select **OK** once your code is entered.

Now look at the menu items under the **File** heading (Fig. 2-3).

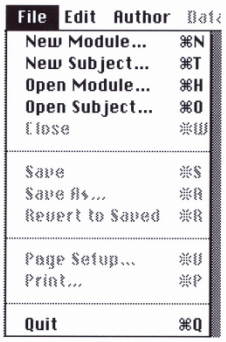


Fig. 2-3. **File** items.

Select **New Module** and an untitled window will be displayed. Type in your initial history and physical and select **Save As** (further editing can be saved by selecting **Save**). You will need to provide a pseudonym (ie. Smith, John A.) to title the module. Subsequent modules for this patient (required for "continuing care") should have an identification number (1-99) enclosed in brackets and appended (without a space) to the base name (ie. Smith, John A.[1]).

The **Edit** menu items (Fig. 2-4) can be used to assist in entering text, and include the ability to **Cut**, **Copy**, **Paste** or **Clear** text within the document, or between documents.

Fig. 2-4. **Edit** items.

If you need to modify text or data in an existing module, select **Open Module**, locate the Cases folder from the file selection dialog, and select **Open**. Figure 2-5 is an example of a completed history and physical examination. Note that the document can be scrolled by selecting controls along the right-hand margin of the window.

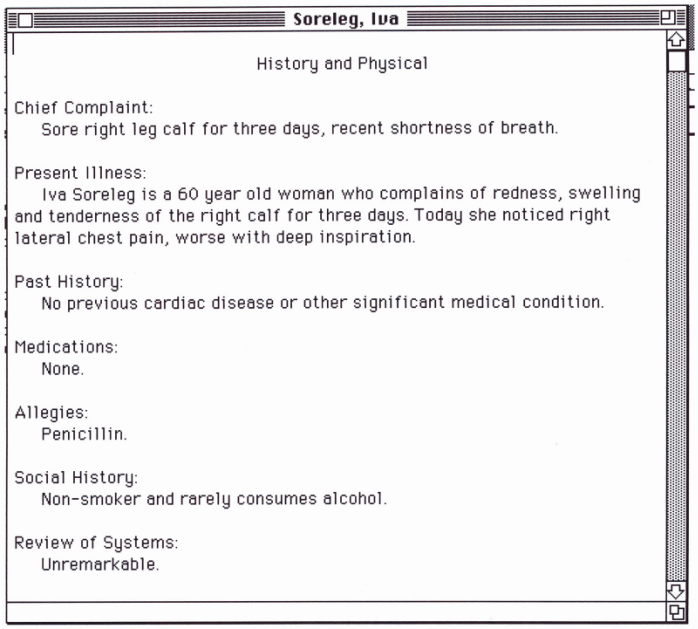


Fig. 2-5. Example of a completed history and physical. Future modules for this patient would contain progress notes and consultations instead, and would have an identification number appended to the name above.

Once a module has been opened and saved, you have completed the first step in authoring of a case, and are ready to enter module-specific data.

Entering Hemodynamic Data

The second step begins by entering initial data, that is the hemodynamic data the trainee would encounter if they examined this patient prior to treatment. The **Initial** item will be checked for you in the extended menu items of **Select Response**, under the **Data** menu heading (Fig. 2-6). You only need to change this when you are ready to enter the data that corresponds with the outcome of each of the four management options.

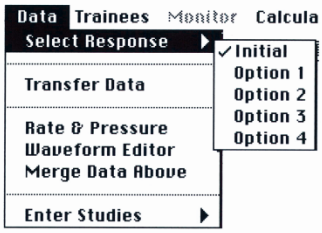


Fig. 2-6. **Data** menu items, and the extended menu items under **Select Response**.

Select **Rate & Pressure**, and enter the data requested in the dialog box (Fig. 2-7). Default data will appear only if you have previously entered data. Move the cursor to the appropriate box and type the values. To change a value, tab to the appropriate box, and type in the new data. Select **Save** to keep the new data, or **Cancel** to keep the old data.

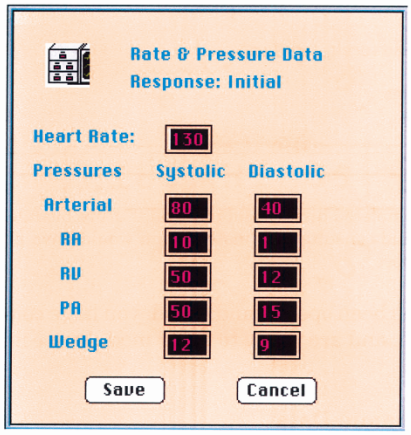


Fig. 2-7. Rate & Pressure dialog. Do not attempt to "interpret" your original waveform data, rather enter the actual minimum and maximum pressures derived from the segment of recording entered below. The trainee will "run a strip" when the cardiac monitor is showing, interpret the waveform (allowing for inspiratory or mechanical ventilation variation) and select the "correct" pressures for determining cardiac indices. Values entered here are used to correctly reproduce the waveform and provide for values seen on the cardiac monitor. Trainees are encouraged to "run a strip" for accurate interpretation, and to recognize the limitation of depending on values shown on the cardiac monitor display.

Next select **Waveform Editor** (Fig. 2-8) and enter the waveforms required for your case. The controls on the right-hand side will display the default data (flat-line if no previously data has been entered).

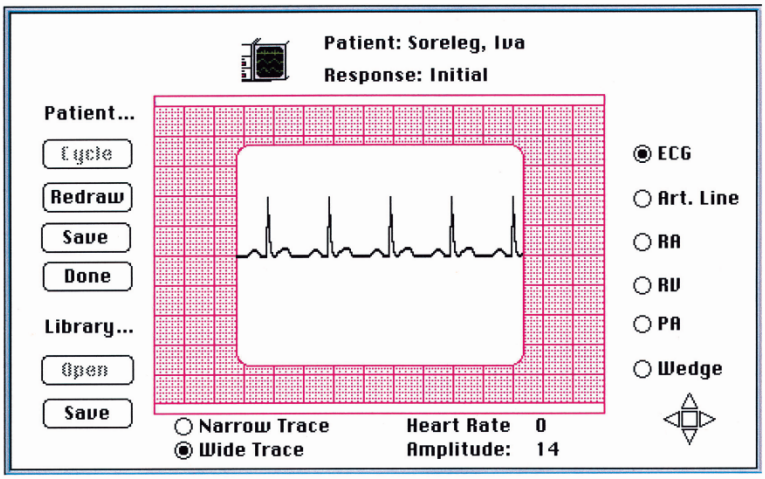


Fig. 2-8. Waveform Editor. The arrow controls (lower right) allow you to inspect the waveform at different rates and pressures, but do no change the data entered and saved.

Select **Redraw** and using the digitizing tablet (see Chapter 5: Entering Waveforms) trace up to a three second interval of original waveform data. Hold the top button of the cross-hair cursor down while drawing. Releasing the button will end the segment. Draw complete cycles timed with the onset of the QRS complex (or any other consistant reference point). The same reference point must be used with all strips for a given patient (fine adjustment of timing is possible later). When selecting in advance the segment of strip to use, starting and stopping at the same baseline will produce a more natural looking display on the cardiac monitor.

Next select **Cycle**, and you will be prompted to enter the number of cycles drawn. Ideally this should be the same for each waveform entered for a given patient. What follows is a tracing that will appear later on the cardiac monitor (Fig. 2-8). The cycled waveform will appear smaller and with some loss of resolution compared to the original data. However, the original data and resolution remains, and the waveform will be displayed accurately when the trainee runs a strip of the cardiac monitor display later. Select **Save** and when all waveforms are entered, **Done**.

Once all of the required waveforms for a given response are entered, you must adjust the waveforms to match the rate and pressure data you entered previously. To do this, select **Merge Data Above**. The merge routine can increase a drawn waveform's rate by about 300% or decrease the rate by 30% (Fig. 2-9). If you requested a rate that exceeds these limits, the program will inform you, and you

must redraw at a rate closer to desired.

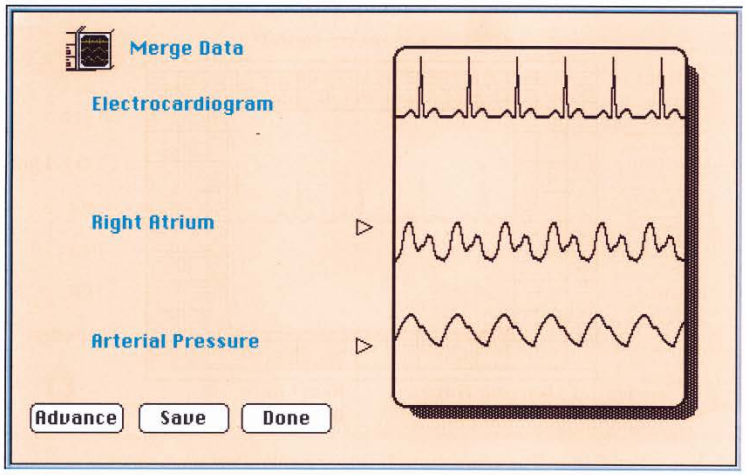


Fig. 2-9. This dialog appears automatically after selecting **Merge Data Above**. You may review the final adjusted waveforms by selecting **Advance**. Align each catheter tracing with the rhythm tracing by selecting the arrow controls above. If you are satisfied with the results, and all waveforms passed the merging process, then **Save** to the patient, and select **Done**.

Once you have entered the initial data, repeat the process above for each of the four management options.

You have begun the process of building a library of waveform data that may be used in this and other modules, as well as in other cases you author. In addition to the single waveform storage in the Waveform folder (Fig. 2-8, **Open** and **Save** controls), data contained in a case may be transferred en block. For example, you may wish for the initial data of another module to be identical to the data resulting from a treatment in the previous module. This is performed by first opening the module requiring data, and then selecting the menu item **Transfer Data** (Fig. 2-10).

You first select the module and response from which the data should come, and then select what data you want. By next selecting **Ready**, the data will be copied from one module to the next, or if desired, between responses in the same module. Data previously contained in the module will be replaced by the new data.

Once you have created five to ten modules, transferring data becomes very helpful. For example, a set of waveforms for cardiac tamponade could be utilized in a variety of case scenarios. Moreover, your first set of "normal" waveforms will probably be useful in almost every case you author!

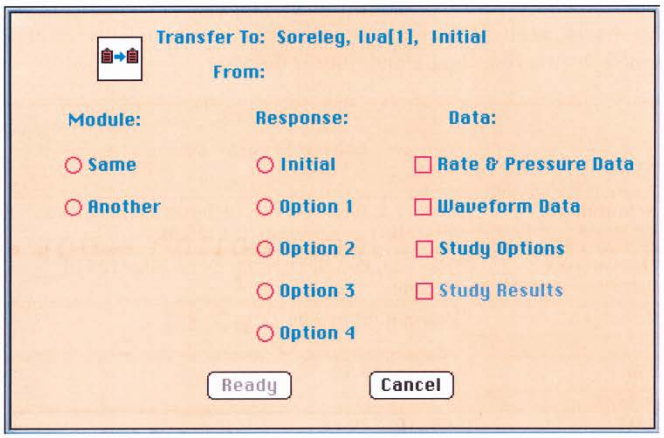


Fig. 2-10. In this example, data is being transferred to the module Soreleg, Iva[1], Option 1, from any module we choose. Note that any response or subset of data can be transferred en bloc to this module.

Entering Study Options & Results

The third step in authoring a case is entry of study options and results. Review the extended menu under **Enter Studies** (Fig. 2-11).

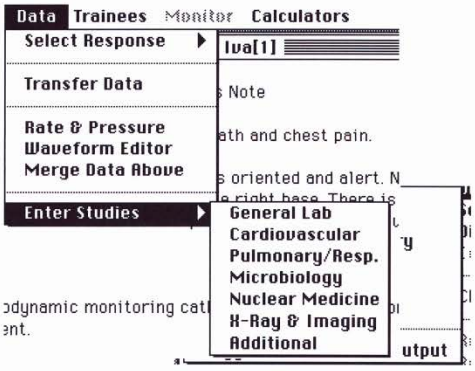


Fig. 2-11. Extended menu items for **Enter Studies**.

Select any of the areas of study shown, and a dialog for entry of both study options and results will appear (Fig. 2-12). As with the hemodynamic data, studies

are also entered for the initial presentation and for the consequence of each study option. Moreover, study data may be transferred en bloc between modules or within a module just like the hemodynamic data.

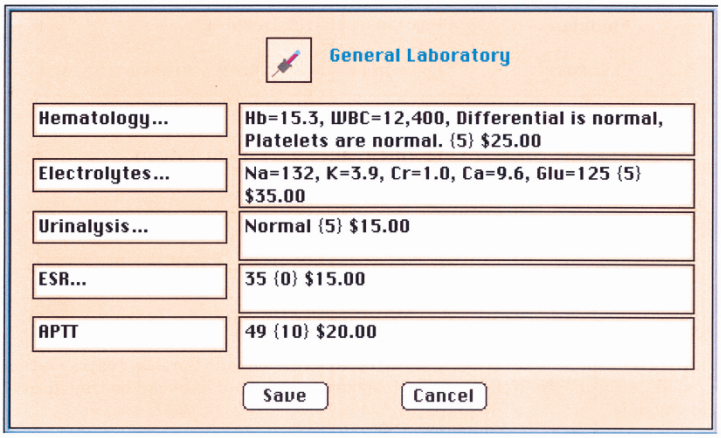


Fig. 2-12. First enter the studies desired on the left-hand side, then the results on the right-hand side. When the trainee is using the simulator, they will have an opportunity to check-off a lab and the results will be revealed. The {} indicate a point value, and the $ an amount the test or procedure costs. Although text will scroll, do not type in more text than can be shown in the visible rectangles above. Any additional text will be truncated when saved (this is true for all of the dialog displays in the program).

Trainee performance is monitored for both cognitive skills in patient management and procedural skills at catheterization. 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.

The author assigns a point value ({-100..100}) to each study and treatment, allowing evaluation based on utilization and quality of care. The author also assigns a dollar amount to each study and treatment ($n,nnn.nn), allowing determination of the total amount of money spent in rendering the care.

Determination of unnecessary or inappropriate studies or treatments is accomplished by automatically scanning an author's text for reserved words. An unnecessary order would be recognized if one of the following words was used: extra, illogical, immaterial, irrelevant, noncontributory, non-essential, superfluous, unimportant or unnecessary. An inappropriate order would be recognized if one of the following words was used: bad, contraindicated, dangerous, harmful, hazardous, ill-suited, ill-timed, improper, inadequate, inappropriate, incapable, incorrect, perilous, poor, precarious, refuses, risky, unable, unsafe, or wrong.

Entering Management Options

The fourth step in authoring a case is to enter from one to four management options. Under the **Author** menu select the item **Enter Management Options** (Fig. 2-13).

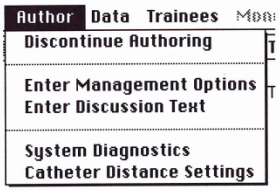


Fig. 2-13. **Author** menu items.

Type each of the management options in the designated boxes and **Save** (Fig. 2-14).

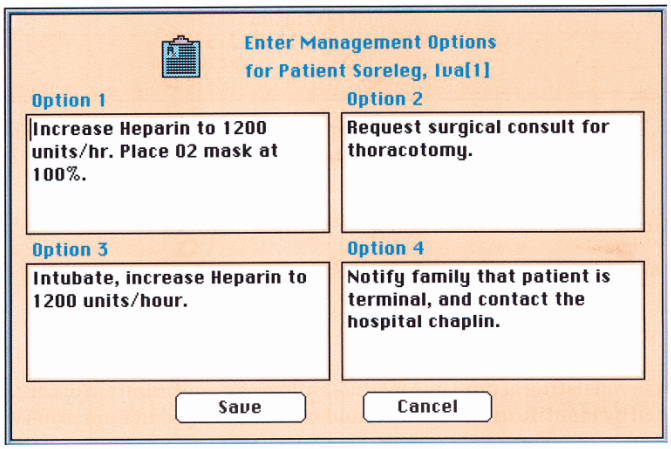


Fig. 2-14. Enter one to four management plans corresponding with the hemodynamic and study data already entered.

Entering Discussion Text

The fifth and last step in authoring a case is to enter discussion text. Under the **Author** menu, select the item **Enter Discussion Text**, type the discussion

corresponding to the management option entered earlier, and **Save** (Fig. 2-15). You should include reserved words (described earlier for use in study results), including points, cost, and synonyms for unnecessary and inappropriate management plans. You may also include a module identification number in brackets [1..99]. This indicates to the system which module to link automatically if the particular management option is selected.

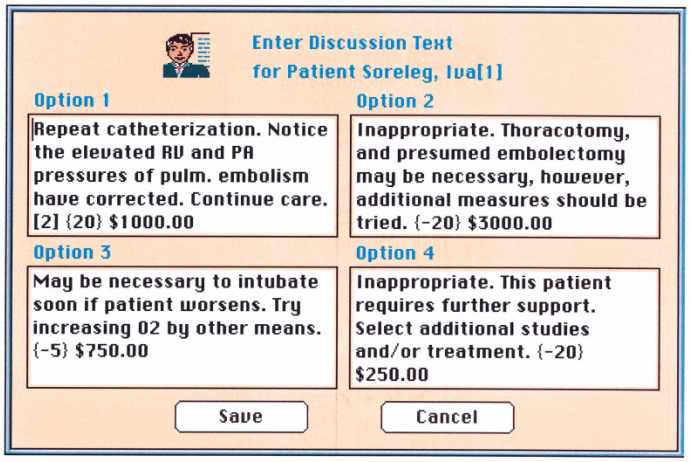


Fig. 2-15. Enter one to four discussions corresponding with the management options entered earlier. Notice that reserved words, including a pointer to another module may be included here.

That concludes the construction of a single module.

Cases with Multiple Modules

A case consisting of multiple modules allows for continuation of care. Modules are linked by identification number, and may be grouped in numerous ways (Fig. 2-16).

Final management of the patient is dependent on the sequence or pathway of modules presented. For example, in **C,** one possible pathway is: [First] - [5] - [3] - [5] - [2] - [4]. Each management problem may end in a variety of ways, depending on the scenarios created by the author and the action taken by the trainee.

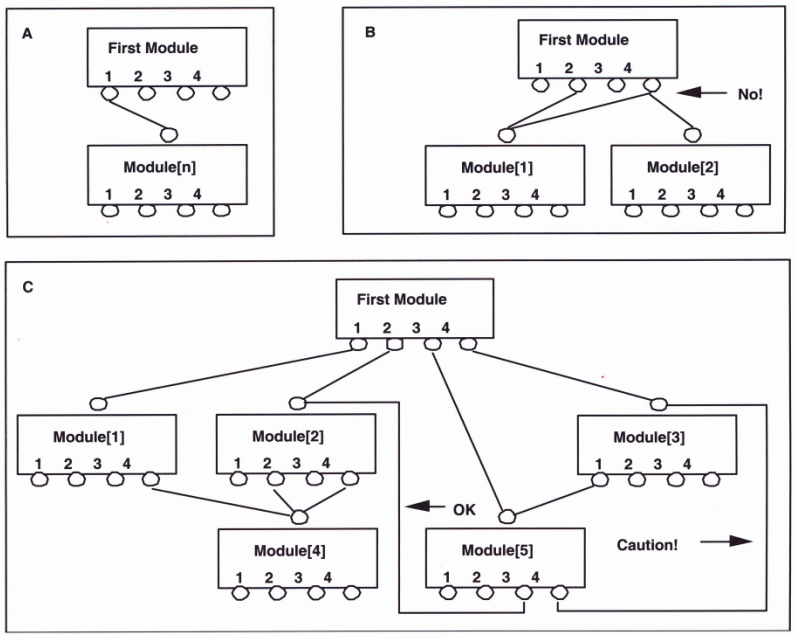


Fig 2-16. Multiple module cases. **A** - Schematic representation of a first module with four branch points, and one linked module. **B** - First module and two linked modules. It is not permissible to have a single management option link to two modules. **C** - Illustration of the multiple capabilities of the linking operation. Notice that it is possible for more than one module to branch to the same module, and that modules can link back to modules already presented. Be careful of recursive linking, so that the trainee does not become caught in an endless management loop.

Author Responsibility

Each author must be responsible for the validity of the curriculum developed. This is particularly important if the system is going to be used for testing or certification purposes. Because no standard of care is purported by the system, authors must give the same attention to detail and accuracy of cases as they would a lecture or publication.

Once a case has been created it should be observed in use to ensure its clarity, utility, and module-to-module consistency.

To enter waveform data, instructors must have either (1) a complete understanding of the hematologic consequences of the disease or therapeutic intervention, or (2) representative data (actual patient tracings) for direct entry into the case.

Before using the system, trainees should be oriented to the torso apparatus

and Macintosh computer, as well as instructed in the proper technique for insertion of a catheter. Once this orientation has been completed, they may work independently with the system and may check their own performance at any time.

Once created, cases may be modified at any time or deleted entirely. Moreover, they may be exchanged with other system users by simply copying and exchanging disk media.

System Diagnostics

When the machine is first installed, or if problems arise, selecting **System Diagnostics** under the **Author** menu can be of assistance (Fig. 2-17). This display allows you to test the optical encoder that senses catheter position, as well as the control panel on the torso apparatus. Notice that you can depress the switches on the apparatus, and the corresponding indicator on the computer display will flash on and off. The reverse is also true, selecting the display button will cause the apparatus indicator to flash on and off.

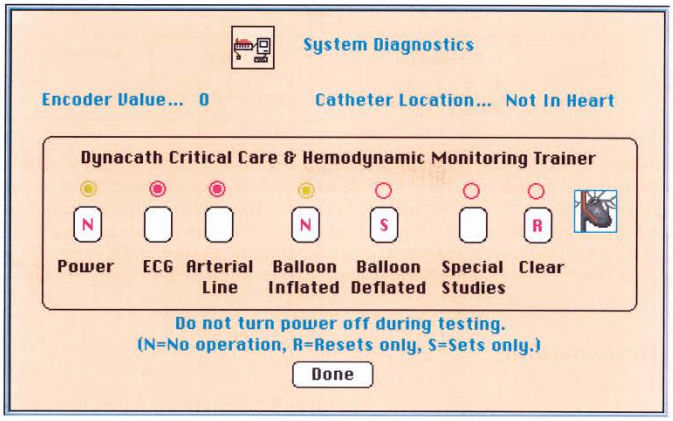


Fig. 2-17. Trainer Diagnostics display. Proper operation of the system can be determined by first selecting the buttons above, and confirming that the corresponding indicator on the control panel flashes on and off. N = no operation, S = sets the indicator only, and R = resets the indicator only. The next step is to press the switch on the control panel, and confirm that the simulated indicators above flash on and off. Finally, the catheter should be advanced into the torso apparatus, and the **Encoder Value** should be observed to rise uniformly. The encoder can be reset by selecting the heart icon on the right-hand side of the display. Notice that the **Catheter Location** will change when the encoder value matches the catheter distance setting (see below).

Changing Catheter Distance Settings

Select **Change Distance Settings** under the **Author** menu (Fig. 2-18). Based on personal preferences or known anatomical differences for the patient group you wish to simulate, you may wish to alter the distances to various anatomical locations within the heart. The values shown initially are the default values.

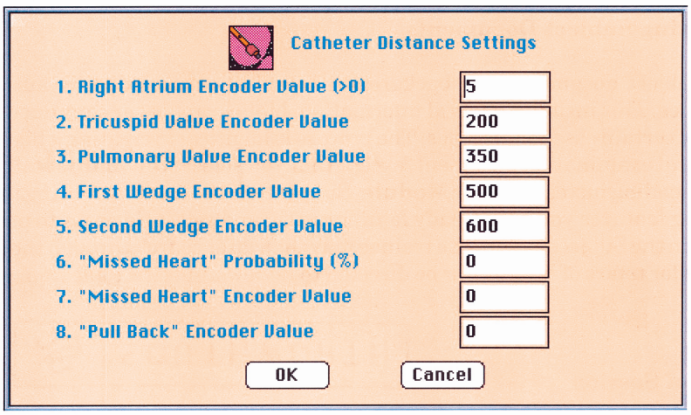


Fig. 2-18. Entry of catheter distance settings and probability of "missing" the heart during placement of the catheter.

Customizing the distance settings is a two-part process. You must first use the **System Diagnostics** display to determine encoder values that correspond with distances the catheter has been advanced. Start by advancing the catheter until the encoder value begins to increase. This occurs as soon as the catheter encounters the internal optical encoder. The distance you have advanced the catheter is the minimum distance (encoder value = 1) that you may assign to the right atrium (or superior vena cava) This distance is determined by the physical limitations imposed by the torso apparatus internal guide-way. Advance the catheter to your pre-selected distances and record the encoder value. Next enter and save these values in the **Catheter Distance Settings** dialog.

You may optionally select a percentage of time that the catheter does not enter the heart (ie. crosses the chest, goes into the neck or down the inferior vena cava). If this is anything but zero, you must select a distance (encoder value) at which the system will make this decision, and another value that the system expects the catheter to be pulled back to before allowing it to be re-advanced properly. From the trainee's perspective, they must recognize that the heart has been missed, pull the catheter back, and advance again.

Two wedge positions are specified in order to allow you to reach a wedge position without inflating the balloon. The first wedge position is for when the balloon is inflated, the second is for when the balloon is deflated. By having both values specified, you may observe the pressure change from wedge to pulmonary

artery by simply deflating the balloon once wedge is obtained. The converse is also true, inflating the balloon will change the pressure from pulmonary artery to wedge, so long as the tip of the catheter is at a distance between the two numbers entered above. This adds to the realism of the procedure.

Creating Subject Documents

Subject documents are background information provided by authors for trainees. This includes general information, bibliographies or continued discussion of certain cases or diseases. The process is identical to creating a history and physical examination document, except that you select **New Subject** under the **File** heading instead of **New Module**. Simply type the document using the same editing features you are already familiar with, and select **Save As** to name and store in the Subject folder. The trainee may then later search through the Subject folder for topics of interest, or be directed to review a specific topic from within a case.

End of Session

To complete your authoring session with the simulator, select **Discontinue Authoring** under the **Author** menu. You may end your session with the simulator by selecting **Quit** under the **File** menu. Be sure to turn off the power to all equipment before disconnecting cables.

Trainee Operation 3

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.

Reviewing the History & Physical Examination

The simulation begins by selecting the **Open Chart** item under the **File** menu heading (Fig. 3-1), 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.

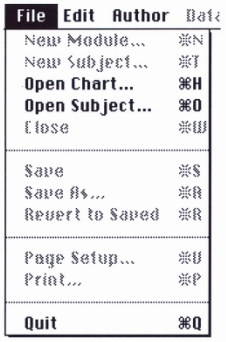


Fig. 3-1. **File** menu items.

Ordering Studies

Once the chart has been reviewed, you may select any of the bold-type items listed under the **Trainee** menu (Fig. 3-2). 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.

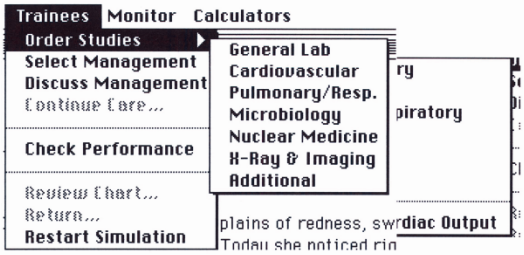


Fig. 3-2. **Trainees** menu items, and the extended **Order Studies** menu items. The **Oxygen Sat. & Cardiac Output** display may also be called directly from the torso apparatus console by pressing the **Special Studies** button when the cardiac monitor is being displayed. When done ordering studies, 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. 3-3).

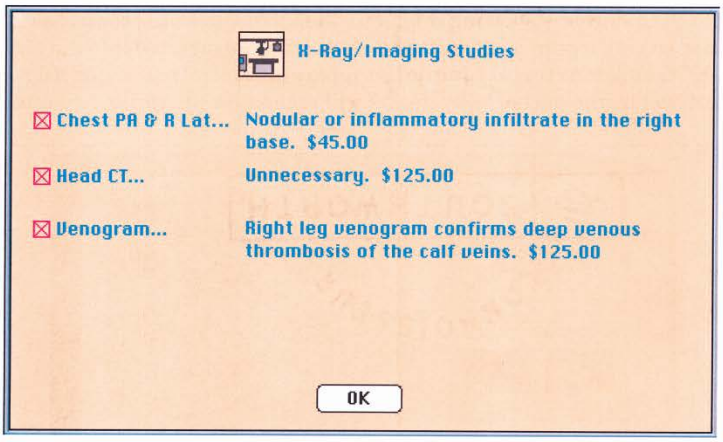


Fig. 3-3. A study is ordered by checking the box on the left-hand side of the display, and the result is displayed on the right-hand side. The system keeps score on the studies ordered, determines unnecesssary or inappropriate orders and tabulates cost of care.

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. 3-4).

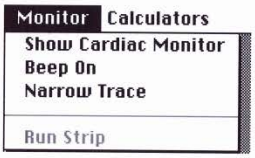


Fig. 3-4. The **Monitor** menu.

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. 3-5), 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.

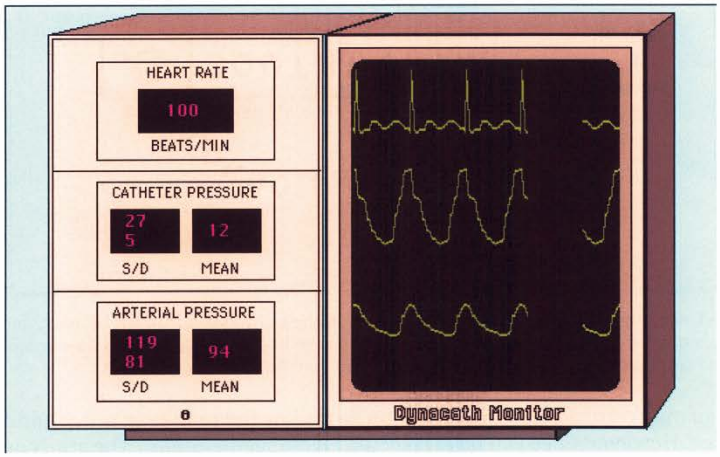


Fig. 3.5. Simulated cardiac monitor.

Most pulmonary artery catheters (ie. Swan-Ganz® catheter) will work with the torso apparatus. (Please review the section **Catheters** in chapter 1 for the correct use of a catheter 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 torso 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.

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.

Running a Strip

When the cardiac monitor is showing, it possible to run a strip of the present ECG and pressure tracing (Fig 3-6). It is necessary to do this if accurate determination of systolic, diastolic and mean pressure data is to be obtained. Moreover, proper timing of pressure data with the ECG is necessary for identification of the components of the pressure waveform (a, c, x descent, v, y descent).

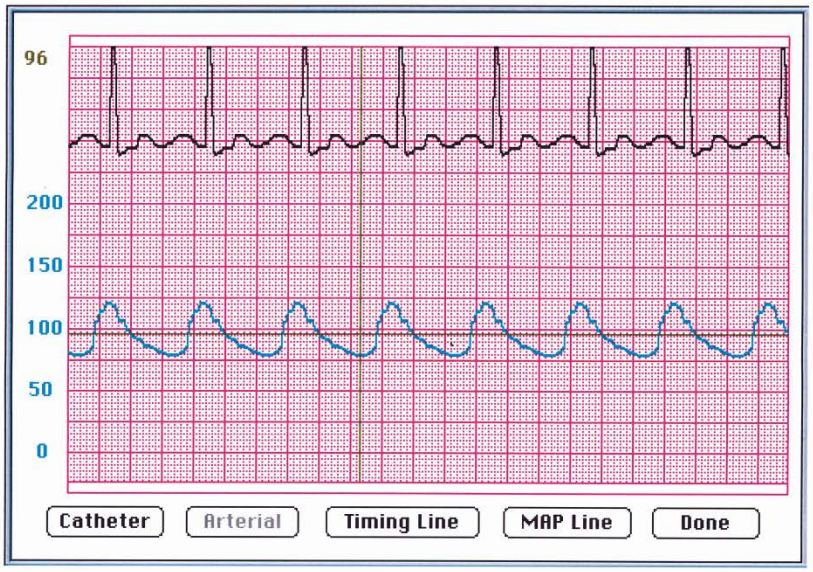


Fig. 3.6. Run strip feature. Both the ECG and selected pressure (including artrial line) may be displayed, and a timing line inserted for accurate interpretation of the waveform components. The CVP (above), PAM, PAW and MAP should be individually identified, and the information is automatically transferred to the Cardiac Indices calculator.

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. 3-7). 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.

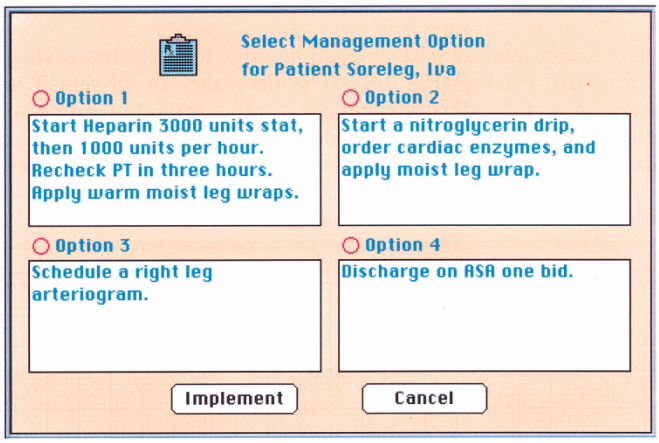


Fig. 3-7. One of four management plans may be selected at a time. After selecting the round button above an option, select **Implement**.

Discussion

After selecting a management plan, you should select **Discuss Management** under the Trainees menu, and receive immediate feedback about your management choice (Fig. 3-8). 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 managment plan you chose. You

are now presented with new study options and results, as well as new management alternatives.

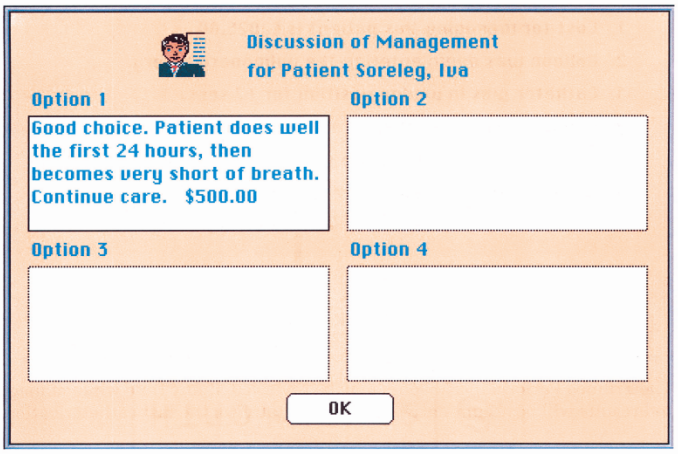


Fig. 3-8. Discussion, or immediate feedback is presented for each management plan.

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. 3-9). 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.

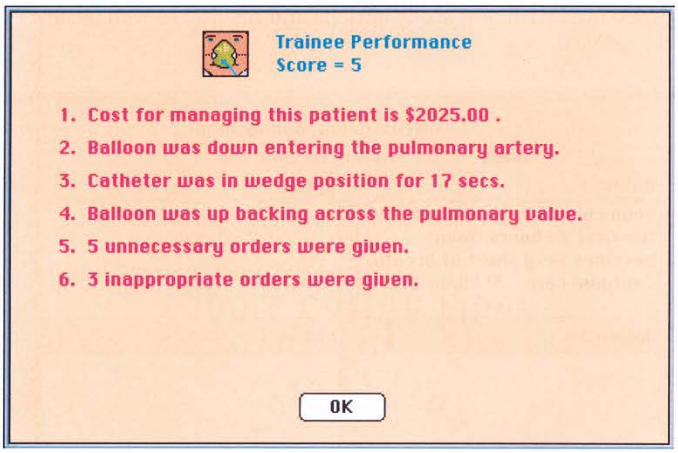


Fig. 3-9. The Trainee Performance display may be reviewed at any time while managing a patient, and results will be accumulative, or representative of the last catheterization performed.

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 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. 3-10).

End of Session

If you wish to leave the present case, select **Hide Cardiac Monitor** under the **Monitor** menu if the monitor is showing, then select **Close** under the **File** menu.

To complete your session with the simulator, exit the program by selecting **Quit** under the **File** menu. Be sure to turn the power off to all equipment before disconnecting cables.

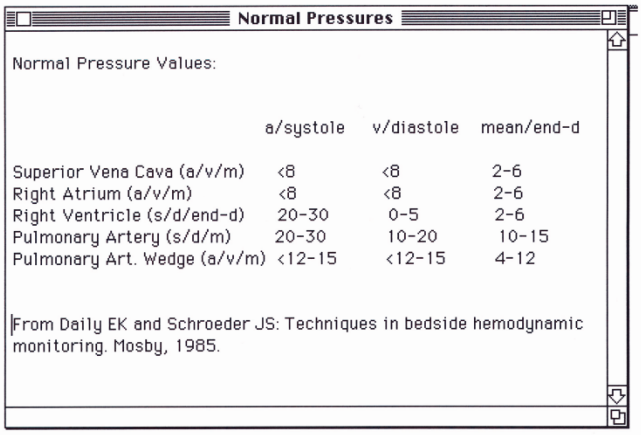


Fig. 3.10. Example subject document.

Calculator Operation 4

Overview

There are four calculators available for determining essential indices of cardiopulmonary and renal function. One of these, the Cardiac Indices Calculator, is dynamically linked to the cardiac monitor "run strip" display, allowing a trainee to identify the correct pressure, and have the information automatically placed in the calculator for determination of indices.

Selection

Under the **Calculator** menu heading select the specific calculator desired (Fig 4-1)

Fig. 4-1. **Calculator** menu items.

Cardiac Indices Calculator

The Cardiac Indices Calculator takes as input the patient's cardiac output, heart rate, mean arterial pressure, central venous pressure, pulmonary artery mean pressure, pulmonary artery wedge pressure, weight and height (Fig. 4-2).

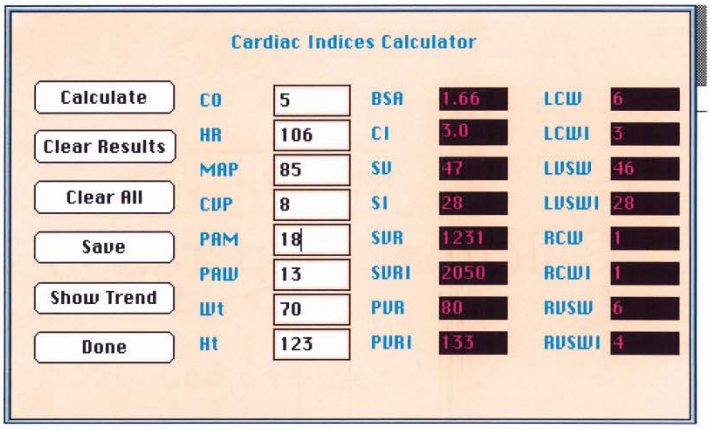


Fig. 4-2. Cardiac Indices Calculator.

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

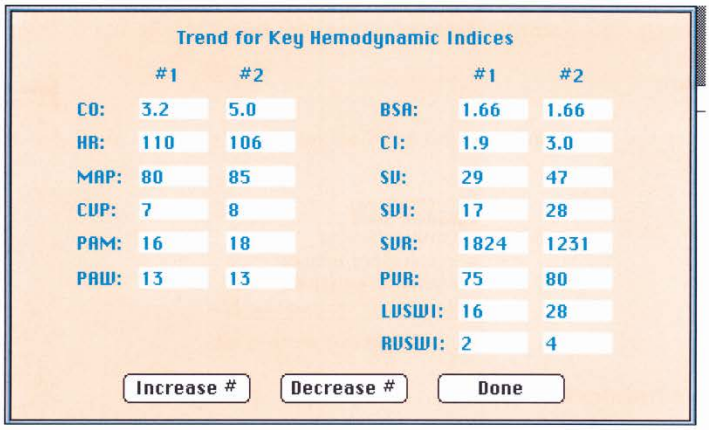


Fig. 4-3. Trend for Key Hemodynamic Indices display. Up to five sets of data may be saved and shown here for comparison.

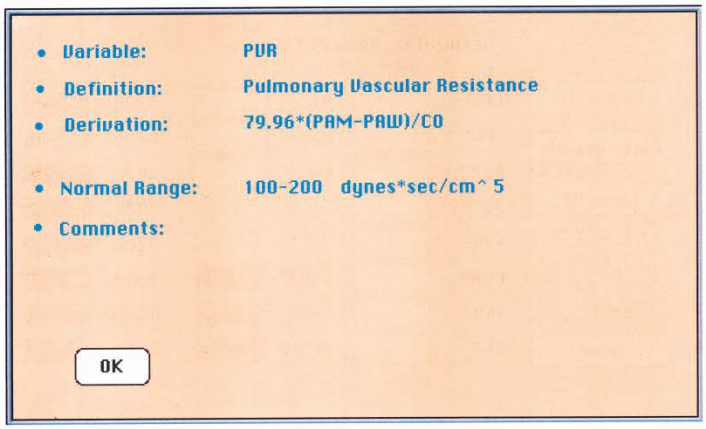


Fig. 4-4. Example of the expanded definition display for pulmonary vascular resistance. The comment area is available for authors to convey additional information to trainees. Entry of text in the comment area is possible after entry of a proper access code under the **Author** menu heading.

Trend for Key Hemodynamic Indices

Selecting **Save** in the Cardiac Indices Calculator will store several indices for trend comparison (Fig. 4-3). Up to five sets of data may be stored. Selecting **Clear All** will clear not only the calculator, but also the trend data. Moreover, selecting a new patient chart will clear the trend memory.

Expanded Definition Display

Selecting any input or output title on a calculator will bring up a display (Fig. 4-4) showing the definition, derivation and if previously authored, normal range and comments. (The latter areas may be authored after an appropriate access code has been entered under the **Author** menu.)

Respiratory Indices Calculator

The Respiratory Indices 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. 4-5).

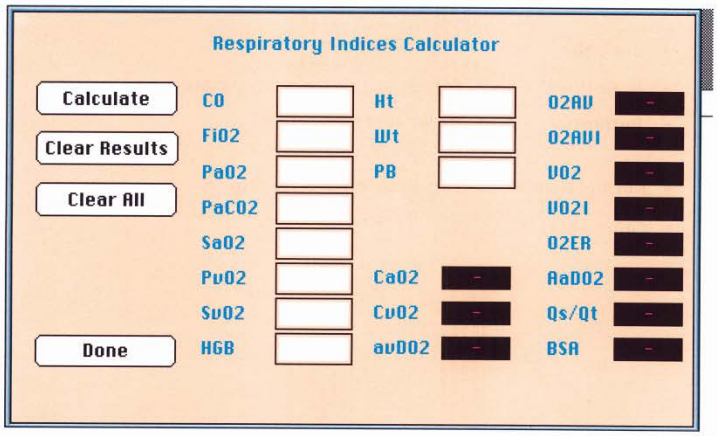


Fig. 4-5. Respiratory Indices Calculator.

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 Indices Calculator

The Ventilatory Indices 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. 4-6).

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. 4-7).

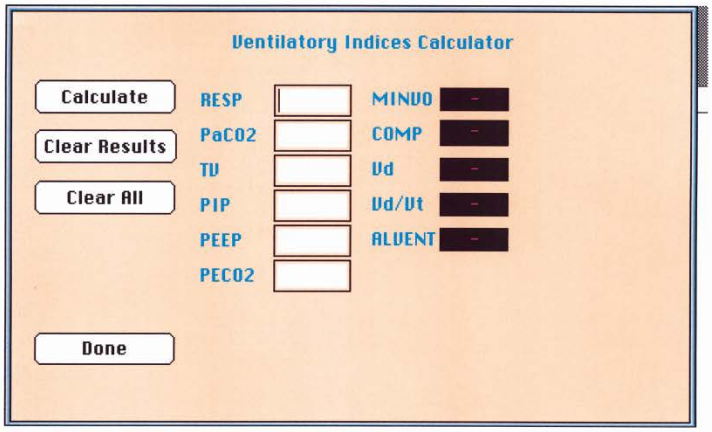


Fig. 4-6. Ventilatory Indices Calculator.

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.

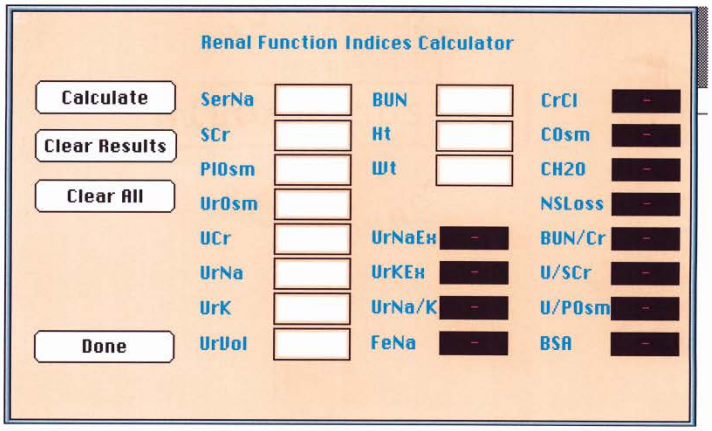


Fig. 4-7. Renal Function Indices Calculator.

Entering Waveforms 5

Overview

Use actual patient strip chart recordings for creating cases. After a little practice, a set of waveforms may be entered in just minutes, yielding realistic displays on both the cardiac monitor and the computer generated strip. Waveform components, such as the *a* wave, *c* wave, *x* descent, *v* wave and *y* descent can be reproduced, and baseline variation from respiration - both spontaneous and mechanical ventilation - can be easily incorporated.

Essential to this process is obtaining complete waveform sets from actual patients undergoing placement of a pulmonary artery catheter. Cardiologists, intensivists and anesthesiologists at your institution should be alerted to your desire for complete strips (ECG, CVP, RV, PA, PAW, arterial line, & airway pressure) from interesting patients. The patient's chart number should be recorded so that you can go back to determine absolute pressure values (strips never seem to come with scales or values written on them!) Going back to the chart to extract clinical history and data such as laboratory results and cardiac output can be helpful when making your case scenario. Remember to maintain patient confidentiality when using any part of a patient's record.

Your job is to identify the segment of each strip that should be traced on the digitizing tablet and to become proficient with using the tablet and software tools.

There is a certain amount of practice necessary before you will be satisfied with the results. This chapter reviews the technique for entering waveforms, and provides suggestions for improving the quality of your cases.

Call Dynacath if you are having trouble entering waveforms. Poorly entered waveforms do not hold up to careful examination by trainees when they run a strip off the cardiac monitor!

Selecting Waveform Data for Entry

Hopefully at this juncture you are looking at a set of waveforms - possibly a two channel output, with ECG on top, and pressure strip below. You may be fortunate enough to have an eight channel display with several pressures already aligned for accurate timing.

The Waveform Editor allows up to a three second "wave bite" to be entered, which should be adequate for most needs.

Select a common reference point, such as the start of the QRS complex on the ECG, and using a vertical ruler, draw little "start" tic marks though each of the waveforms. Count over an integral number of cardiac cycles less than three seconds total, and make "stop" tic marks though each of the waveforms. Use a pencil for this in the event you change your mind.

Note the absolute maximum and minimum pressure values contained in the isolated segments, as well as the number of complete cardiac cycles. This data entered in the Rate & Pressure display.

Common mistakes are using to few cycles, not having a consistent start and stop point, incorrectly reading the original pressure values (a common problem when using a tracing from a publication), and not having a common start and stop baseline.

A common start and stop baseline makes the waveform look more realistic when cycling on the cardiac monitor. When you select segments for entry, try to include the respiratory variation within the segment, so that you start and stop at the same baseline. Some manual adjustment of the baseline may be necessary near the end of the segment when it is entered.

Resolution & Rastering

A Macintosh screen displays information with a resolution of 72 pixels per inch, far less resolution than an actual analog strip obtained from a patient. For comparison, the type font you are reading is 300 pixels per inch. The result is an effect called rastering - a stairway like appearance to lines and curves seen on the computer.

The Dynacath software was originally designed for a nine inch computer display, which limited the size of the cardiac monitor, and of course the waveforms it displayed. Moreover, the original Macintosh computers were in black & white only.

When waveforms are entered presently, they are scaled down a bit to create a realistic display in the cardiac monitor. This adds to the previously described

problem of limited resolution, resulting in some degredation of the waveform appearance. This is particularly noticeable when entering rhythm strips, with the sharp up and down lines of the QRS complex being most vulnerable.

The good news is that when a trainee runs a strip of the cardiac monitor display, no down-scaling occurs, and an accurate reproduction is achieved. Later versions of the software will offer a larger format monitor so that this problem is eliminated entirely. The cardiac monitor display is suitable for waveform identification as a catheter is passed, and gross reading of pressure data. Running a strip allows for detailed analysis. This is not unlike the real world, and has not been a pressing concern in the simulation. Cardiac monitors should not be relied upon for accurate reading of mean pressure data, even though this is commonly done.

Digitizing Waveforms

The digitizing tablet and cross-hair cursor are essential and allow accurate conversion of the analog waveform data into digital data that can be used and displayed by the computer.

Kurta Tablet

The Kurta ADB tablet connects to the computer by daisy chaining with the keyboard and mouse. Turn the computer off, and disconnect the cable that is presently plugged into the keyboard (disconnect at the keyboard end only). Connect this to the tablet port labeled "interface". Next take the short cable provided with the tablet and plug one end into the other port labeled "interface". Plug the other end into the keyboard. The mouse connects to the other side of the keyboard.

Penworks

The next step is to install the Penworks software that comes with the Kurta Tablet. Follow the directions in chapter one of the Kurta Penworks Driver manual and install the Penworks ADB driver (not the serial driver). Confirm that the cursor moves smoothly across the screen as you move the cross-hair cursor on the tablet. (It sometimes helps to moisten your fingers and grip the cordless cursor firmly on its edges. This helps transmit the cursor location data to the tablet.)

Scaling

It is necessary to match the scale on your strip chart paper with that of the

computer display. You may wish to use a photocopy machine first and enlarge the tracing. This is helpful for tracings with low amplitude or narrow complexes.

Install the Penworks software as described previously. It is important to restart the computer after the intial Penworks installation. Be sure the Kurta tablet is connected before you restart the computer. Next follow these steps:

Step 1: Run the Dynacath program, enter the author mode, open a module, and select **Waveform Editor** under the **Data** menu.

Step 2: Prepare your tracing by outlining a three-second section of grid (15 by 10 large boxes). Slide your tracing and center under the plastic cover of the Kurta tablet (be sure the grid is square with the tablet). You may wish to use a fine marker pen and draw an outline (or corner dots) of the grid section on the plastic cover (then future tracings can be aligned rapidly).

Step 3: Slide the tablet cursor up to the menu bar at the top of the tablet and briskly click twice (using the top-most button on the cursor) on the **SET** item.

Step 4: Position the tablet cursor over the top left-hand corner of your strip and click once. Then position the tablet cursor over the bottom right-hand corner of your strip and click once again.

Step 5: Move the tablet cursor up to the menu bar and briskly click twice on the **WIN** item.

Step 6: Looking at the computer screen, move the tablet cursor so that the computer cursor is over the upper left-hand corner of the computer generated strip, and click once. Next move the tablet cursor so that the computer cursor is over the lower right-hand corner of the computer strip, and click again.

This completes the scaling process. Confirm this by moving the tablet cursor and noting that the computer cursor remains confined to the computer strip display. You may now proceed with entering your tracings.

If you turn the computer off, the next time you display the **Waveform Editor**, simple move the tablet cursor up to the menu and click once on **SET**, and then once on **WIN**. This reestablishes the scaling you already entered.

Drawing a Waveform

You will not need to use the tablet again until you are ready to enter waveforms with the **Waveform Editor** display (Fig. 5-1).

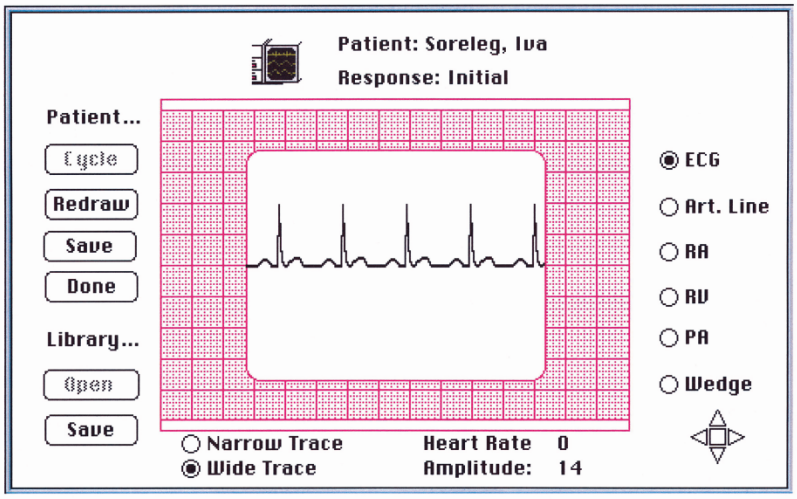


Fig 5.1. Waveform Editor. See Chapter 2: Author Operation for a complete discussion of entering hemodynamic data.

In a new case the default waveforms will all be flatline. Select the **ECG** button on the right-hand side of the display to observe this. Select **Redraw,** and move the arrow (using the tablet cursor) over the drawing grid. Note that the arrow turns into a cross-hair.

Take the actual strip you want to trace and lay it on the tablet under the plastic cover. Align the strip so that your starting tic mark is just inside the grid you drew earlier on the plastic cover. Move the tablet cursor over your starting tic mark, and confirm that the computer cross-hair cursor is showing. You may need to reposition the strip under the plastic cover slightly. The strip should be square with the tablet and held firmly in place by the plastic cover before you begin tracing.

Hold down the top button on the cursor and begin tracing. It does not matter if you hold the cursor at an angle - only that you keep the cursor over the tracing. Glide the cursor over the strip until you reach your end tic mark. At this point release the button and inspect the result. Select **Redraw** if necessary, otherwise proceed with selecting **Cycle** as described in Chapter 2: Author Operation.

You can improve the appearance of your drawings a few ways. Most problems occur with ECGs. The wider the QRS complex on the original strip the better it can be digitized. Drawing occurs only when the cursor is moving forward. This means you can slide the cursor backwards, move up the grid slightly, then forward again, resulting in a sharper vertical segment. Another tip is to draw ECGs by following the left-hand side of the tracing when going up or down vertical segments, and

on the right-hand side when returning towards the baseline. Anotherwords, taking advantage of the fact that the cross-hair cursor will allow you to follow either side of the normal width of an actual tracing. Sometimes making a little rounding motion with your hand at sharp peeks will help the appearance.

Enlarging a tracing first (and rescaling) is helpful for tracings with low amplitude and narrow complexes.

Pressure tracings are usually entered without problem. It is important to keep the same start and stop baseline. This can be manually controlled by altering your "course" slightly while tracing. It helps to pencil-in this first on your strip before starting.

Chapter 2: Author Operation covers the remaining procedure for entry of waveforms, including cycling and merging with rate and pressure data.

Library

The library feature on the Waveform Editor display is for storing a single waveform at a time. This is helpful for temporarily saving an existing waveform while entering and evaluating alternative waveforms. It is also useful for moving a wavefrom from one location to another (ie. RA to RV) in the event that you originally drew the waveform in the wrong location. To remove a waveform after entry you must either enter a new one or open the Waveform Folder with the library controls, and select a previously saved flatline.

The "true" library is your group of cases and the complete set of waveforms contained in each case. This data can be moved about between modules en bloc as described in Chapter 2 rather than via the Waveform Editor.

Airway Pressure 6

Overview

It is possible at the time of creating a new case to swap-out the arterial line channel for an airway pressure channel on the cardiac monitor. This may be useful in those cases you author that require accurate timing of end-expiration for analyzing hemodynamic pressure, or for demonstrating alterations in the waveform under certain clinical settings such as airway disease and mode of respiration - ie. spontaneous vs. mechanical ventilation. This chapter reviews the method of entering and displaying airway pressure information, and some of the present limitations. With few exceptions the method is identical to that of handling arterial line pressure data.

Selecting an Airway Pressure Channel

After typing an initial history & physical or progress note (Chapter 2: Author Operation), it is necessary to select **Save** under the **File** menu to complete the operation of authoring a module. When the file is saved, space is also reserved for entry of module specific data, including studies, hemodynamic data, management options and discussion text. Figure 6-1 shows the prompting that occurs after selecting **Save** or **Save As**.

Ordinarily the arterial line is selected as the third channel on the cardiac monitor display. If you want instead an airway channel, indicate such at this juncture. From this point on all further references to arterial pressure have been

removed, and airway pressure substituted. The Rate & Pressure display, Waveform Editor, Merging display, Cardiac Monitor and Run Strip display will all refer to airway pressure rather than arterial pressure.

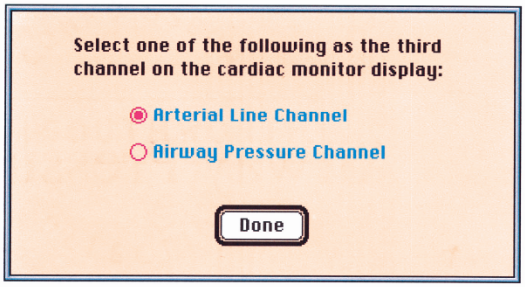


Fig. 6-1. If you wish to include an airway pressure channel, select the appropriate option and then select **Done**.

Entering Airway Pressure Data

You may enter from one to three cycles, corresponding to a respiratory rate of from 20 to 60 breaths per minute. This lower limit results from the maximum three second "wave bite" sampling that the Waveform Editor allows. You may manually decrease the rate further by using the arrow controls in the lower right-hand corner of the Waveform Editor, and then selecting **Save**. If your actual patient strip contains a respiratory rate less than 20, you will need to redraw the strip by hand at a rate of 20, enter normally, then adjust lower with the arrow controls.

The merge routine will not alter the airway pressure rate as it does other pressures. The reason for this is that the cardiac rate and respiratory rate are not necessarily syncronized, and alteration in cardiac rate does not imply a given respiratory rate.

When using airway pressure data, it is best to have actual patient information, and to maintain that information throughout the merging process. If you arbitrarily change the cardiac rate using the Rate and Pressure display, you must independently use the Waveform Editor to change the airway pressure rate. The Rate and Pressure display is used however to enter and change the airway pressure (maximum and minimum).

Although it is not possible to simultaneously display the arterial pressure and airway pressure, in a single case consisting of multiple modules it is possible for some modules to contain the arterial line channel while others have an airway

channel.

Trainee Operation

The trainee does not need to do anything different in running a case. When the appropriate case is opened, the airway channel is automatically inserted into the cardiac monitor, and an airway pressure tracing will be displayed if a strip is run.

Author Workbook 7

Overview

The following pages may be copied and used to assist in authoring a case module. The title page can be very helpful in keeping a record of module linking.

The fill-in sheets follow the outline of Table 2-1, and contain actual screen displays from the program.

It is a good idea to author several single module problems before undertaking authoring of a multiple module case.

Make use of the resources available to you for obtaining data, such as your critical care unit or catheterization laboratory. There is no substitute for actual patient data when making an informative case. Remember that there is no single representative patient (or set of waveforms!) to describe a given disease, and you are encouraged to author several cases in each subject area.

Designating one or more members of your instructional team to work with the system is impairative if you are going to develop and maintain an excellent curriculum. Encourage former trainees to try their hand at authoring a case. The mental process of taking a complicated management problem and reducing it to a set of instructive modules is a tremendous learning experience itself. Consideration for proper and improper treatments, as well as unexpected outcomes can challenge even the best instructor.

Case Module
for the
Dynacath Critical Care Patient
Simulator

Patient _____ [ ]

Author _____

Date _____

Arrived at this module from:							
[ID]							
Response							

This module branches to:				
Response	1	2	3	4
[ID]				

Date	Revision History

Page: _____

I. ☐ **History & Physical**
☐ **Progress Note**
☐ **Consultation**

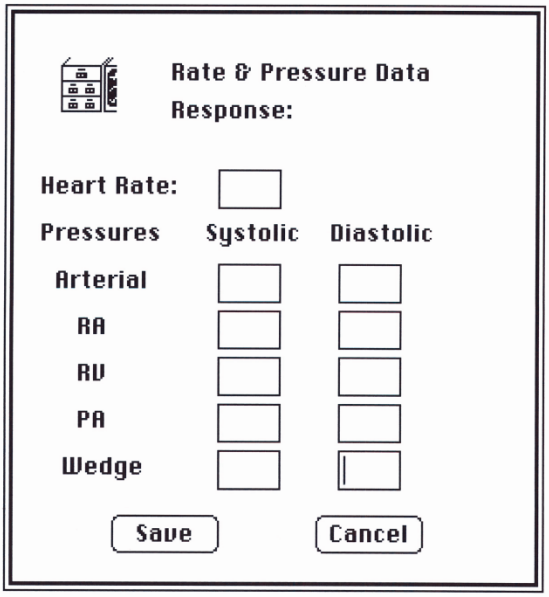
Page: _____

IIA. Hemodynamic Data

(This page should be duplicated five times.)

☐ Transfer Rate & Pressure data from: _____ [ ] Response: _____

☐ Initial ☐ Option 1 ☐ Option 2 ☐ Option 3 ☐ Option 4



Page: _____

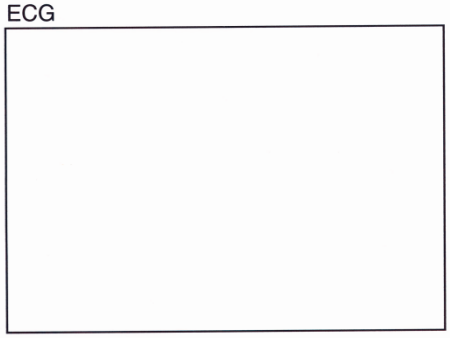
IIB. Hemodynamic Data

(This page should be duplicated five times.)

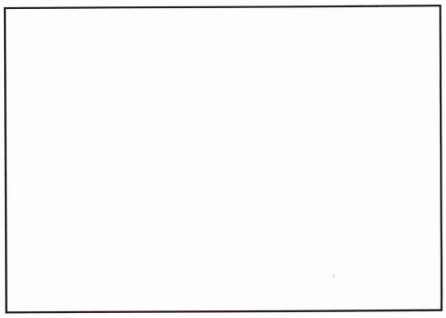
☐ Transfer waveform data from: _____ [ ] Response: _____

☐ Initial ☐ Option 1 ☐ Option 2 ☐ Option 3 ☐ Option 4

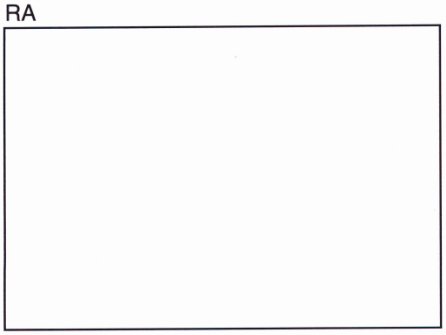
ECG



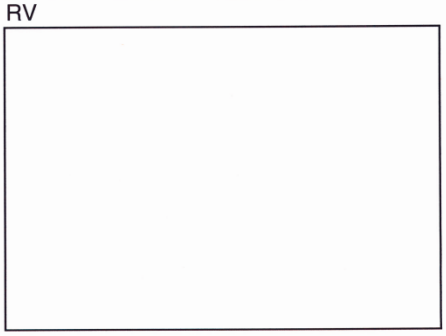
Arterial Line



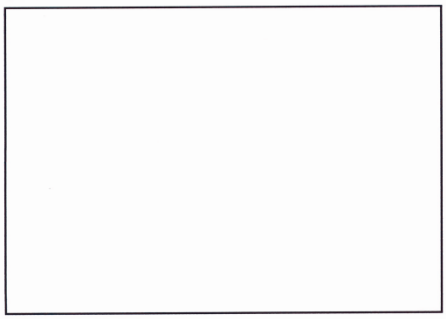
RA



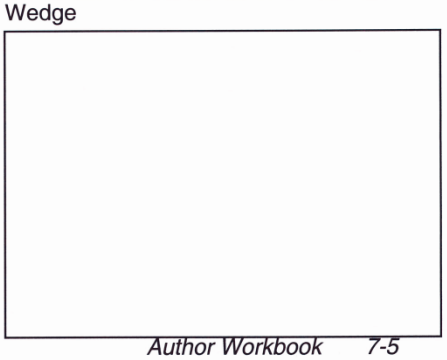
RV



PA



Wedge



Page: _____

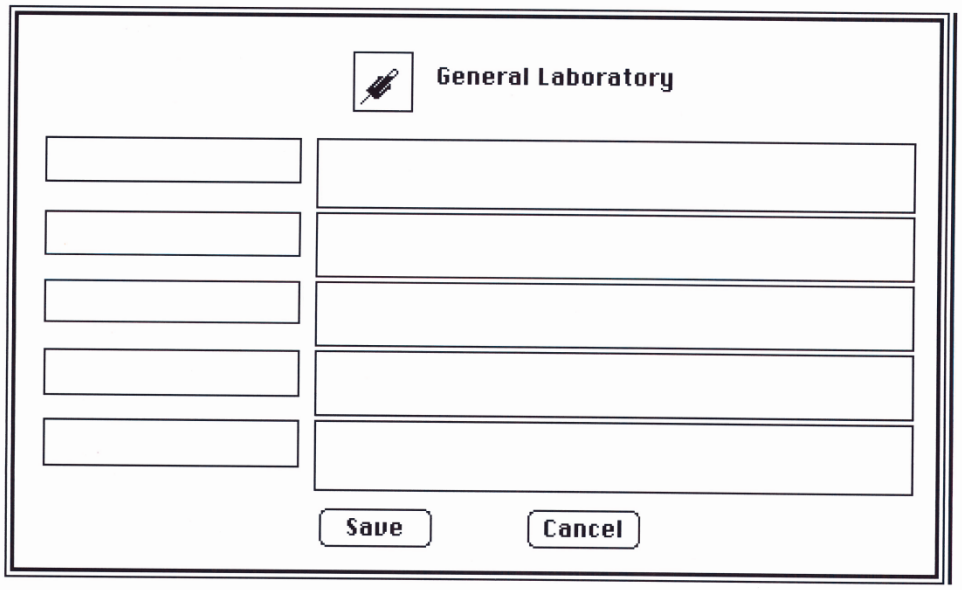
III. Study Options & Results

(This section should be duplicated five times.)

☐ Transfer study options from: _____ [ ] Response: _____

☐ Transfer study results from: _____ [ ] Response: _____

☐ Initial ☐ Option 1 ☐ Option 2 ☐ Option 3 ☐ Option 4



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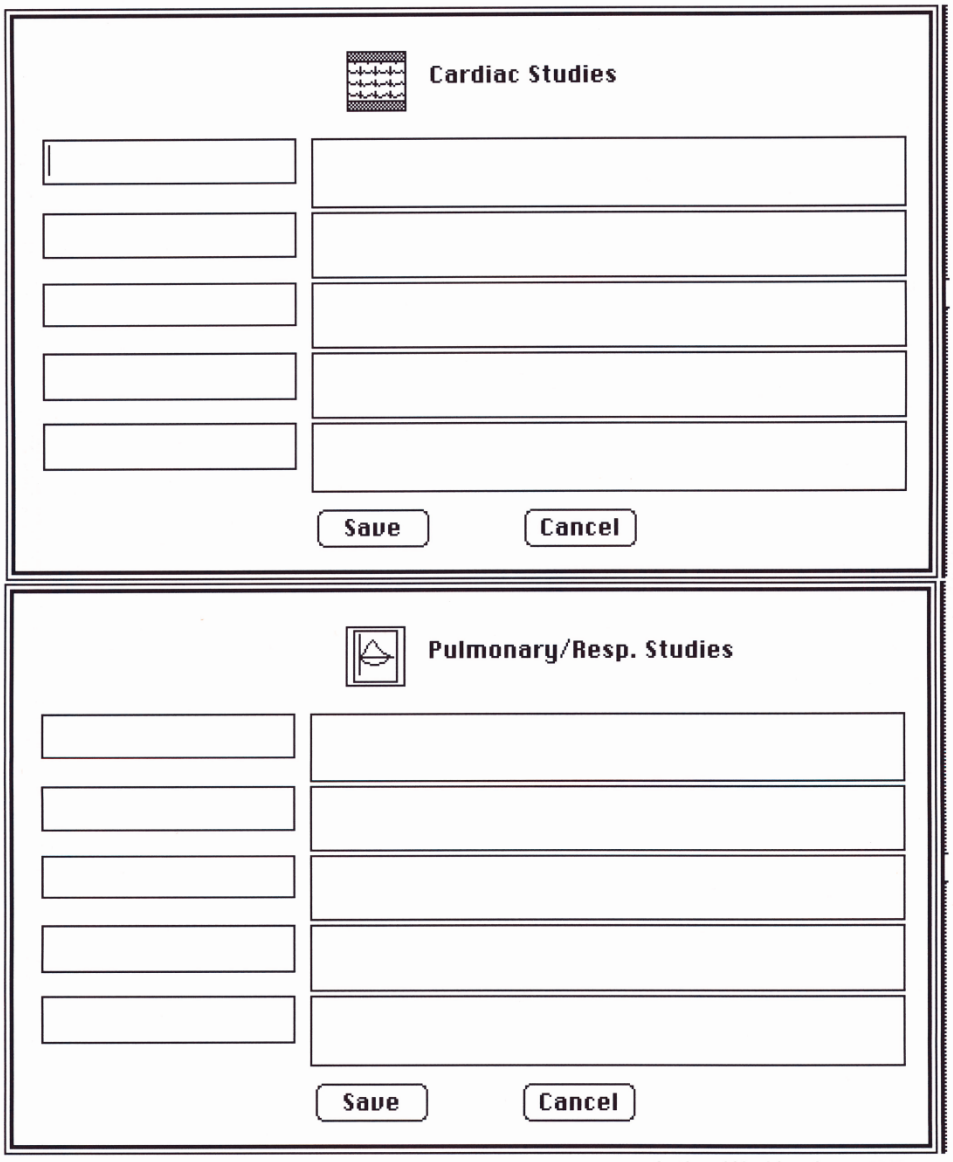
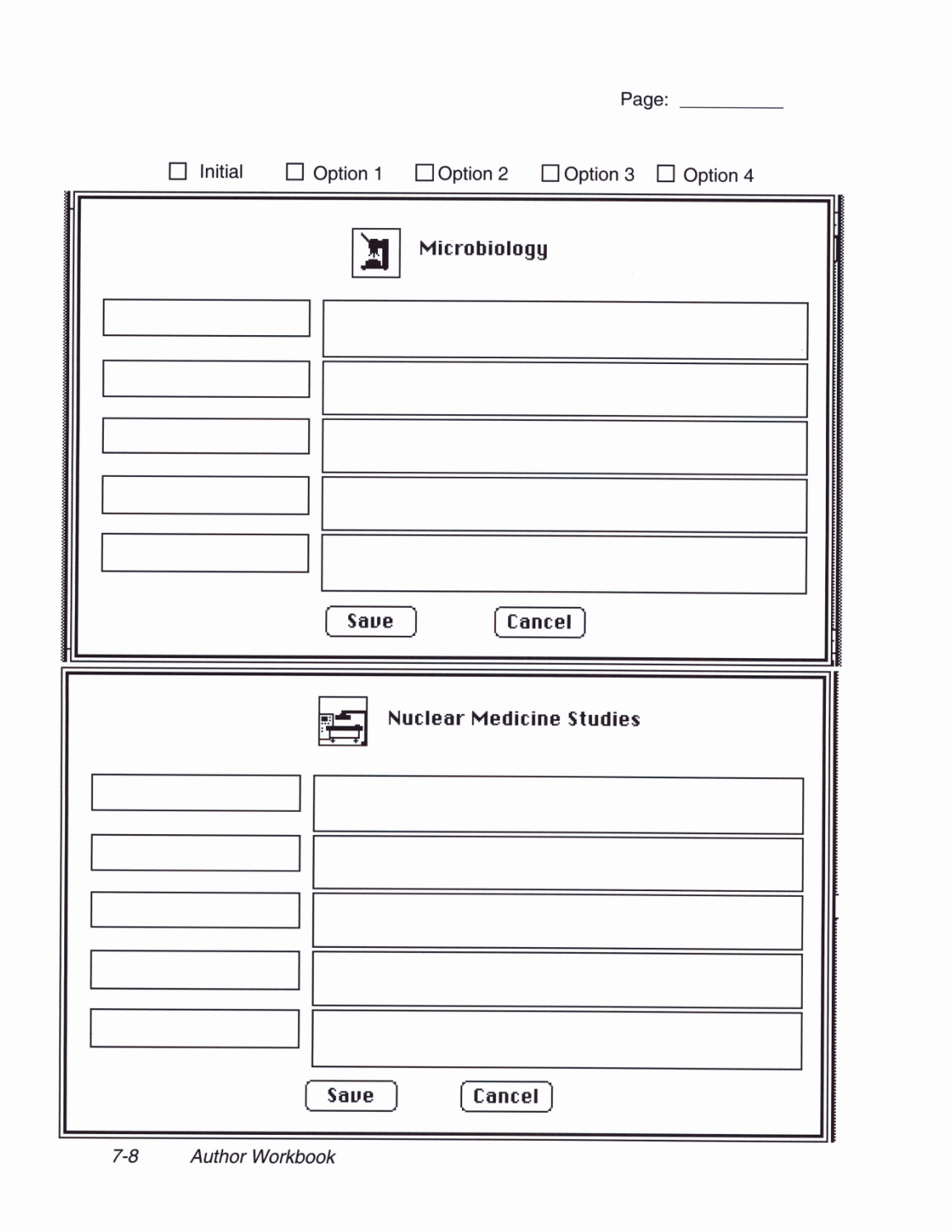
☐ Initial ☐ Option 1 ☐ Option 2 ☐ Option 3 ☐ Option 4

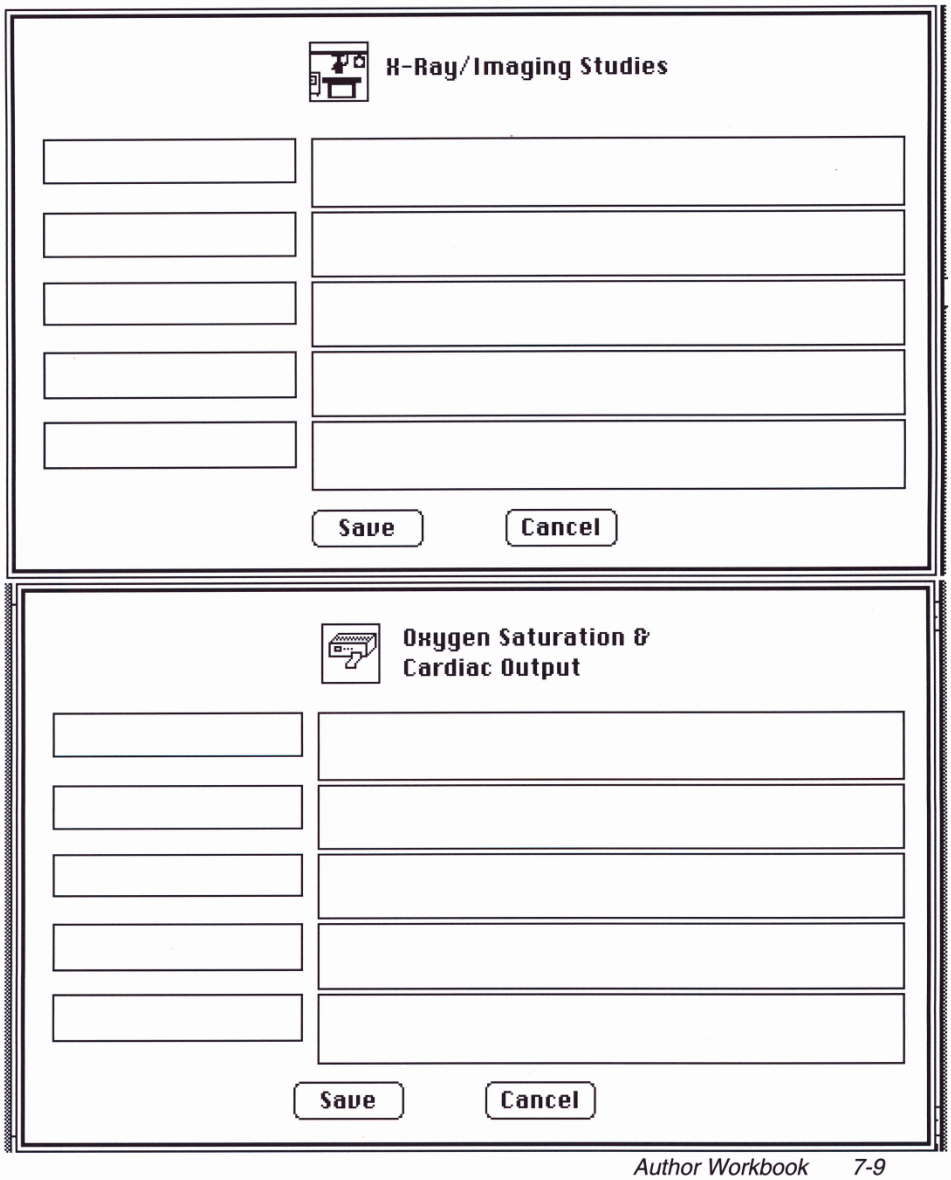




7-8 Author Workbook

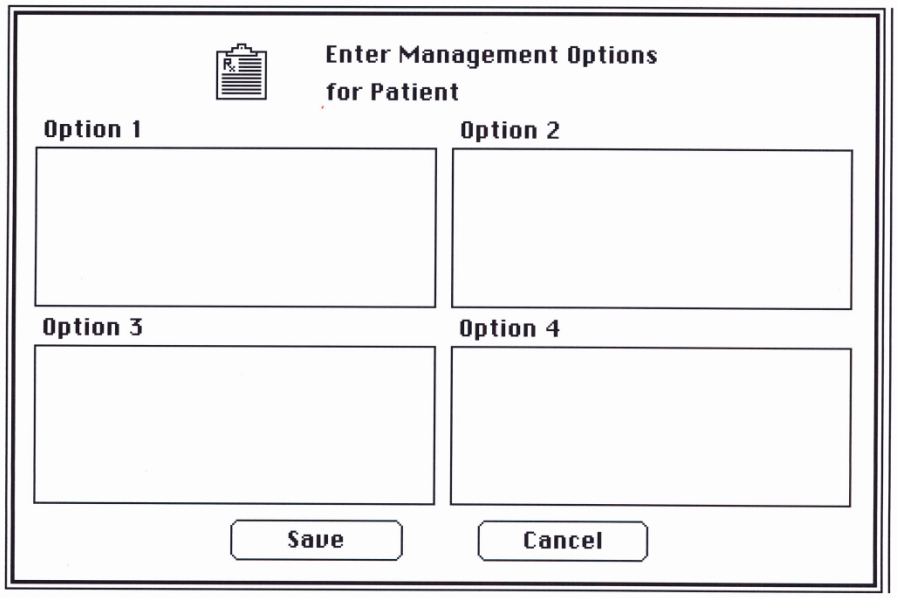
Page: _____

☐ Initial ☐ Option 1 ☐ Option 2 ☐ Option 3 ☐ Option 4



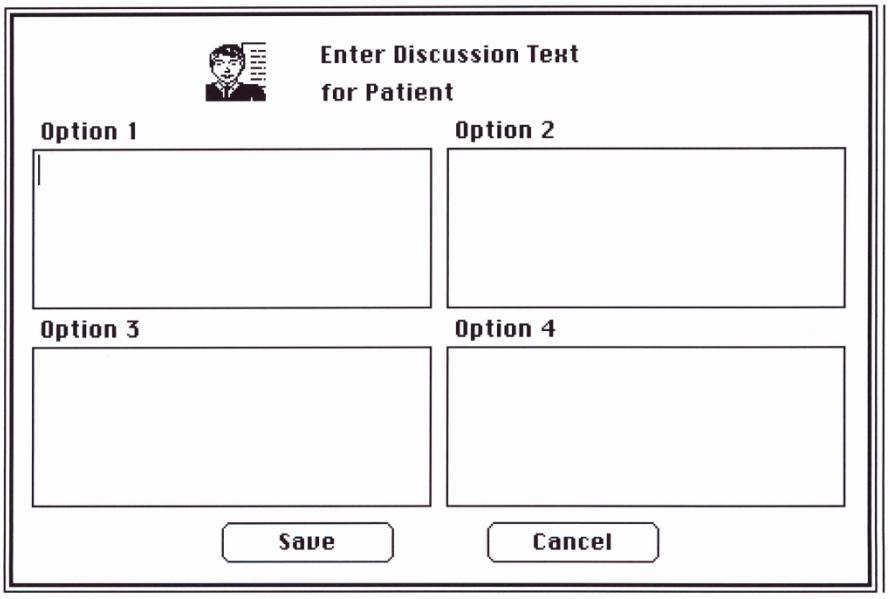
Page: _____

IV. Management Options



Page: _____

V. Discussion Text



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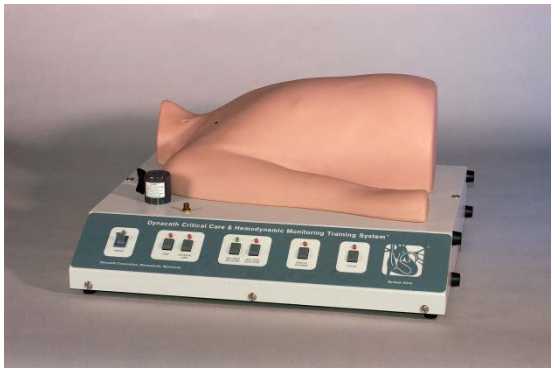
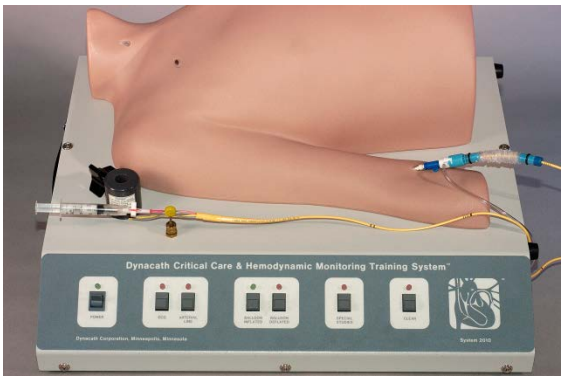
Hardware

Production Model

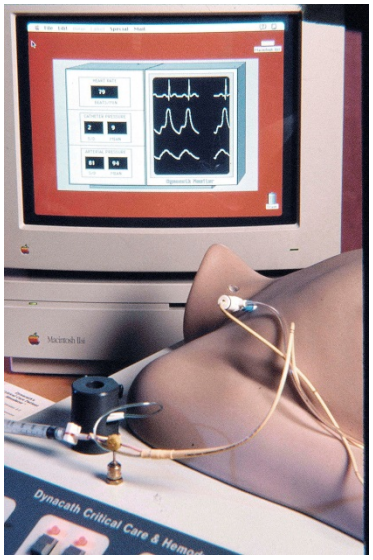
Photographs
Mechanical Drawings
Electronic Schematics
Circuit Boards



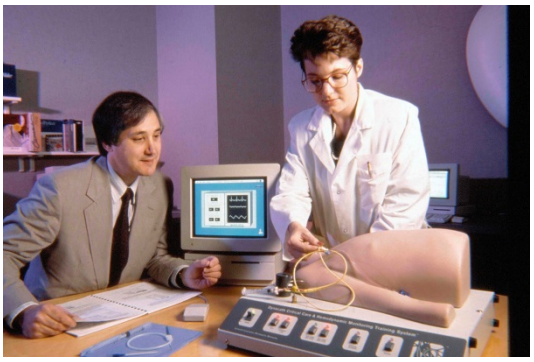
Dynacath Trainer



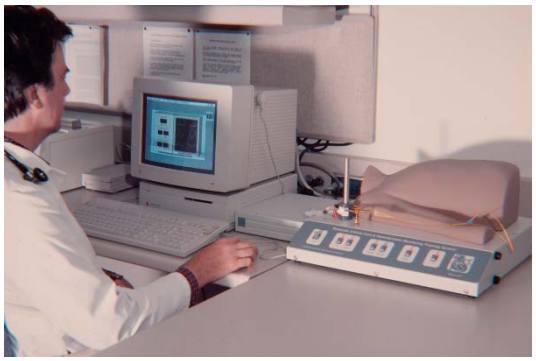
Catheter in Place



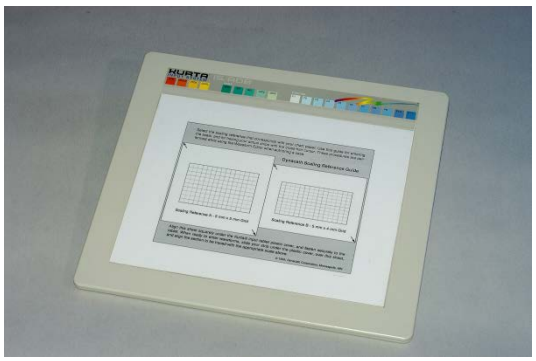
Simulated Cardiac Monitor



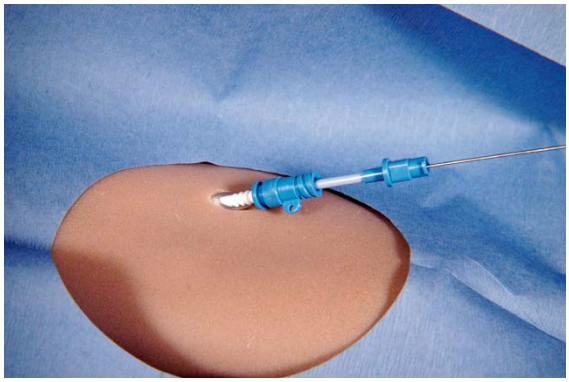
Training Session



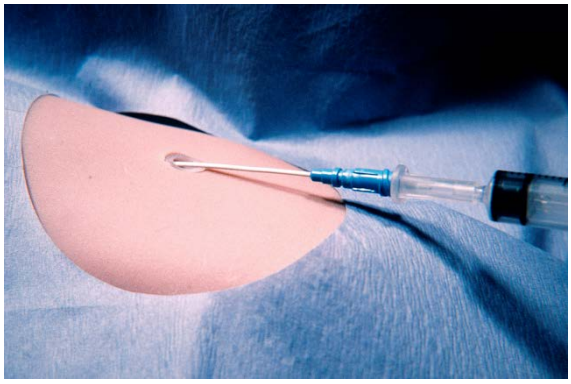
Case Authoring



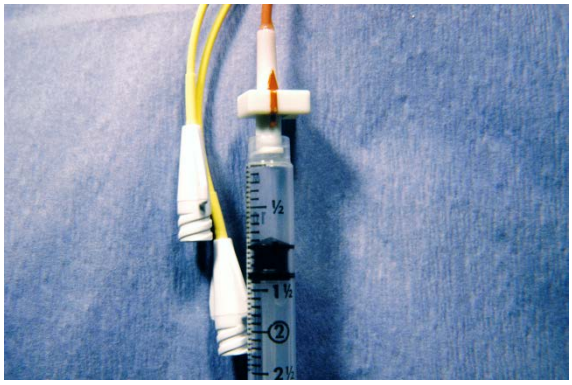
Kurta tablet for Waveform Tracing



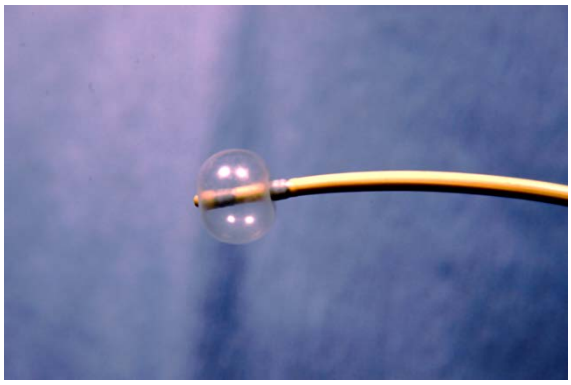
Introducer, Dilator and Spring Wire



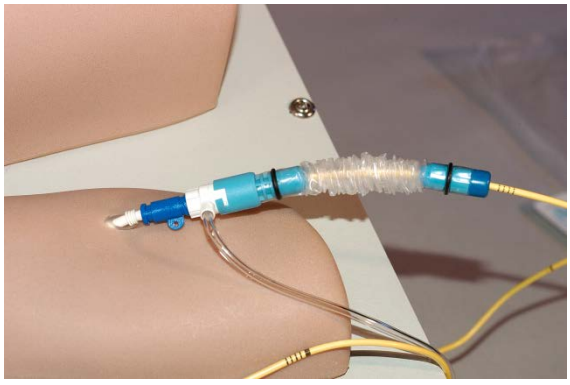
Venous Catheter and Needle



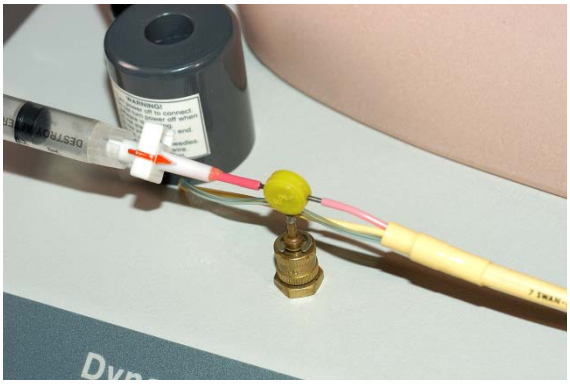
Balloon Syringe



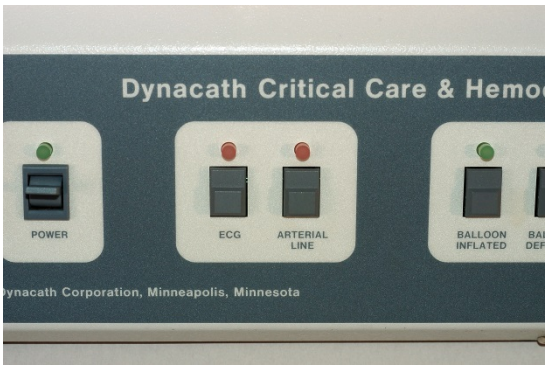
Catheter Balloon



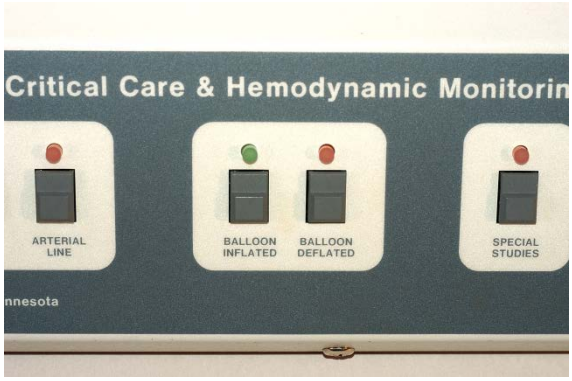
Inserted Pulmonary Artery Catheter



Balloon Air Diverter

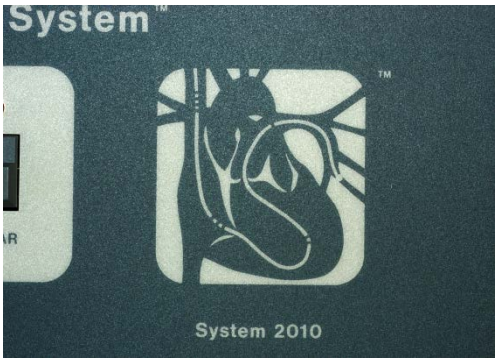


Power, ECG and Arterial Line Switches



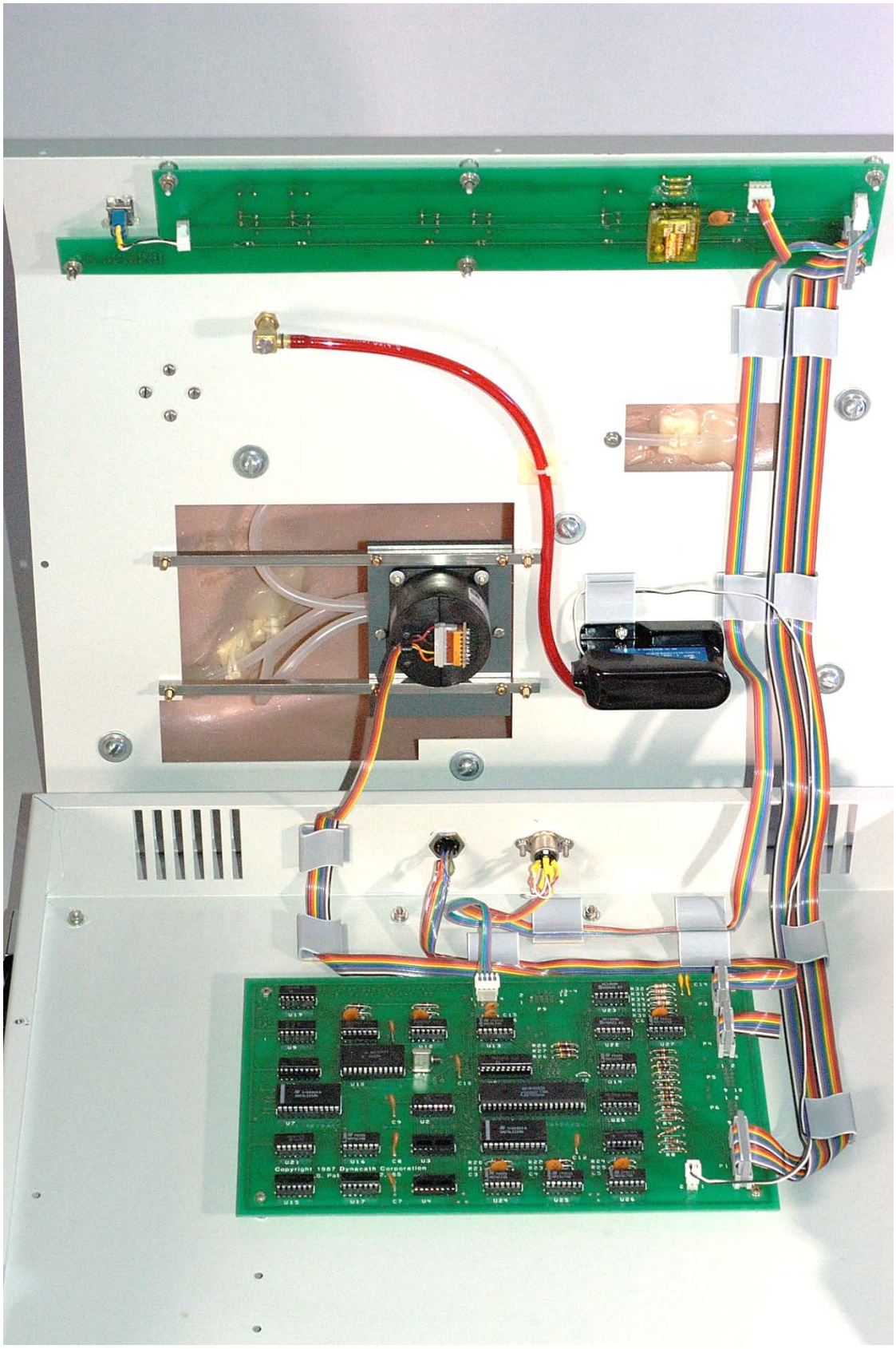
Manual Override of Balloon State

Quick Access to Studies & Clear Switches

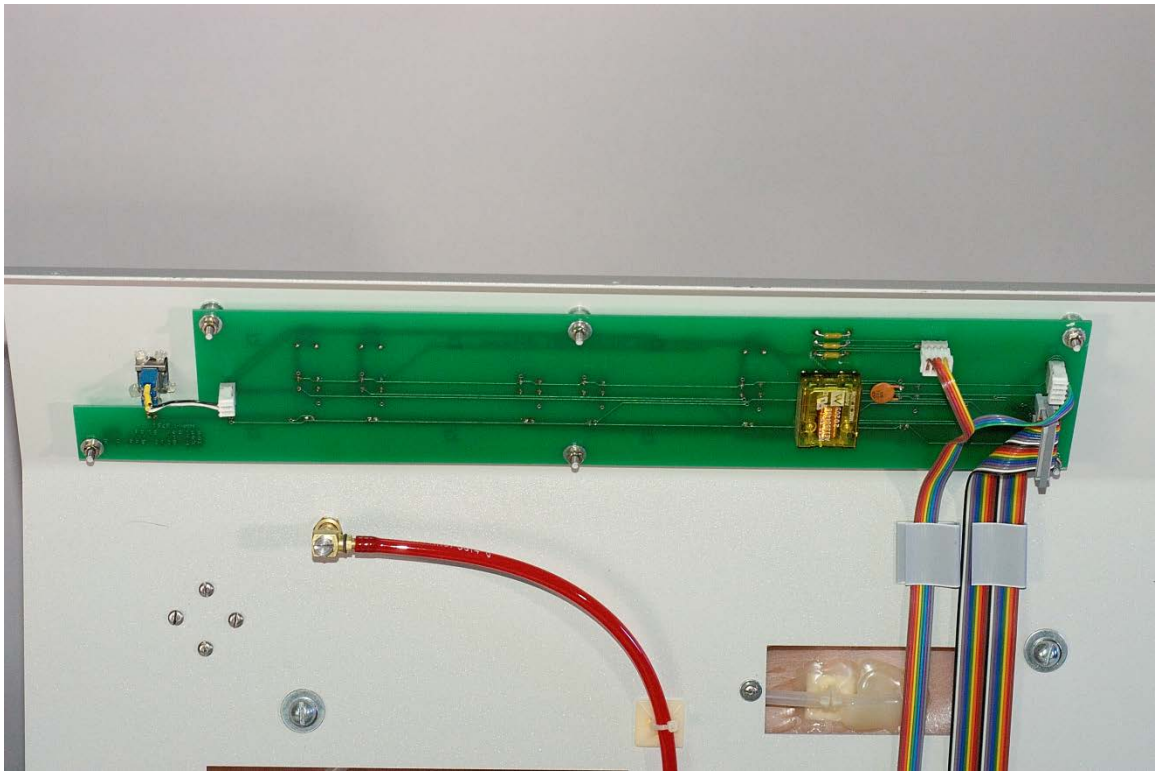


Dynacath Trainer Logo

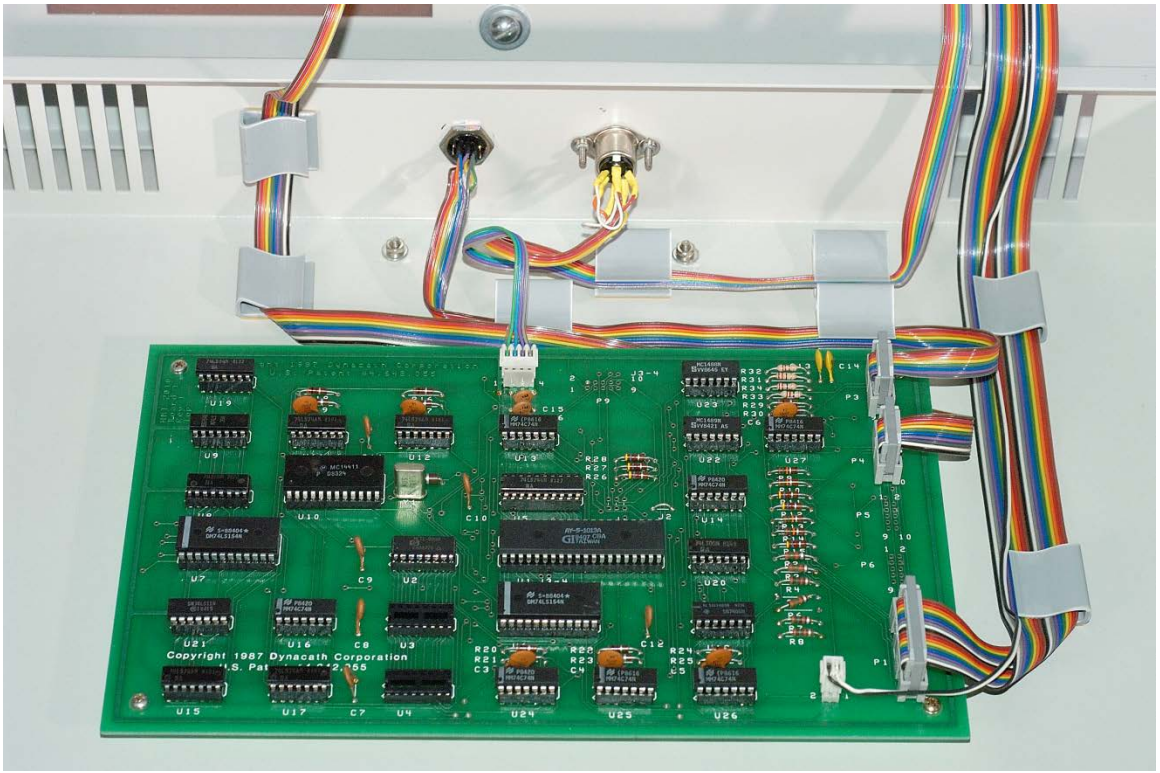
Rear Power and Computer Connectors, Labeling



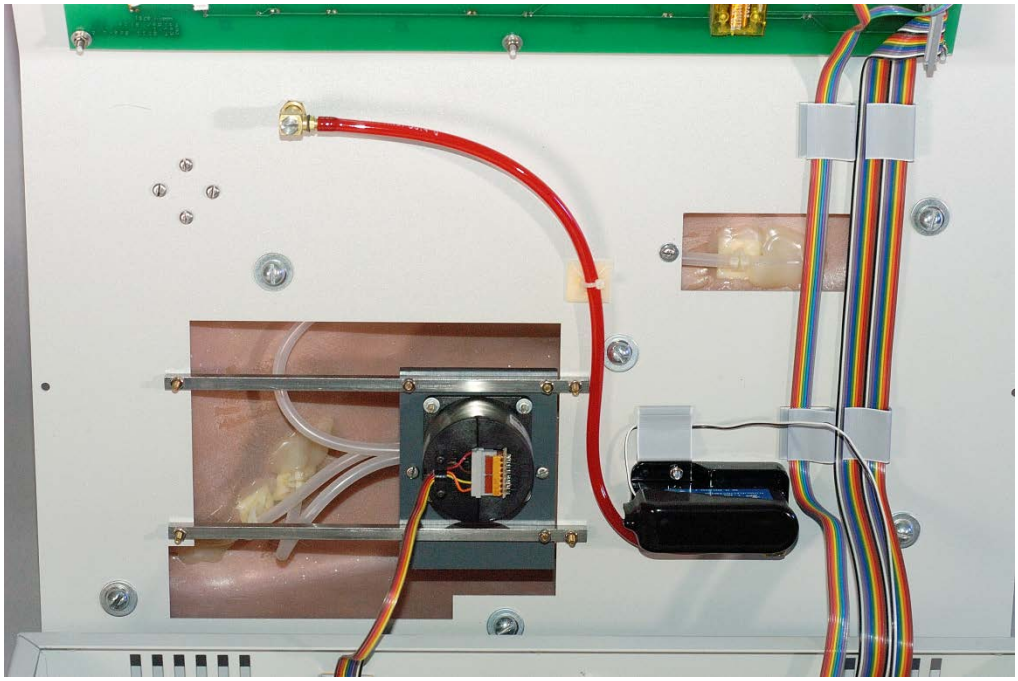
Inside View of Dynacath Trainer



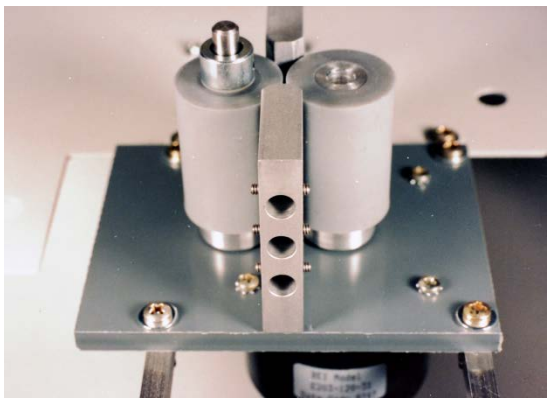
Backside of Front Panel Circuit Board



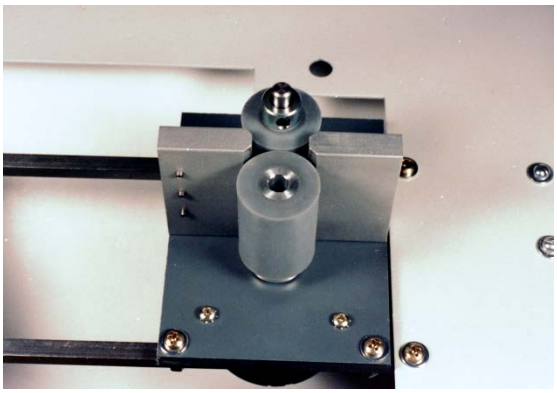
Populated Side of Main Circuit Board



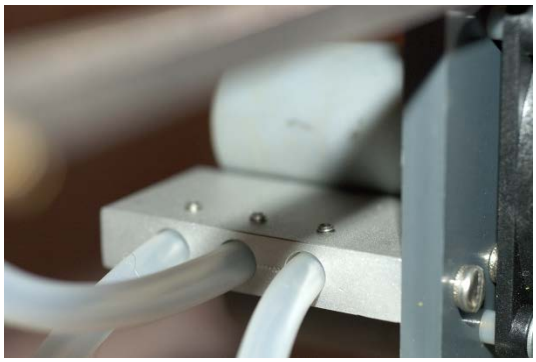
Catheter Motion Optical Encoder and Air Switch



Optical Encoder Roller Assembly

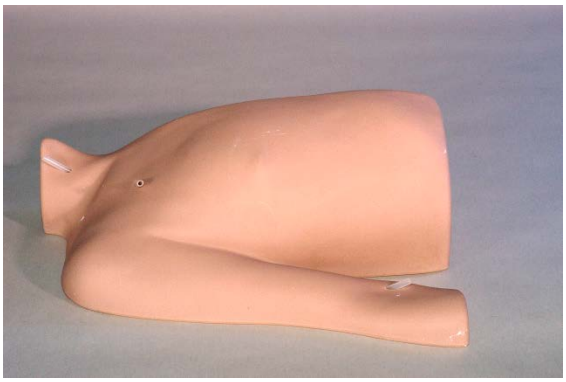


Optical Encoder Roller Assembly

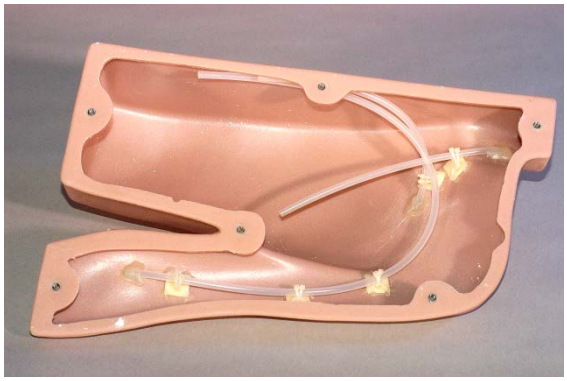


Catheter Guideway to Optical Encoder

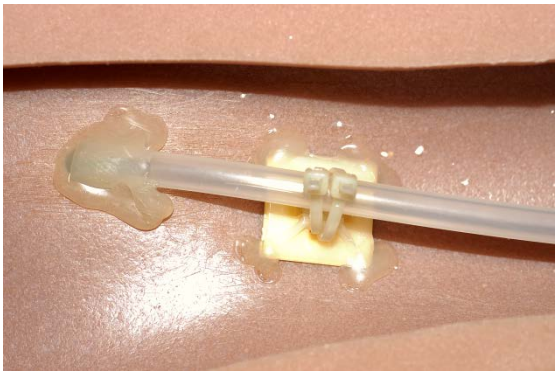
Guideway and Encoder



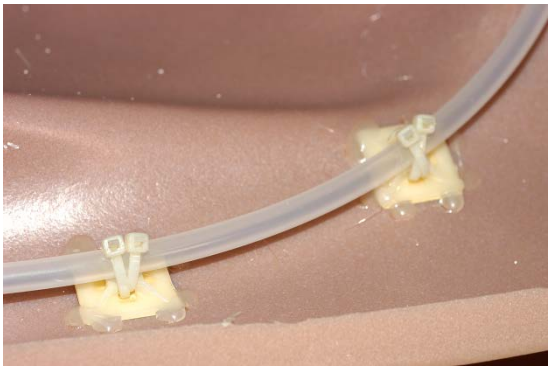
Dynacath Trainer Manikin Shell



Inside View of Routed Shell

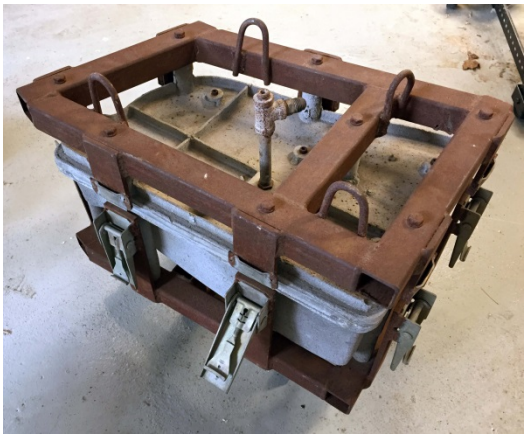


Start of Cather Guideway



Guideway Tie-Down

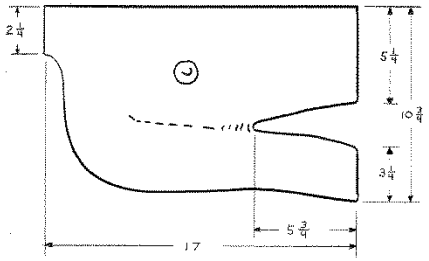
Inside of Dynacath Manikin Mold



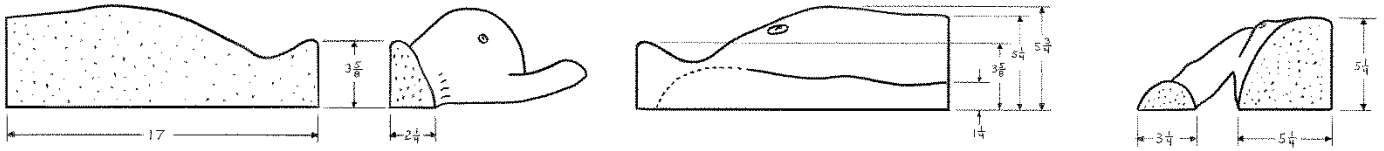
Assembled Mold for Rotational Molding

NOTES
1. TONGUE AND GROOVE AI CAST ROTATIONAL MOLD TOOL
2. REMOVE SURFACE FLAWS
3. FILL SHELL HOLLOW
4. SQUARE SIDES BACK & BOTTOM
5 CREATE $\frac{1}{8}$" RADIUS ON BOTTOM
6. NUTS A-F PLACED IN TOOL PRIOR TO EACH ROTATIONAL MOLDING OPERATION
7. FINISH TOOL TO YIELD PART WITH MATTE TOP AND PEBBLE TEXTURE SIDES - SEE SAMPLES
8. DISCUSS LOCATIONS B & D

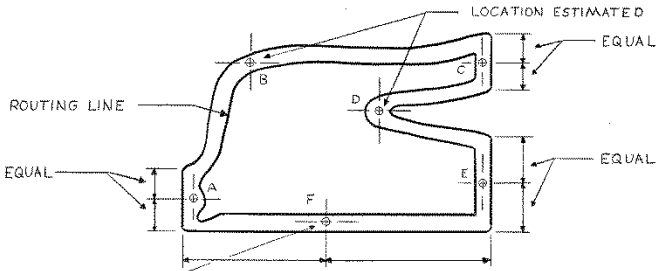
REVISIONS			
NO	DESCRIPTION	BY	DATE
1	NUTS MOVED IN $\frac{1}{2} \rightarrow \frac{5}{8}$	SSS	3/21/87



PATTERN MEASUREMENTS ≈ FROM FIBERGLASS SHELL



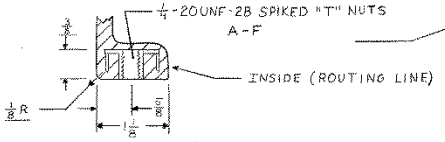
PATTERN VIEWS ABOVE ↑



PART DIM. DEP ON ALCAST AND PLASTIC SHRINKAGE

BOTTOM VIEW MOLDED PART

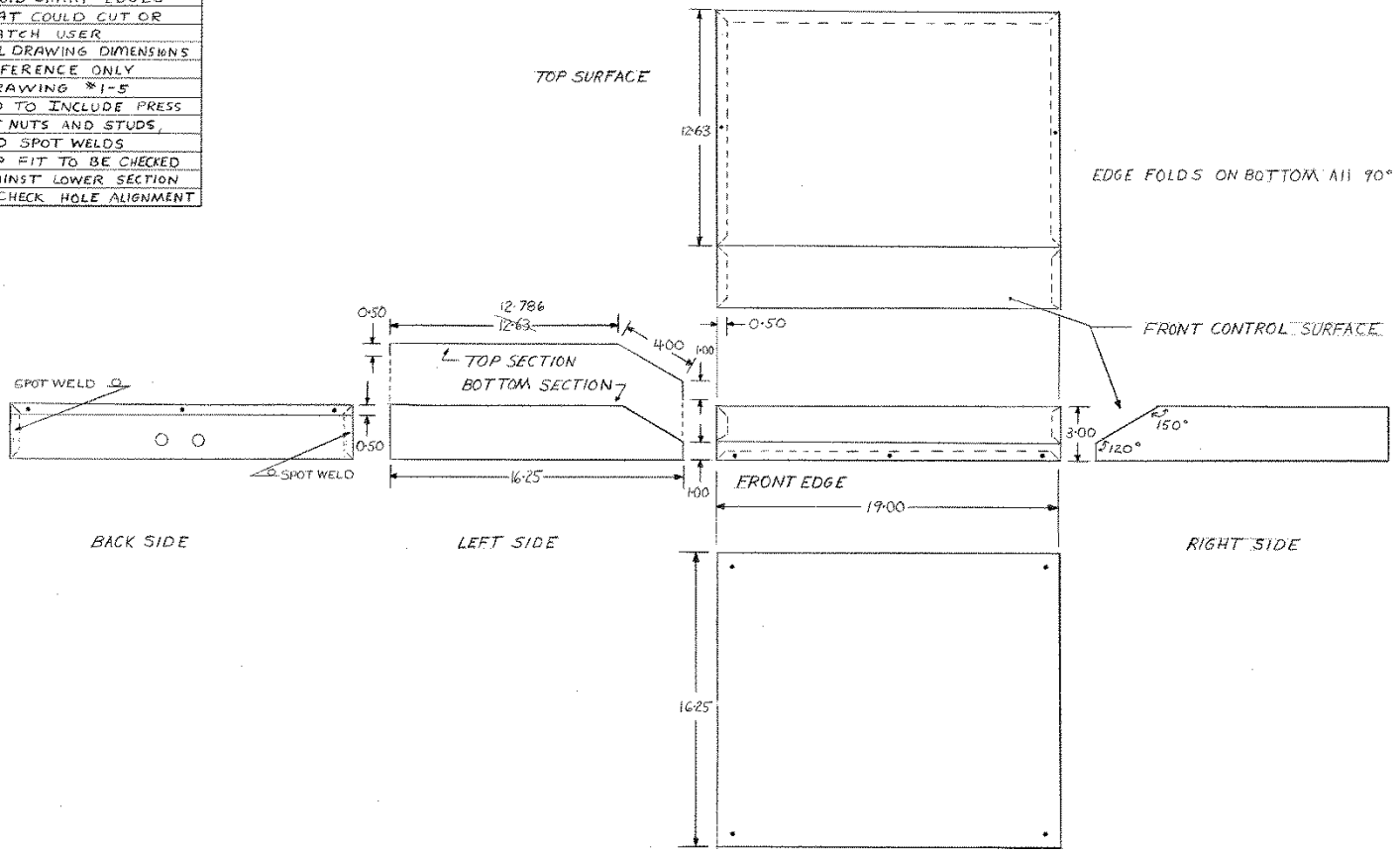
CROSS SECTIONAL VIEW



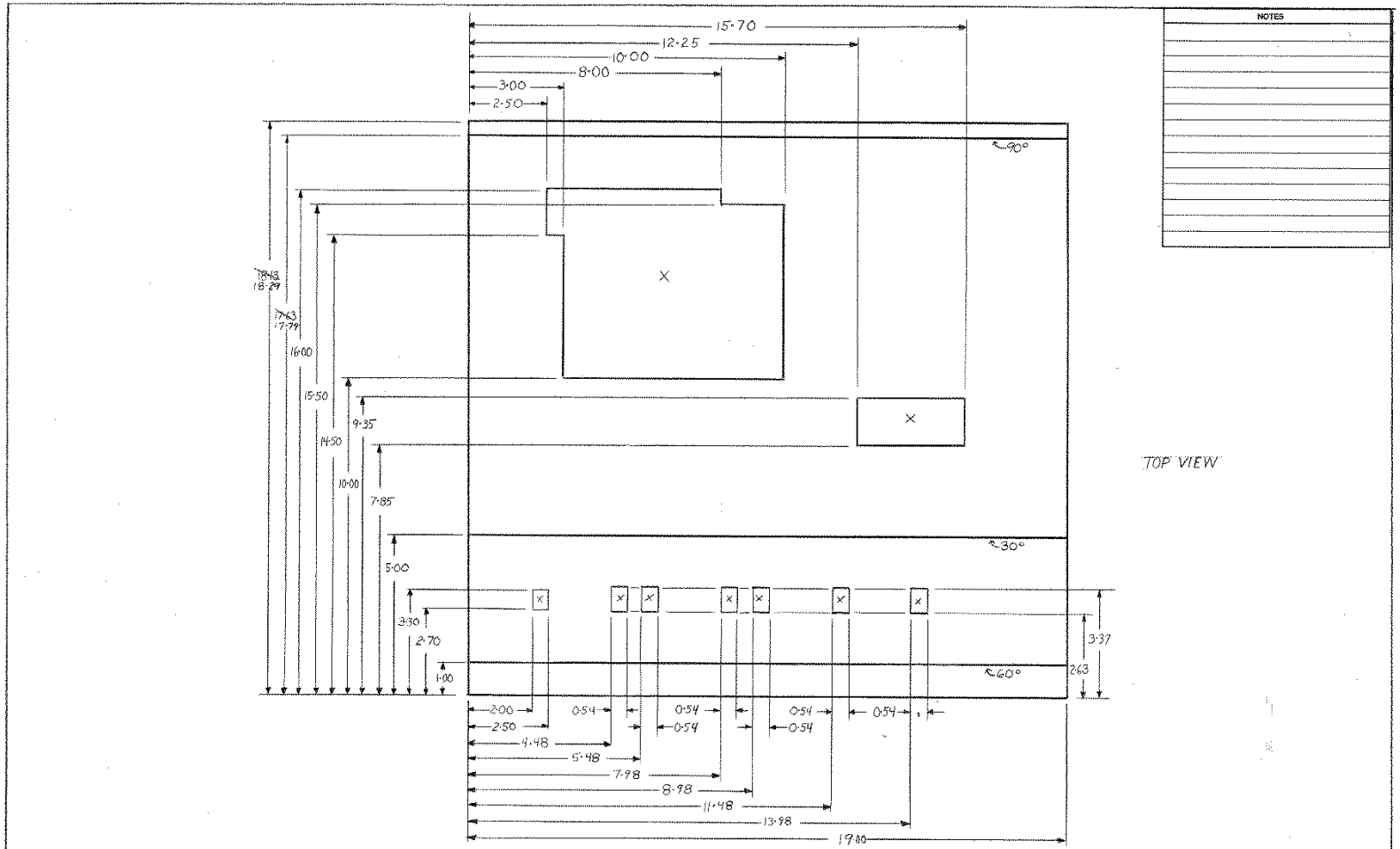
(FASTEN TO CHASSIS WITH ¼-20 UNF-2A ⅜ RND HD MACH SCR)

Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4296	TOLERANCES (EXCEPT AS NOTED) DECIMAL . FRACTIONAL . ANGULAR .	TRAINER 2010 SCALE 1/4 | DRAWING BY S SALITERMAN | APPROVED BY TITLE MANIKIN PATTERN/PART DATE 1/30/87 | DRAWING NUMBER HMT 001
MATERIAL		
TREATMENT		
FINISH		

NOTES
1) TOP SECTION COVERS
LOWER SECTION COMPLETLY
2) AVOID SHARP EDGES
THAT COULD CUT OR
CATCH USER
3) ALL DRAWING DIMENSIONS
REFERENCE ONLY
DRAWING #1-5
4) BID TO INCLUDE PRESS
FIT NUTS AND STUDS,
AND SPOT WELDS
5) TOP FIT TO BE CHECKED
AGAINST LOWER SECTION
TO CHECK HOLE ALIGNMENT



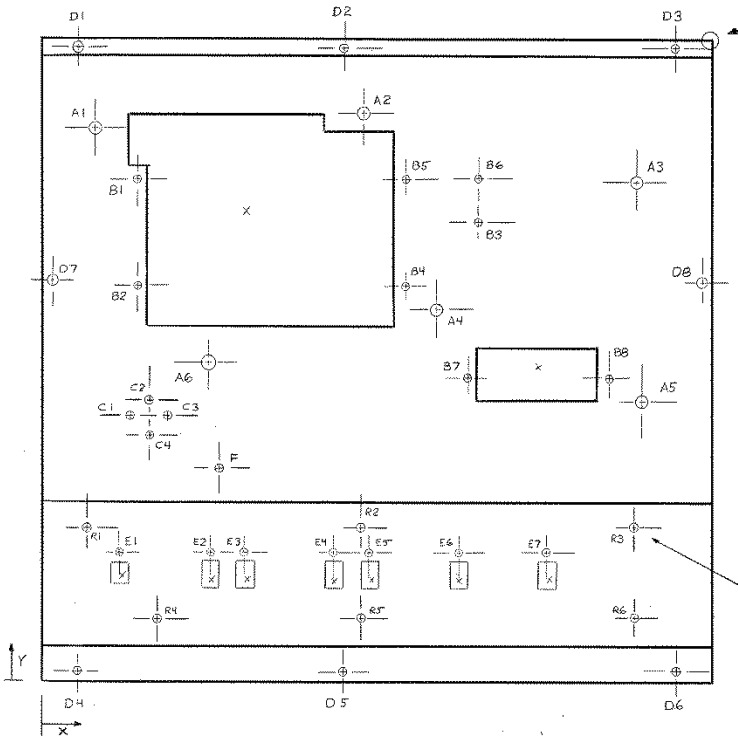
Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4288	TOLERANCES (EXCEPT AS NOTED) DECIMAL ± 0.005	HMT 2010		
			SCALE 1/4	DRAWING BY S. SALITERMAN APPROVED BY
0.0625 1/16" MATERIAL 16 GAGE CR STEEL	FRACTIONAL :	TITLE ENCLOSURE OVERVIEW		
TREATMENT FINISH	ANGULAR :	DATE 10/8/87	DRAWING NUMBER 1	



Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4290	TOLERANCES (EXCEPT AS NOTED) DECIMAL .0005	HMT 2010 SCALE 1/2 X DRAWING BY S SALITERMAN APPROVED BY
0.0625 1/16" MATERIAL 16 GAGE CR STEEL TREATMENT FINISH	FRACTIONAL ANGULAR	TITLE TOP SECTION CUTOUTS DATE 10/10/87 DRAWING NUMBER 2

		(1/4)	(6-32)	(6-32)	(LED)
NO. REQD		6	12	8	7
HOLE DIA.		0.375 #3/8	0.166 #14	0.166 #19	0.213 #3
POSITION		HOLE SYMBOL			
X →	Y ↑	A	B,C	D	E
1.48	15.55	A1			
9.02	16.04	A2			
16.72	14.05	A3			
11.12	10.50	A4			
16.90	7.84	A5			
4.60	8.98	A6			
2.75	14.15		B1		
2.75	11.15		B2		
18.25	12.90		B3		
10.25	11.15		B4		
10.25	14.15		B5		
12.25	14.15		B6		
12.00	8.60		B7		
15.95	8.60		B8		
2.50	7.50		C1		
3.00	8.00		C2		
3.50	7.50		C3		
3.00	7.00		C4		
1.00	17.88			D1	
9.50	17.88			D2	
18.00	17.88			D3	
1.00	0.25			D4	
9.50	0.25			D5	
18.00	0.25			D6	
2.25	3.60				E1
4.75	3.60				E2
5.75	3.60				E3
8.25	3.60				E4
9.25	3.60				E5
11.75	3.60				E6
14.25	3.60				E7
3.50	6.50				
0.25	11.32			D7	
18.75	11.32			D8	

NO REQD.		6	1		
HOLE DIA.		6-32 STUDS TOP FLUSH	11/32		
POSITION		HOLE SYMBOL			
X →	Y ↑	R	F		
1.25	4.25	R1			
9.00	4.25	R2			
16.75	4.25	R3			
3.25	1.75	R4			
9.00	1.75	R5			
16.75	1.75	R6			
5.00	6.00		F		



NOTES

1. D SIZE HOLES MAY NEED TO BE LARGER TO ALIGN WELL WITH LOWER SECTION PRESS FIT NUTS. ✓FIT
2. ROUND EDGE CORNERS × 4 ~1/16" RADIUS
3. D2, D5 OR D7, D8 MAY NOT BE NECESSARY IF SOLID FIT OTHERWISE.
4. R1-R6 6-32 - 3/4" STUDS. OUTSIDE SURFACE FLUSH

TOP SECTION, OUTSIDE (TOP) VIEW

Dynacath Corporation
FORD CENTRE, SUITE 570
420 NORTH FIFTH STREET
MINNEAPOLIS, MINNESOTA 55401
612-333-4298

TOLERANCES (EXCEPT AS NOTED)
DECIMAL ±.005
FRACTIONAL ±
ANGULAR ±

HMT 2010

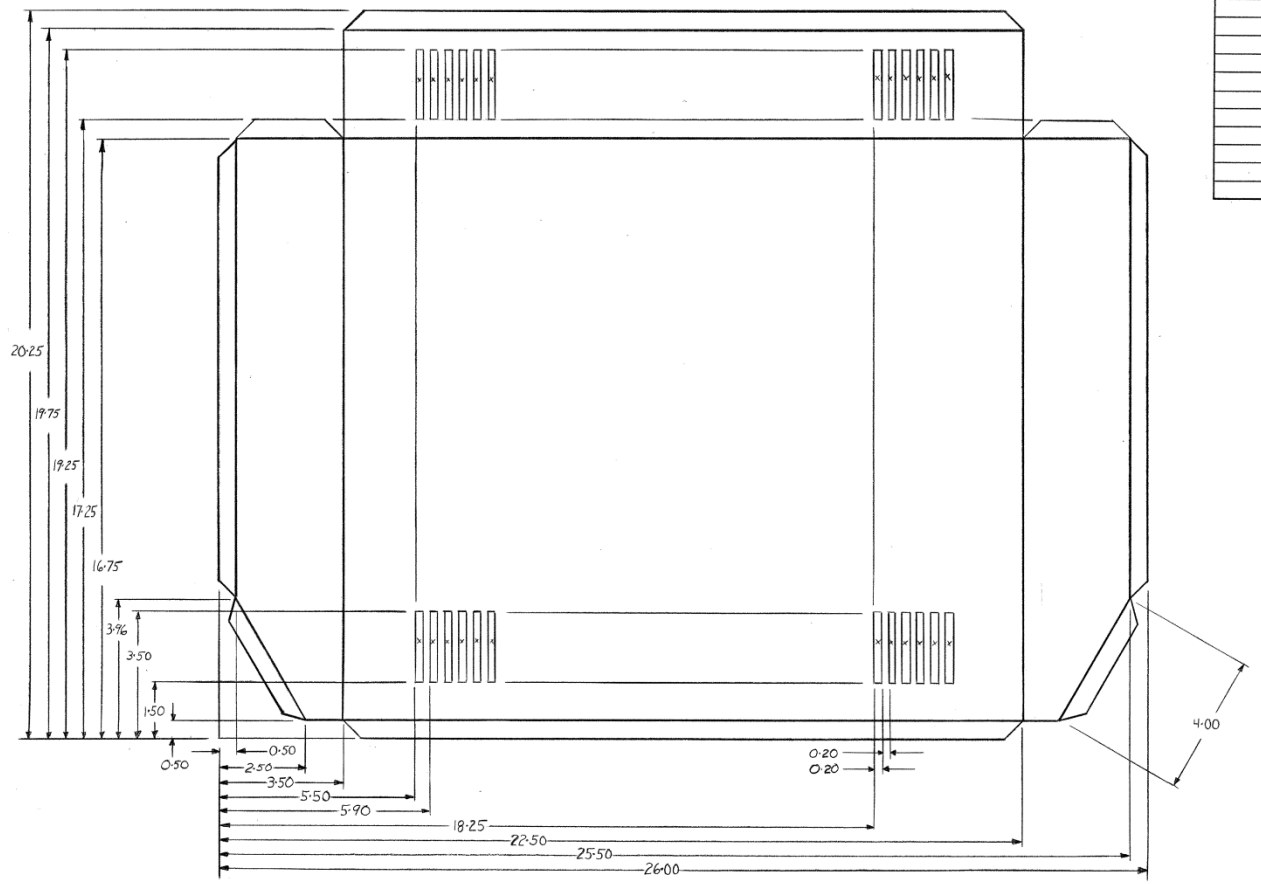
SCALE 1/2 X
DRAWING BY S. SALITERMAN
APPROVED BY

MATERIAL 16 GAGE CR STEEL 0.0625" 1/16"
TREATMENT
FINISH

TITLE TOP SECTION HOLES

DATE 10/12/87
DRAWING NUMBER 3

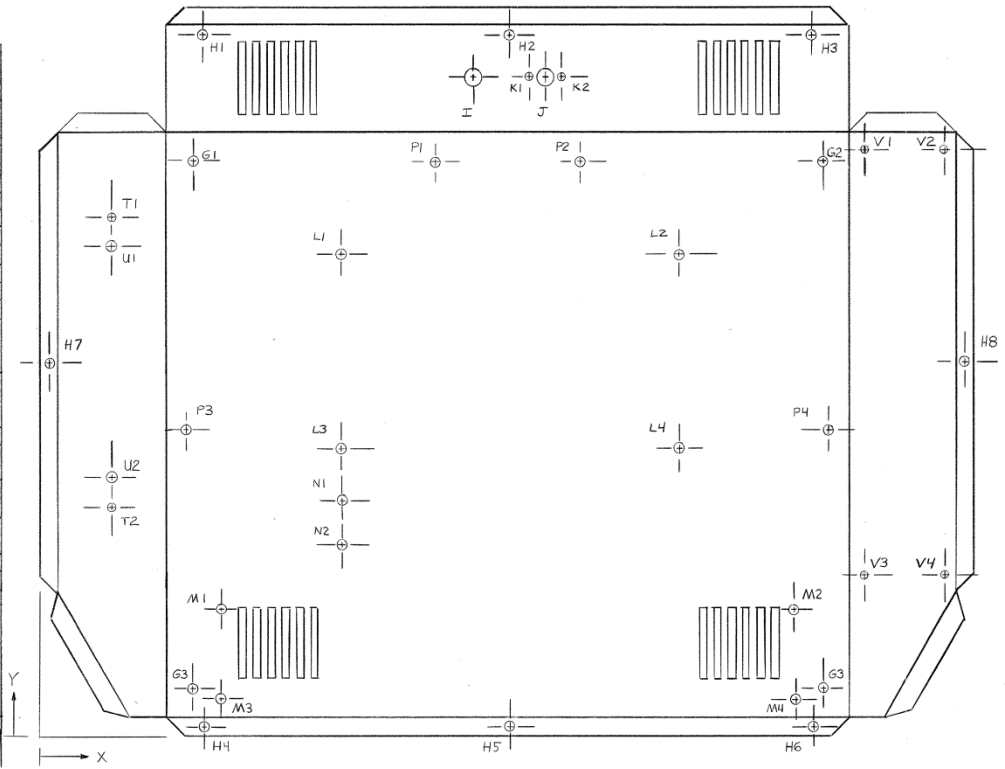
NOTES



Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4296	TOLERANCES (EXCEPT AS NOTED) DECIMAL .0·005	HMT 2010	
		SCALE ½ X	DRAWING BY S SALITERMAN APPROVED BY
0·0625 1/16"	FRACTIONAL :	TITLE BOTTOM SECTION CUTOUTS	
MATERIAL 16 GAGE CR STEEL			
TREATMENT	ANGULAR :	DATE 10/14/87	DRAWING NUMBER 4
FINISH			

		(6-32 SCREWS)		(4-40 SCREWS)		
NO. REQD		6	18	8	1	1
HOLE DIA.		6-32 NUT PRESS FIT	0.166 #19	0.140 #28	0.563 9/16	0.625 5/8
POSITION		HOLE SYMBOL				
X →	Y ↑	H	G,L,M,N,P	K,T,V	I	J
4.50	19.5	H1				
13.00	19.5	H2				
21.50	19.5	H3				
4.50	0.25	H4				
13.00	0.25	H5				
21.50	0.25	H6				
4.25	16.00		G1			
21.75	16.00		G2			
4.25	1.25		G3			
21.75	1.25		G4			
8.30	13.40		L1			
17.70	13.40		L2			
8.30	8.00		L3			
17.70	8.00		L4			
5.00	3.50		M1			
21.00	3.50		M2			
5.00	1.00		M3			
21.00	1.00		M4			
8.30	6.50		N1			
8.30	5.25		N2			
13.56	18.25			K1		
14.48	18.25			K2		
12.00	18.25				I	
14.00	18.25					J
11.00	16.00		P1			
15.00	16.00		P2			
4.00	8.50		P3			
22.00	8.50		P4			
0.25	10.36	H7				
25.75	10.36	H8				
2.00	14.40			T1		
2.00	6.33			T2		
22.90	16.25			V1		
25.10	16.25			V2		
22.90	4.46			V3		
25.10	4.46			V4		

NO. REQD		2				
HOLE DIA		8-32 NUT PRESS FIT				
POSITION		HOLE SYMBOL				
X →	Y ↑	U				
2.00	13.57	U1				
2.00	7.16	U2				



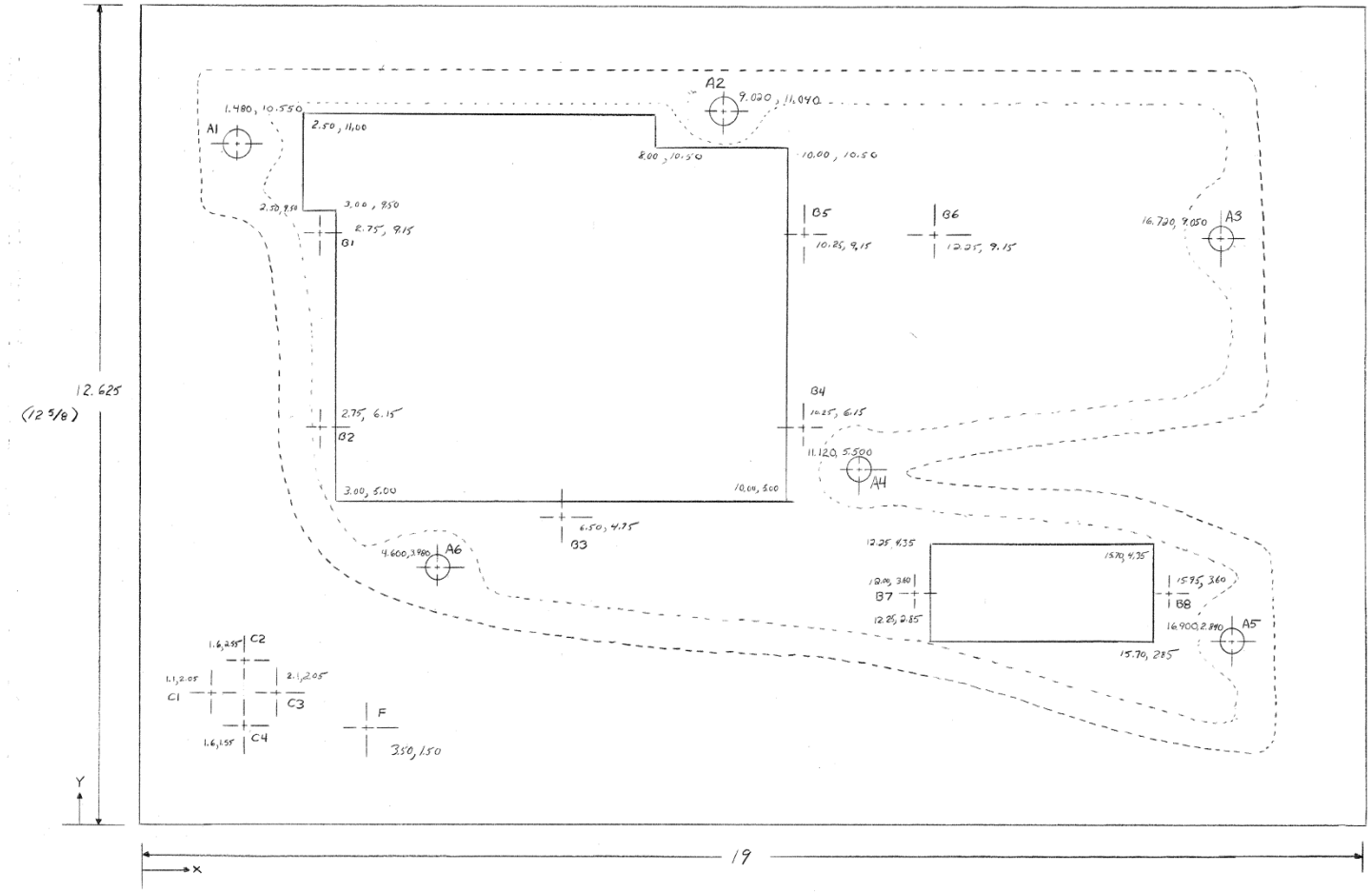
BOTTOM SECTION, INSIDE (TOP) VIEW

NOTES

1) H1-H8 ARE 6-32 PRESS FIT NUTS, FLUSH TO MATING TOP SECTION
2) U1 & U2 ARE 8-32 PRESS FIT NUTS FLUSH OUTSIDE FOR ENCLOSURE HANDLE
3) H2, H5 OR H7, H8 MAY NOT BE NECESSARY IF SOLID FIT OTHERWISE. (SAME 02, D5 OR D7, D8 DRAWING #3)

Dynacath Corporation
FORD CENTRE, SUITE 570
420 NORTH FIFTH STREET
MINNEAPOLIS, MINNESOTA 55401
612-333-4298

TOLERANCES (EXCEPT AS NOTED)	HMT 2010		
DECIMAL .0.005		SCALE 1/2X	DRAWING BY S SALITERMAN
FRACTIONAL 0.0625 1/16"	TITLE BOTTOM SECTION - HOLES		APPROVED BY
MATERIAL 16 GAGE CR STEEL			
TREATMENT	ANGULAR .	DATE 10/14/87	DRAWING NUMBER 5
FINISH			

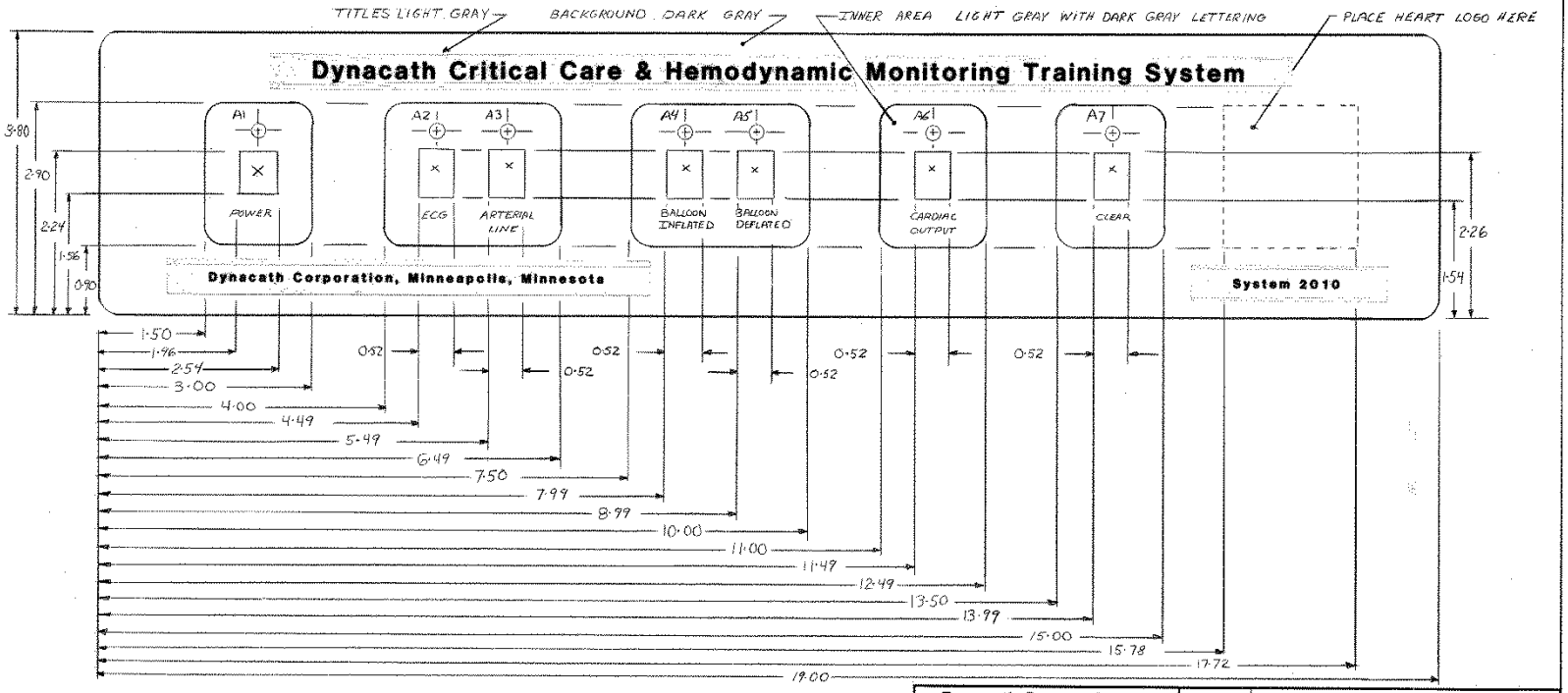


Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4296	TOLERANCES (EXCEPT AS NOTED) DECIMAL .	HMT 2010	SCALE 1X DRAWING BY Saliterman APPROVED BY
	FRACTIONAL .	TITLE TOP SURFACE ASSEMBLY	
MATERIAL TREATMENT FINISH	ANGULAR .	DATE 10/10/87	DRAWING NUMBER 6

NO. REQD		7	
HOLE DIA.		0.209 "4	
POSITION		HOLE SYMBOL	
X→	Y↑	A	
2.25	2.50	A1	
4.75	2.50	A2	
5.75	2.50	A3	
8.25	2.50	A4	
9.25	2.50	A5	
11.75	2.50	A6	
14.25	2.50	A7	

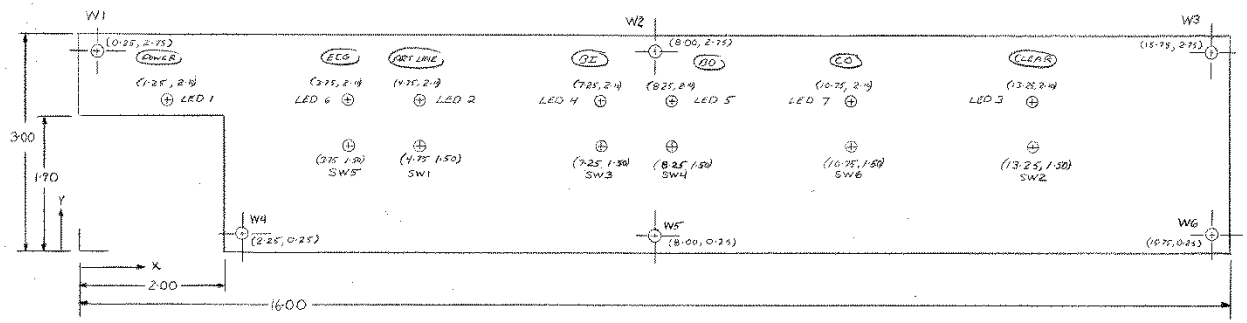
NOTES

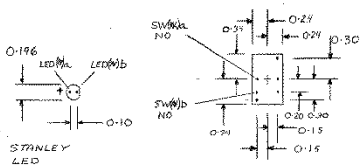
1. CORNER RADIUS = 9/16
2. TWO COLOR - SEE SAMPLES
   "A" = LIGHT GRAY
   "B" = DARK GRAY



Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4296	TOLERANCES (EXCEPT AS NOTED)	HMT 2010	
	DECIMAL .0.005	SCALE ~1X	DRAWING BY S SALITERMAN
	FRACTIONAL .	TITLE FRONT PANAL ARTWORK	APPROVED BY
MATERIAL .010 VELVET LEXAN	ANGULAR .	DATE 10/18/87	DRAWING NUMBER 7
TREATMENT			
FINISH			

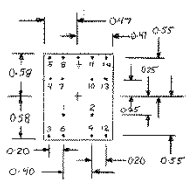
BOTTOM (SOLDER SIDE, FACES OUT THROUGH ENCLOSURE CUTOUTS) VIEW





ITT SHADOW
DIGITAST
(TOP VIEW)

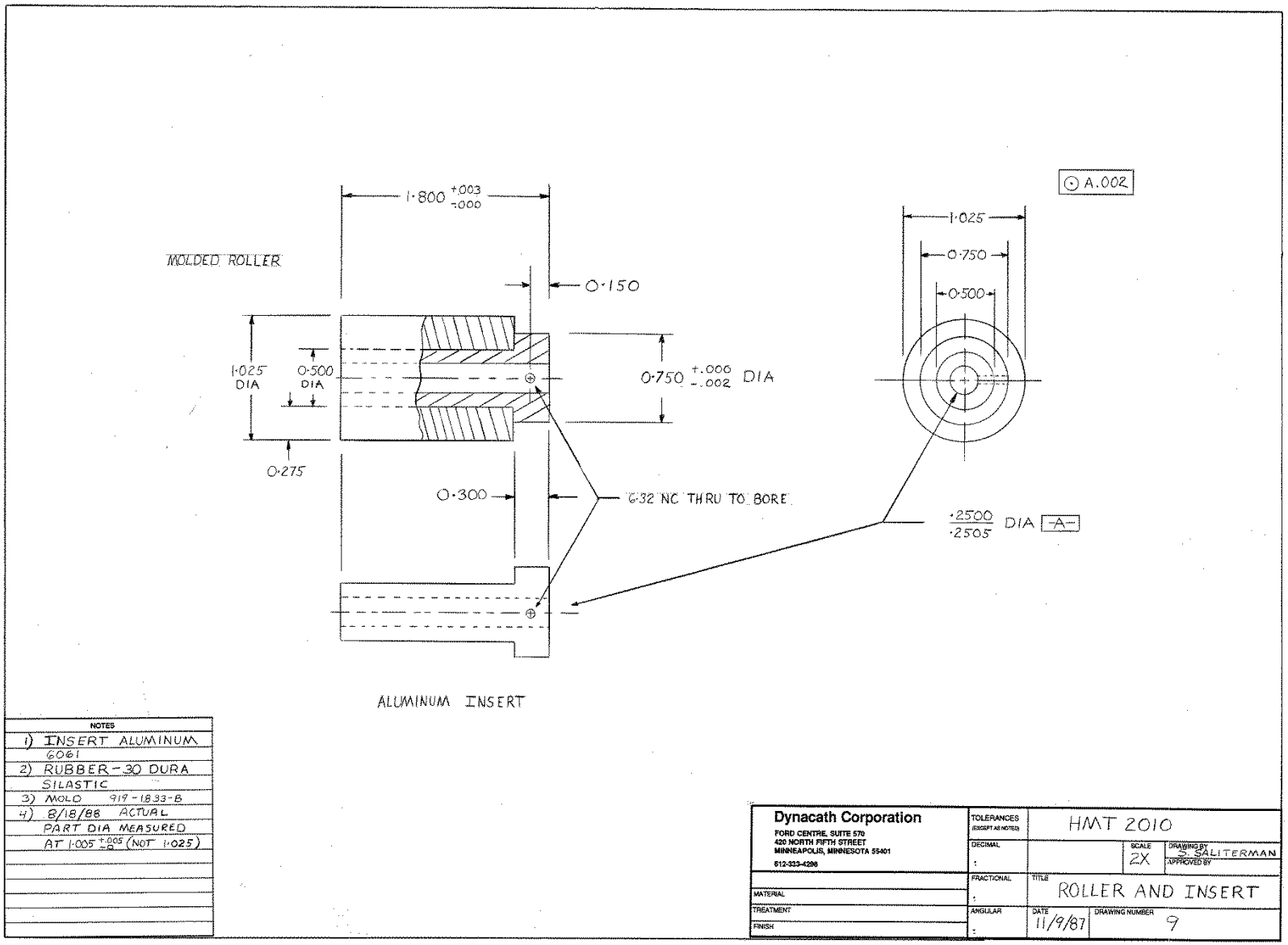
RL1 (pin #)



(TOP VIEW)
AROMAT
NPAE-SV

NOTES
1) HOLES W1-W6 0.166 ⌀19
FOR 6-32 MOUNTING STUD
2) LED & SWITCH NUMBERS
IN ( ) ARE PART CENTERS
3) RELAY, CONNECTORS, CAPACITORS
ON TOP (COMP) SIDE OF PCB
(FACES INSIDE ENCLOSURE)
4) SWITCHES & LEDS ON BOTTOM
(SOLD) SIDE OF PCB
(FACE OUT THROUGH ENCLOSURE
CUTOUTS)

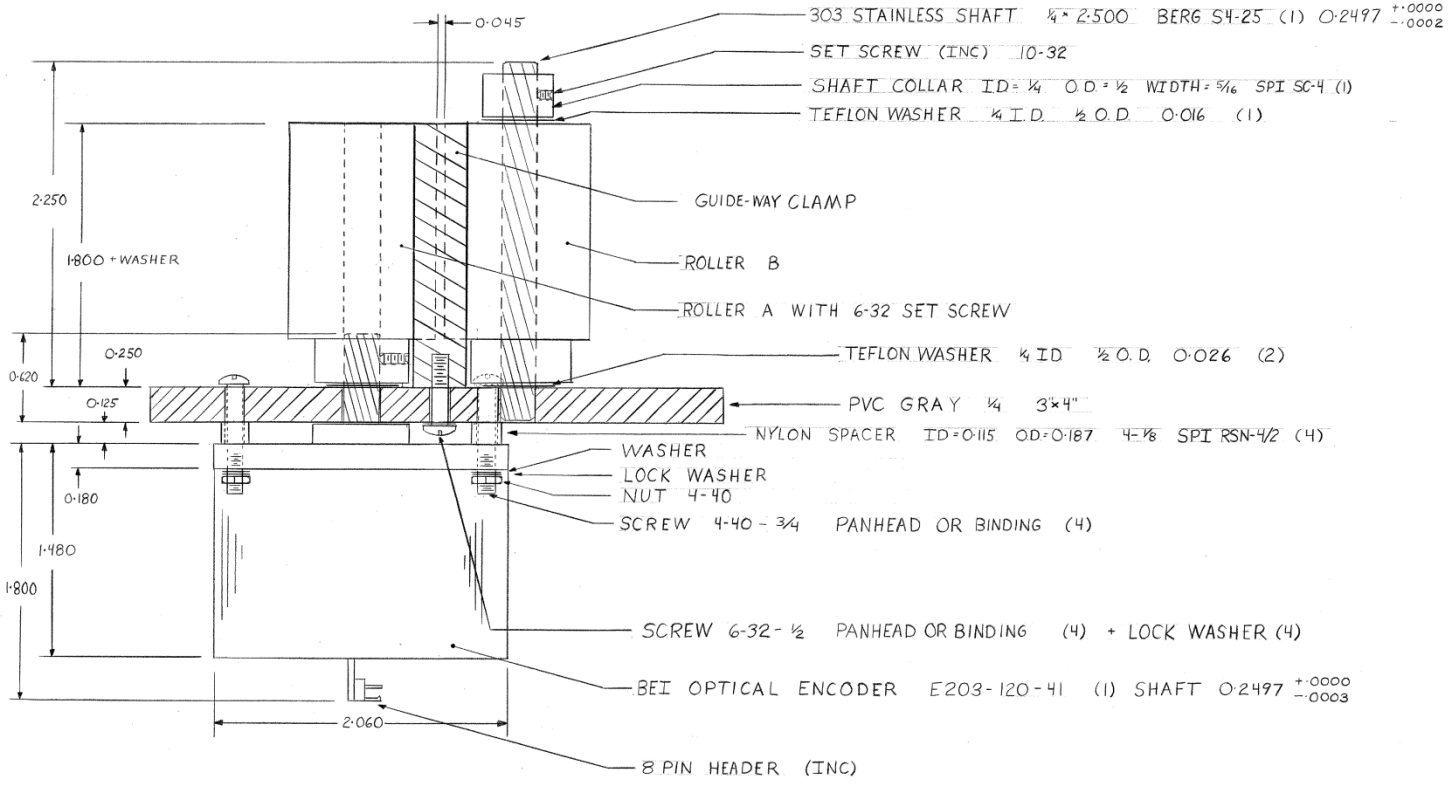
Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4298	TOLERANCES (EXCEPT AS NOTED)	HMT 2010	
	DECIMAL ±	SCALE 1X	DRAWING BY S. SALITERMAN
	FRACTIONAL ±	APPROVED BY	
MATERIAL		TITLE BOARD 2 OVERVIEW	
TREATMENT	ANGULAR ±	DATE 10/25/87	DRAWING NUMBER # 8
FINISH			



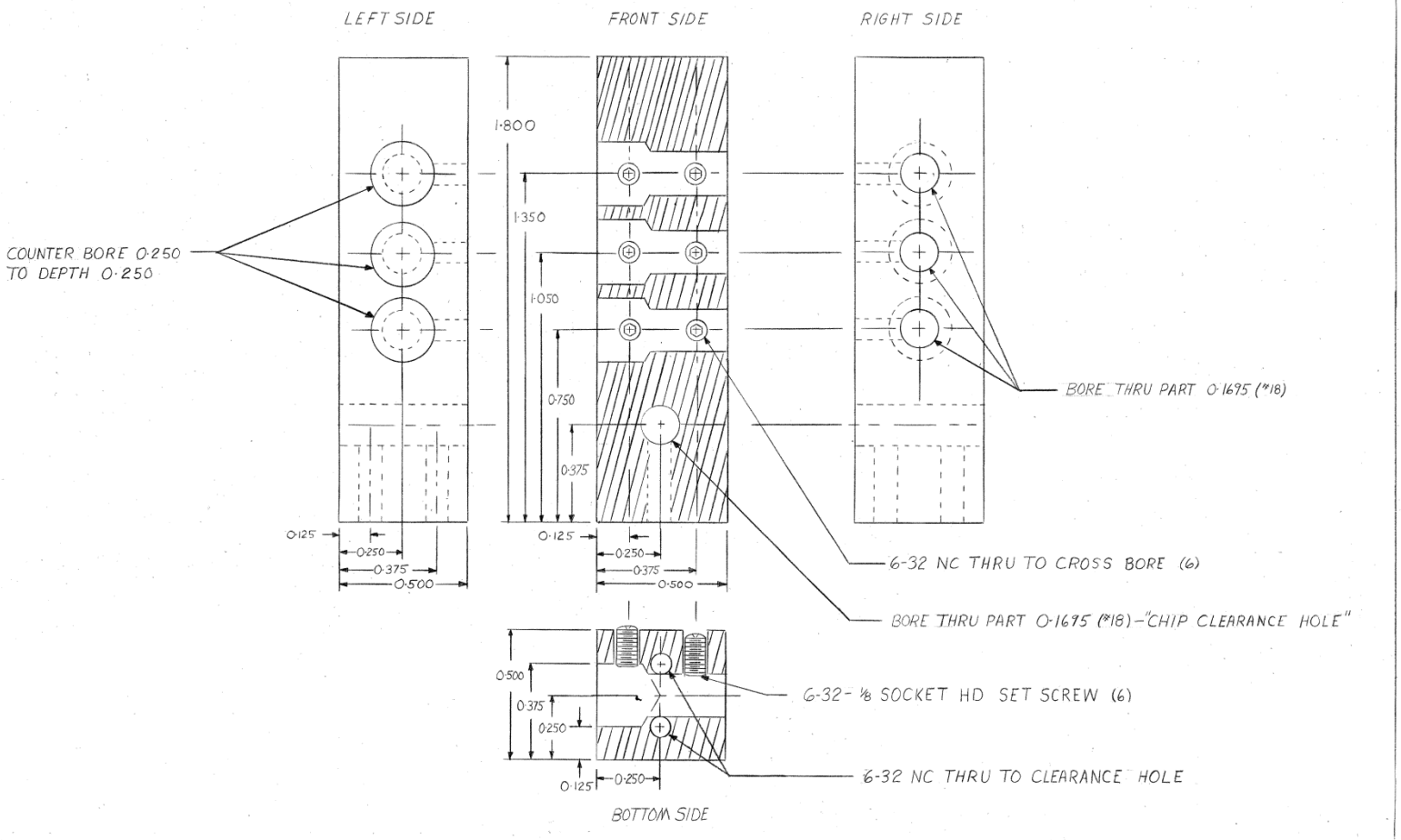
NOTES
1) INSERT ALUMINUM 6061
2) RUBBER - 30 DURA SILASTIC
3) MOLD 919-1833-B
4) 8/18/88 ACTUAL PART DIA MEASURED AT 1·005 +.005 -0 (NOT 1·025)

Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4296	TOLERANCES (EXCEPT AS NOTED) DECIMAL .	HMT 2010 SCALE 2X DRAWING BY S. SALITERMAN APPROVED BY
MATERIAL	FRACTIONAL .	TITLE ROLLER AND INSERT
TREATMENT FINISH	ANGULAR .	DATE 11/9/87 DRAWING NUMBER 9

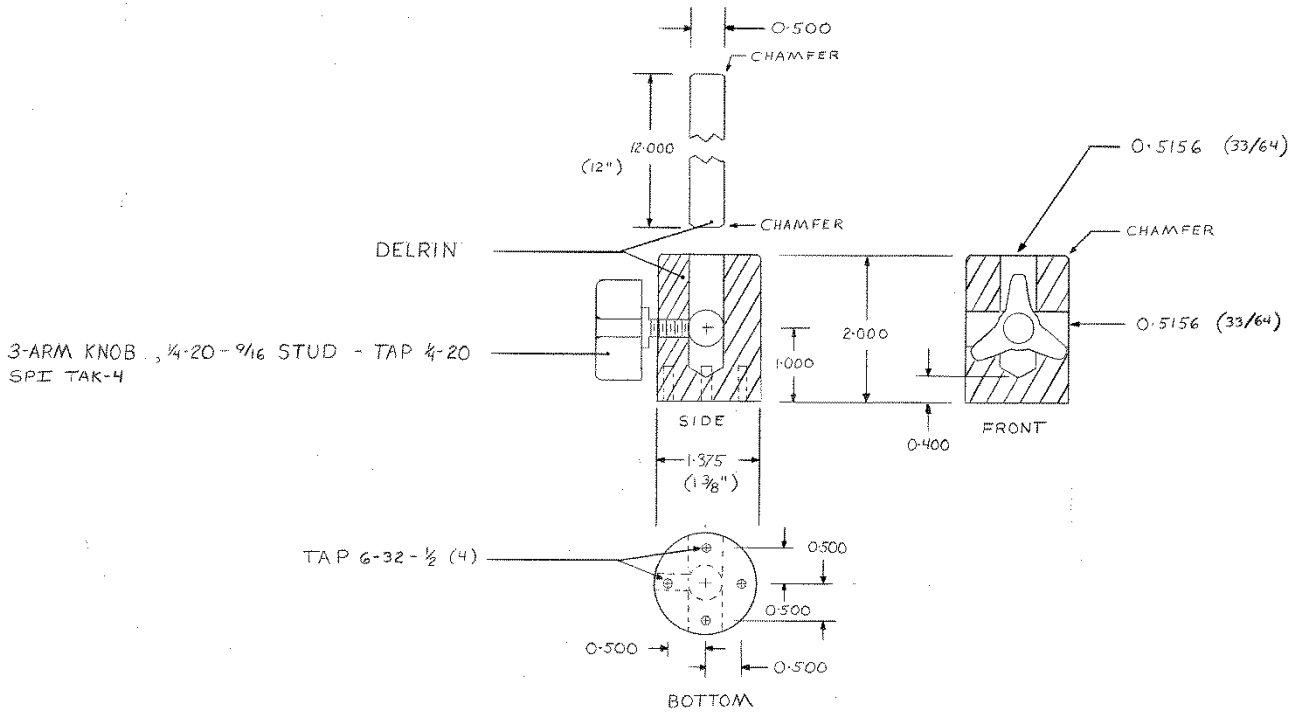
REVISIONS			
NO	DESCRIPTION	BY	DATE



Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4296	TOLERANCES (EXCEPT AS NOTED)	HMT 2010	
	DECIMAL ± .002	SCALE 2X	DRAWING BY S. SALITERMAN APPROVED BY
	FRACTIONAL ±	TITLE MOTION SENSOR ASSEMBLY	
MATERIAL			
TREATMENT	ANGULAR ±	DATE 8/18/88	DRAWING NUMBER 11
FINISH			



Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4298	TOLERANCES (EXCEPT AS NOTED) DECIMAL : ·003 FRACTIONAL : ANGULAR :	HMT 2010 SCALE 4X DRAWING BY S SALITERMAN APPROVED BY TITLE COMBINER CLAMP DATE 11/15/87 DRAWING NUMBER 12	
MATERIAL ALUMINUM 6061 TREATMENT FINISH			

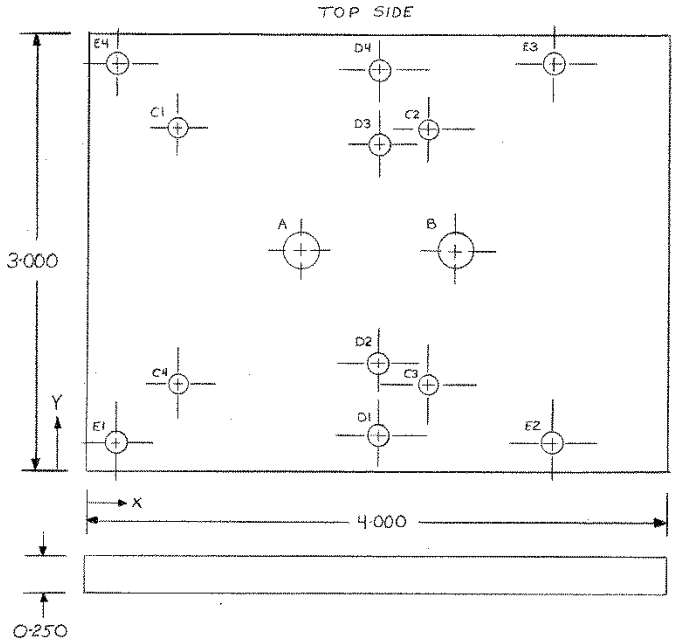


Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4296	TOLERANCES (EXCEPT AS NOTED) DECIMAL .	HMT 2010	
		SCALE 1X	DRAWING BY S. SALITERMAN APPROVED BY
MATERIAL DELRIN	FRACTIONAL .	TITLE IV POLE AND MOUNT BASE	
TREATMENT FINISH	ANGULAR .	DATE 12/4/87	DRAWING NUMBER 13

NOTES

HOLE B :
DRILL FOR FORCE FIT
OF SHAFT OF DIA :
0.2497 ±.0002
(SEE SAMPLE)

HOLE A : 5/16 (.3125)



NO REQD			4	4	4
HOLE DIA		SEE NOTE	0.1562 (5/32)	0.166 (#19)	0.166 (#19)
POSITION		HOLE SYMBOL			
X →	Y ↑	A, B	C	D	E
1.475	1.500	A			
2.525	1.500	B			
0.600	2.375		C1		
2.350	2.375		C2		
2.350	0.625		C3		
0.600	0.625		C4		
2.000	0.250			D1	
2.000	0.750			D2	
2.000	2.250			D3	
2.000	2.750			D4	
0.200	0.200				E1
3.200	0.200				E2
3.200	2.800				E3
0.200	2.800				E4

REVISIONS

NO	DESCRIPTION	BY	DATE

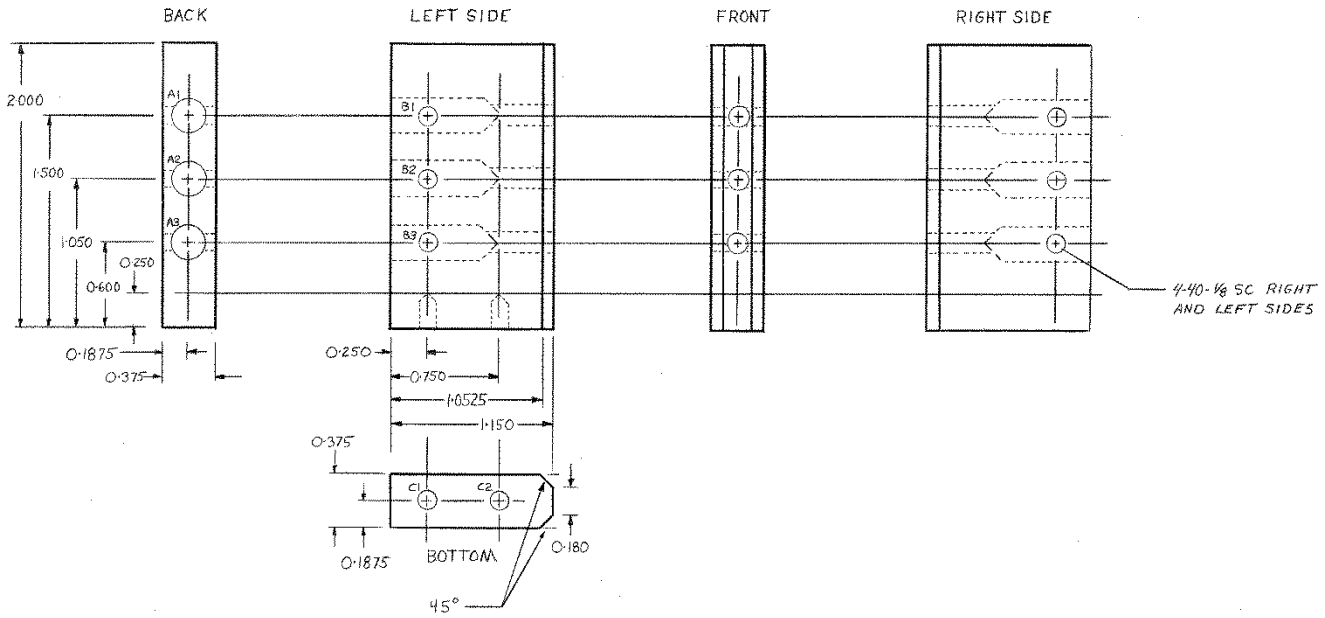
Dynacath Corporation
FORD CENTRE, SUITE 570
420 NORTH FIFTH STREET
MINNEAPOLIS, MINNESOTA 55401
612-333-4298

TOLERANCES (EXCEPT AS NOTED)
DECIMAL .
FRACTIONAL -
ANGULAR -
MATERIAL
TREATMENT
FINISH

HMT 2010
SCALE 2X
DRAWING BY S SALITERMAN
APPROVED BY
TITLE MOTION SENSOR BASE
DATE 8/17/88
DRAWING NUMBER 14

NOTES	
A) HOLES CLAMP A	
A1-A3	#30 (0.1285)
	COUNTER BORE:
	"F" (0.257)
	(DEPTH = 0.750)
B1-B3	4-40 NC
	THRU PART
C1-C3	6-32 NC
B) HOLES CLAMP B	
A1-A3	#25 (0.1495)
	(NO COUNTER BORE)
NO B1-B3	
C1-C3	6-32 NC

REVISIONS			
NO	DESCRIPTION	BY	DATE

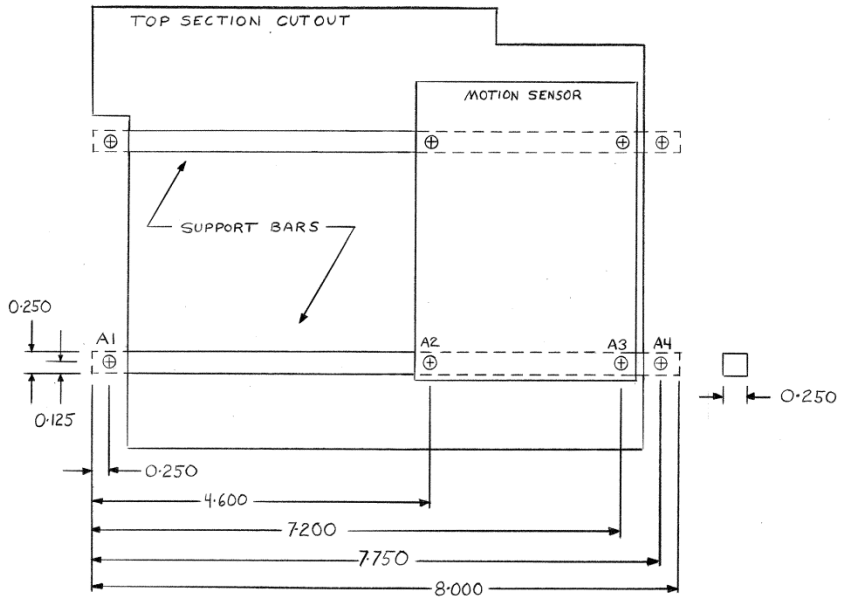


Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4298	TOLERANCES (EXCEPT AS NOTED)	HMT 2010	
	DECIMAL .	SCALE 2X	DRAWING BY S. SALITERMAN APPROVED BY
MATERIAL	FRACTIONAL .	TITLE GUIDE-WAY CLAMPS A & B	
TREATMENT	ANGULAR .	DATE 7/24/88	DRAWING NUMBER 15
FINISH			

NOTES
HOLES
A1 - A4 6-32 - NC

REVISIONS			
NO	DESCRIPTION	BY	DATE

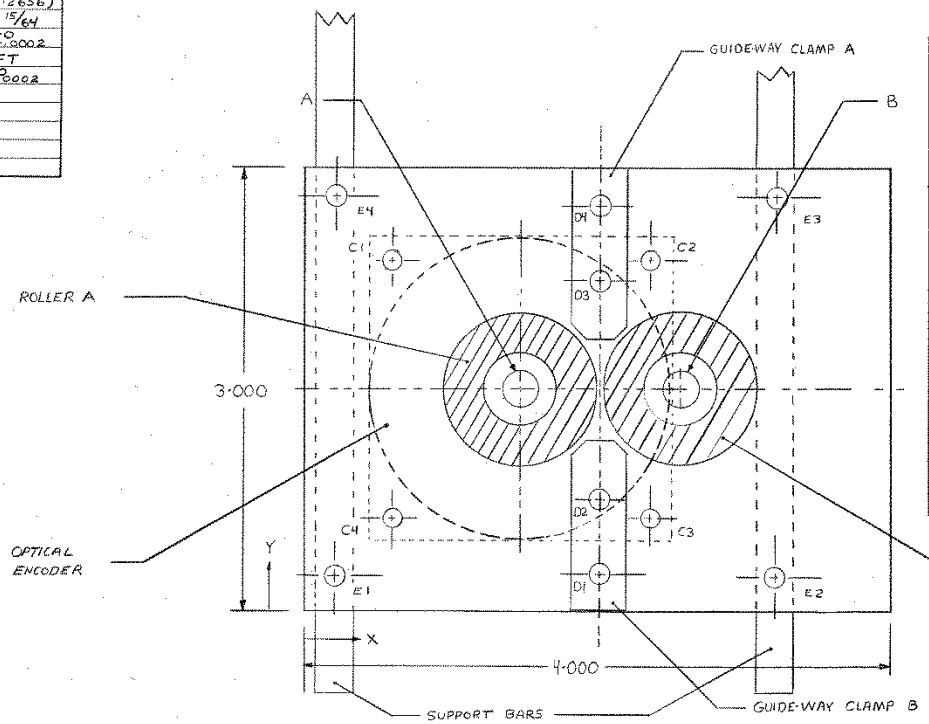
TOP VIEW



Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4298	TOLERANCES (EXCEPT AS NOTED)	HMT 2010	
	DECIMAL :	SCALE 1X	DRAWING BY S. SALITERMAN APPROVED BY
MATERIAL	FRACTIONAL :	TITLE SUPPORT BAR	
TREATMENT	ANGULAR :	DATE 8/18/88	DRAWING NUMBER 16
FINISH			

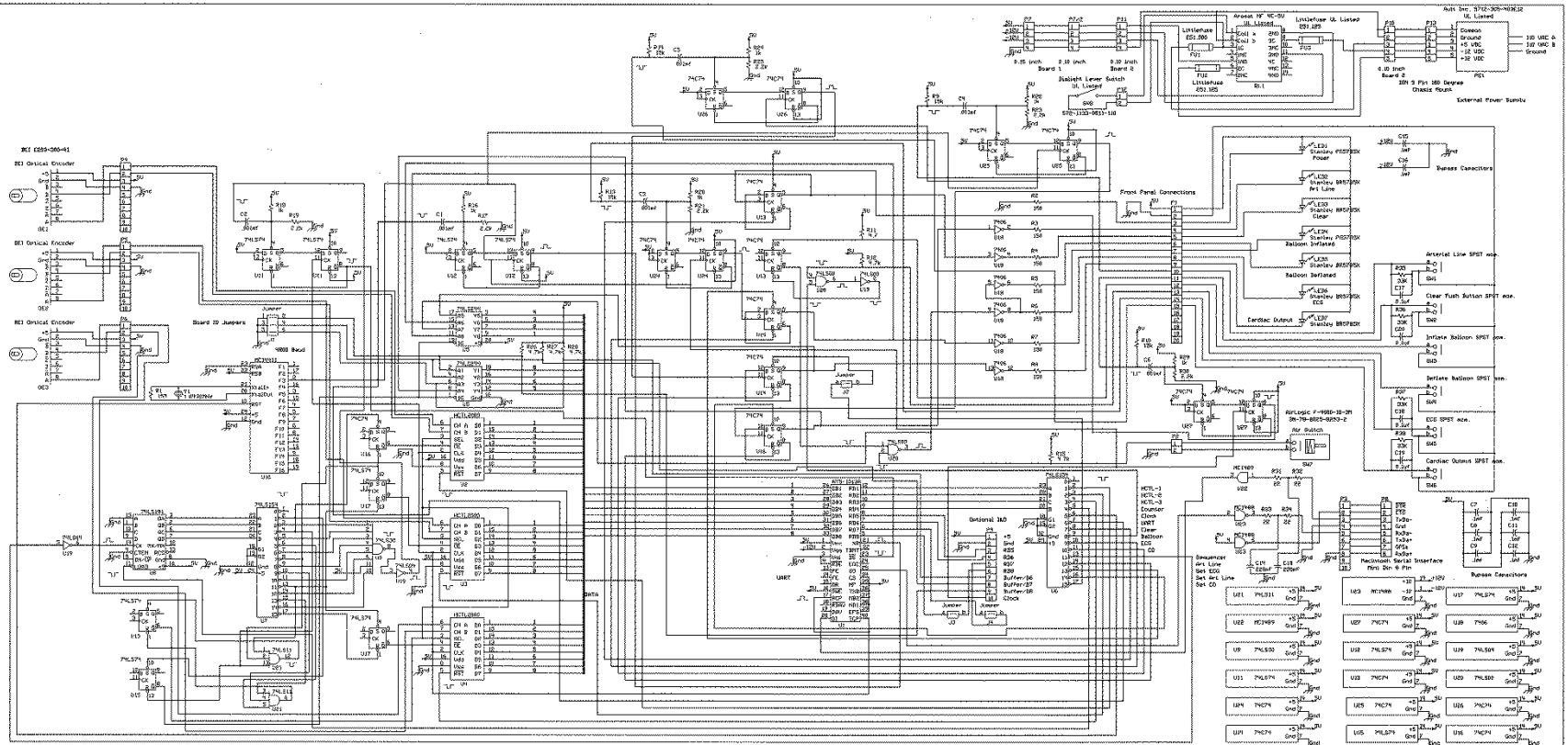
NOTES

1) ROLLER A TO B GAP = 0.045
2) ROLLER DIA. = 1.005"
3) IN PROTOTYPE:
   HOLE A = 17/64 (0.2656)
   HOLE B = START 15/64
   REAM 0.2490 +0.0002
   PRESS FIT SHAFT
   DIA. 0.2497 +0.0002



			(CLEAR 4-40 SCREW)	(CLEAR 6-32 - 1/4 NC SCREW)	
NO. REQD			4	4	4
HOLE DIA		SEE NOTE	0.1562 (5/32)	0.166 (#19)	0.166 (#19)
POSITION		HOLE SYMBOL			
X →	Y ↑	A, B	C	D	E
1.475	1.500	A			
2.525	1.500	B			
0.600	2.375		C1		
2.350	2.375		C2		
2.350	0.625		C3		
0.600	0.625		C4		
2.000	0.250			D1	
2.000	0.750			D2	
2.000	2.250			D3	
2.000	2.750			D4	
0.200	0.200				E1
3.200	0.200				E2
3.200	2.800				E3
0.200	2.800				E4

Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4296	TOLERANCES (EXCEPT AS NOTED) DECIMAL :	HMT 2010	
		SCALE 2X	DRAWING BY S SALITERMAN APPROVED BY
MATERIAL	FRACTIONAL :	TITLE MOTION SENSOR ASSEMBLY	
TREATMENT FINISH	ANGULAR :	DATE 8/18/88	DRAWING NUMBER 17



NOTES

Data Buffer

Data Bit	Test Bit	Contents
0 (1)	7	Reset Request Flag
1 (2)	6	Balloon Initiated Flag
2 (3)	5	ECG Request Flag
3 (4)	4	Cardiac Output Request Flag
4 (5)	3	Arterial Line Request Flag
5 (6)	2	ID Bit 1
6 (7)	1	ID Bit 2
7 (8)	0	ID Bit 3

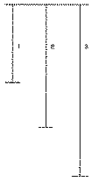
Receiver Buffer

Code	Action
1	Reset MCTL-2060 #1
2	Reset MCTL-2060 #2
3	Reset MCTL-2060 #3
4	Reset Sequencer Counter
5	Reset System Clock
6	Reset UART
7	Reset Restart Request
8	Reset Balloon To Deflated
9	Reset ECG Request
10	Reset Cardiac Output Request
11	Advance (Pulse) Sequence Counter
12	Reset Arterial Line Request
13	Set ECG Request Flag
14	Set Arterial Line Request Flag
15	Set Cardiac Output Request Flag
16	

Sequencer

Count	Action
0	No Action
1	Enable Data Buffer
2	Data Strobe UART
3	Enable OE1, SEL, Disable Data Buffer
4	Data Strobe UART
5	Disable SEL
6	Data Strobe UART
7	Enable OE2, SEL, Disable OE1
8	Data Strobe UART
9	Disable SEL
10	Data Strobe UART
11	Enable OE3, SEL Disable OE2
12	Data Strobe UART
13	Disable SEL
14	Data Strobe UART
15	Disable OE3

Number of Encoders Installed



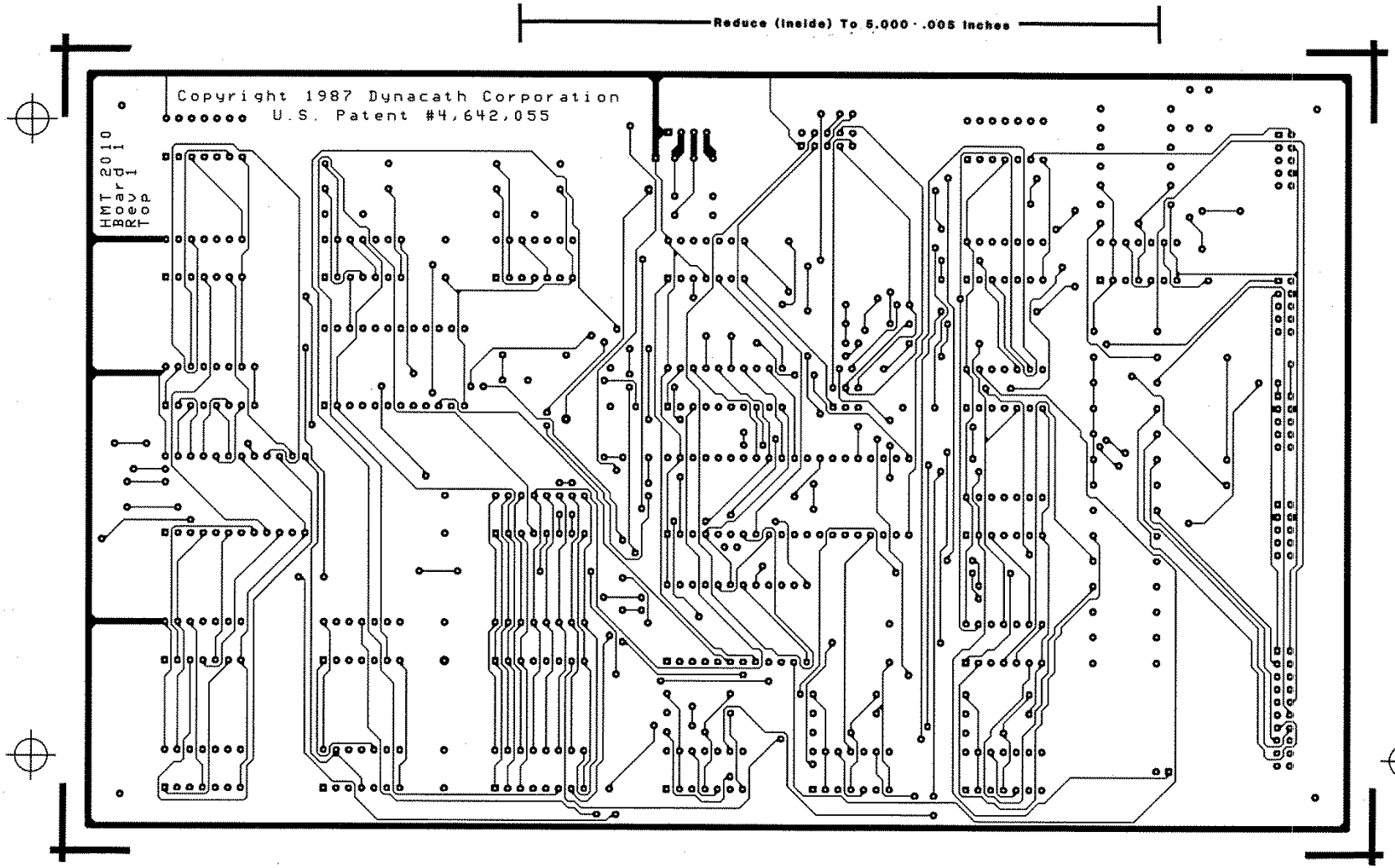
Transmitted Word Order

Encoders Installed	Number of Bytes	Contents
1	3	Data Buffer | High Byte OE1 | Low Byte OE1 |
2	5	Data Buffer | High Byte OE1 | Low Byte OE1 | High Bytes OE2 | Low Byte OE2 |
3	7	Data Buffer | High Byte OE1 | Low Byte OE1 | High Bytes OE2 | Low Byte OE2 | High Byte OE3 | Low Byte OE3

Revision History

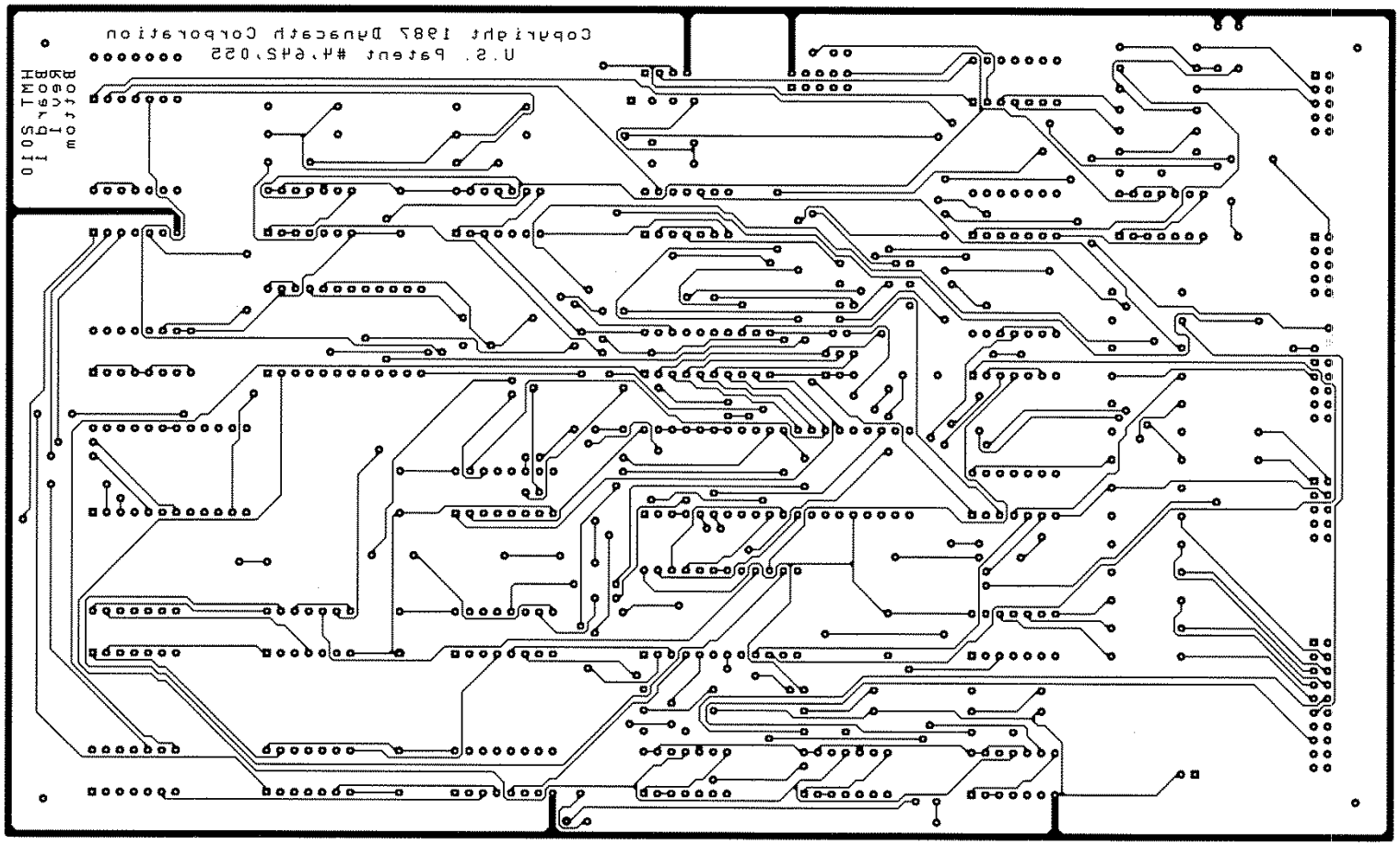
5-3-90 790a; C17-20; R20-28; Removed LED 4 & 5; 89.28.23.09
ONLY units produced have these changes incorporated already!

BIOMEDATA CORPORATION Meadowbrook Medical Bldg. 6490 Excelsior Blvd. M-102 Minneapolis, Minnesota 55426 612-926-8773	Tolerances	Critical Care & Neodynamic Monitoring Trainer
	Decimal	Scale: Drawing By: Steven G Saltzman Approved By:
Material	Fractional	Main Circuit Logic
Treatment Finish	Angular	Date: 9/26/87 Drawing Number: Dunal dwg/E1

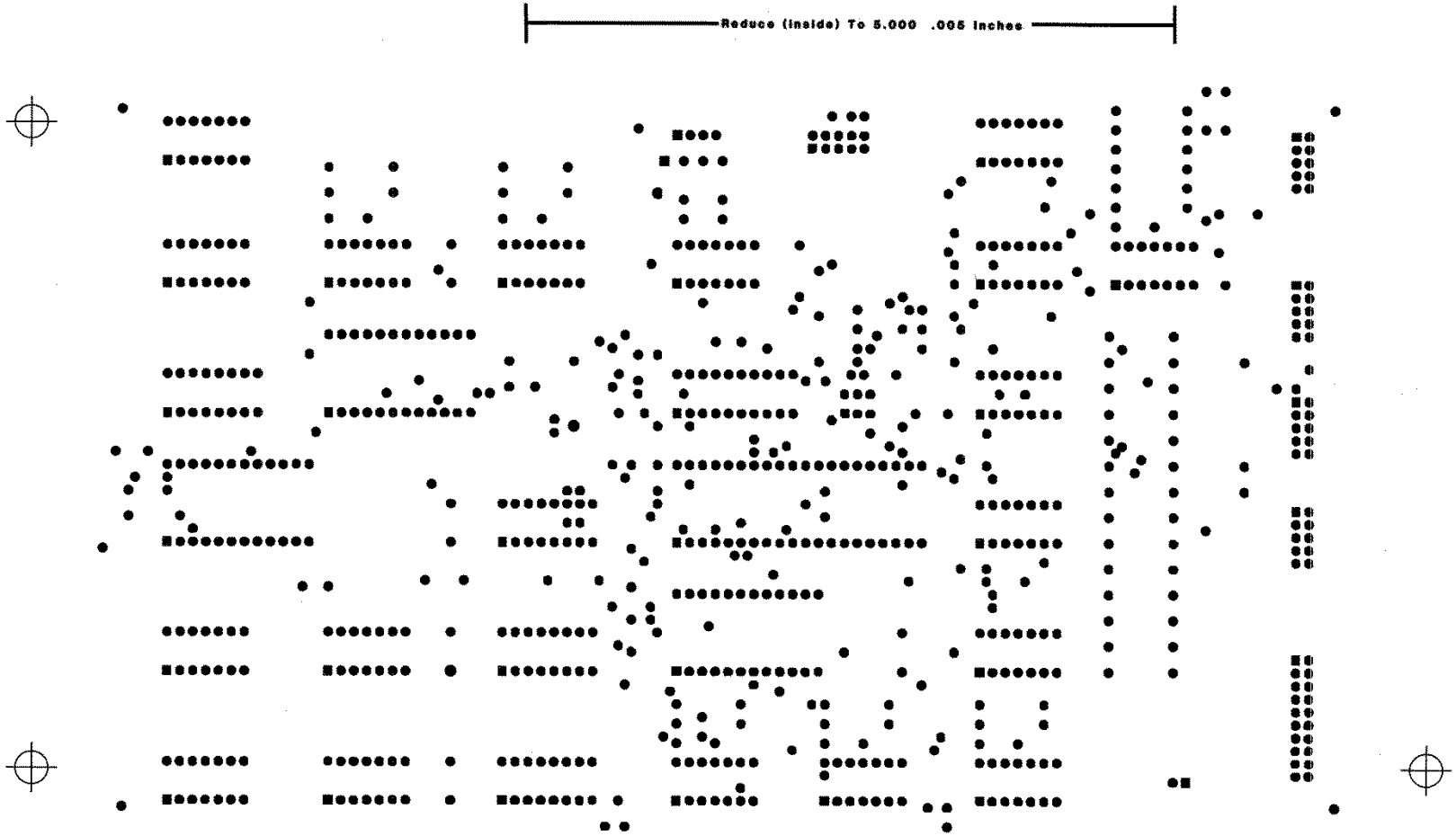


Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4296	TOLERANCES (EXCEPT AS NOTED) DECIMAL .	HMT 2010	
		SCALE 2X	DRAWING BY Saltzman APPROVED BY
MATERIAL	FRACTIONAL .	TITLE Component Layer (Top)	
TREATMENT FINISH	ANGULAR .	DATE 9/29/87	DRAWING NUMBER Board 1 * 1

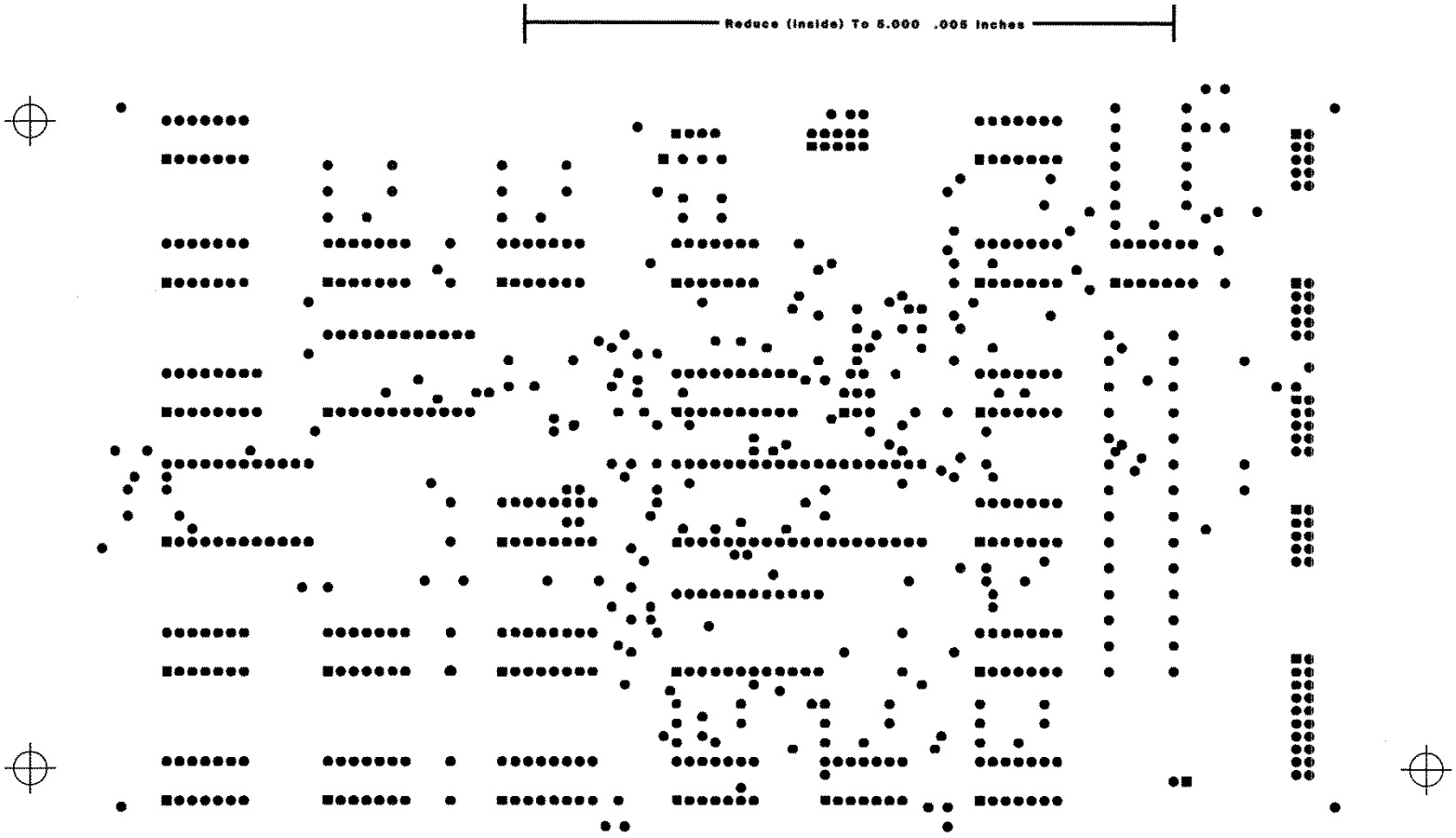
Reduce (inside) To 5.000 .005 inches



Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4298	TOLERANCES (EXCEPT AS NOTED) DECIMAL :	HMT 2010	
		SCALE 2X	DRAWING BY Saliterman APPROVED BY
MATERIAL	FRACTIONAL :	TITLE Solder Layer (Bottom)	
TREATMENT	ANGULAR :	DATE	DRAWING NUMBER Board 1 #2
FINISH			

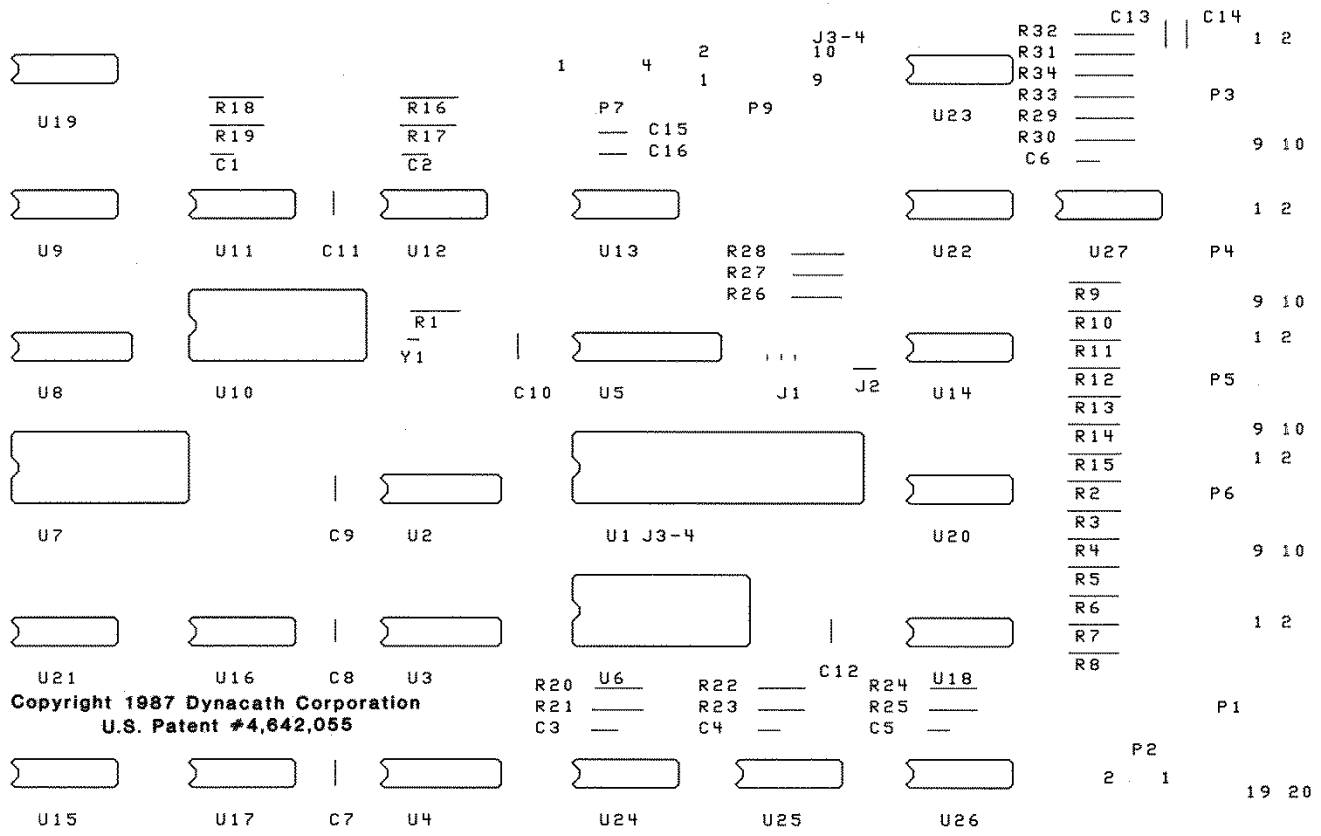


Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4298	TOLERANCES (EXCEPT AS NOTED) DECIMAL :	HMT 2010 SCALE 2X DRAWING BY Saliterman APPROVED BY
MATERIAL	FRACTIONAL :	TITLE Component Mask (Top)
TREATMENT FINISH	ANGULAR :	DATE 9/29/87 DRAWING NUMBER Board 1 # 3



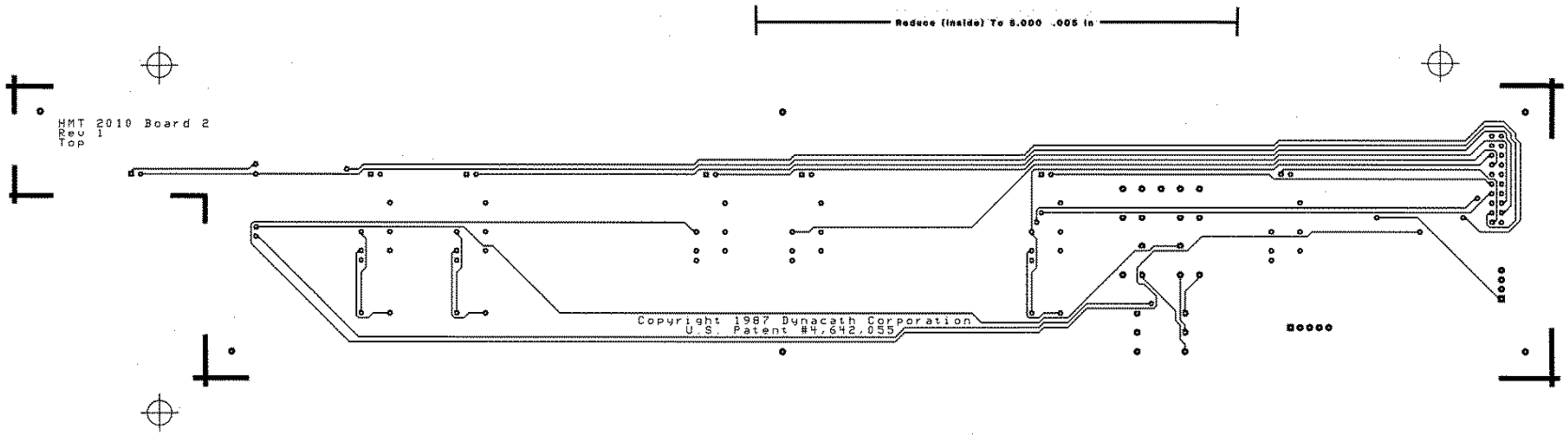
Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4298	TOLERANCES (EXCEPT AS NOTED) DECIMAL .	HMT 2010 SCALE 2X	DRAWING BY Galiterman APPROVED BY
MATERIAL	FRACTIONAL .	TITLE Solder Side Mask (Bottom)	
TREATMENT FINISH	ANGULAR .	DATE 9/29/87	DRAWING NUMBER Board 1 #4

Reduce (Inside) To 5.000 .005 Inches

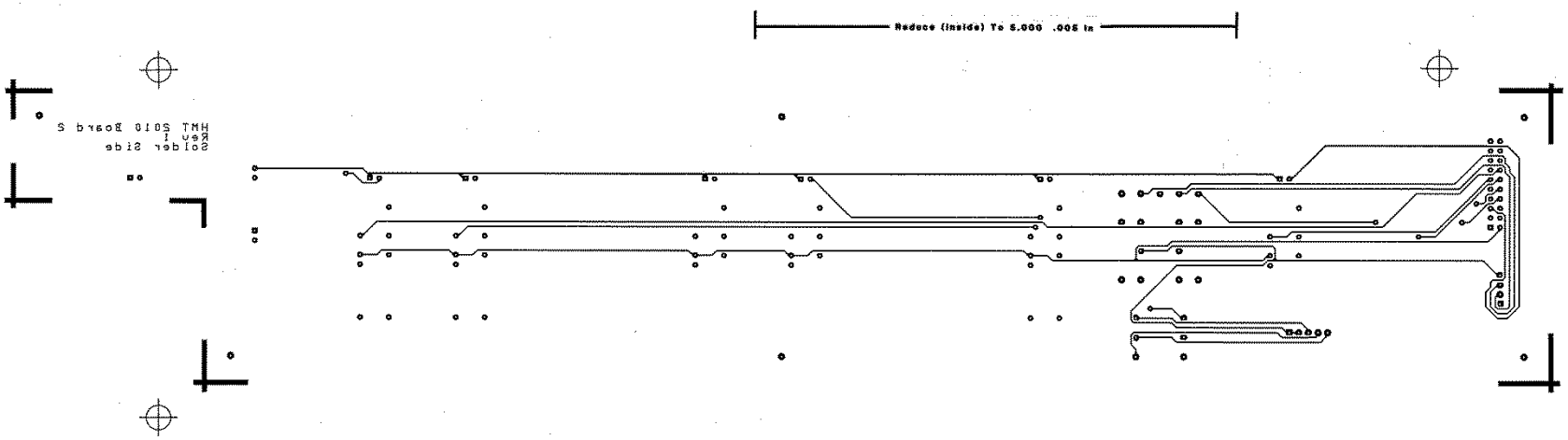


Copyright 1987 Dynacath Corporation
U.S. Patent #4,642,055

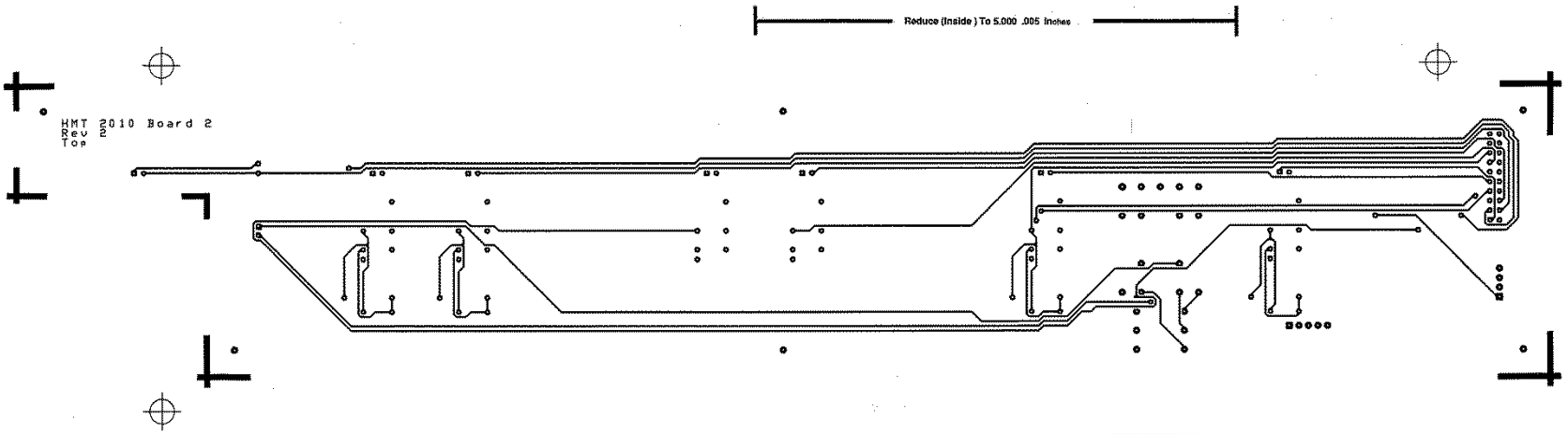
Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4296	TOLERANCES (EXCEPT AS NOTED) DECIMAL .	HMT 2010 SCALE 2X DRAWING BY SALITERMAN APPROVED BY
MATERIAL TREATMENT FINISH	FRACTIONAL ANGULAR .	TITLE Silkscreen DATE DRAWING NUMBER Board 1 # 5



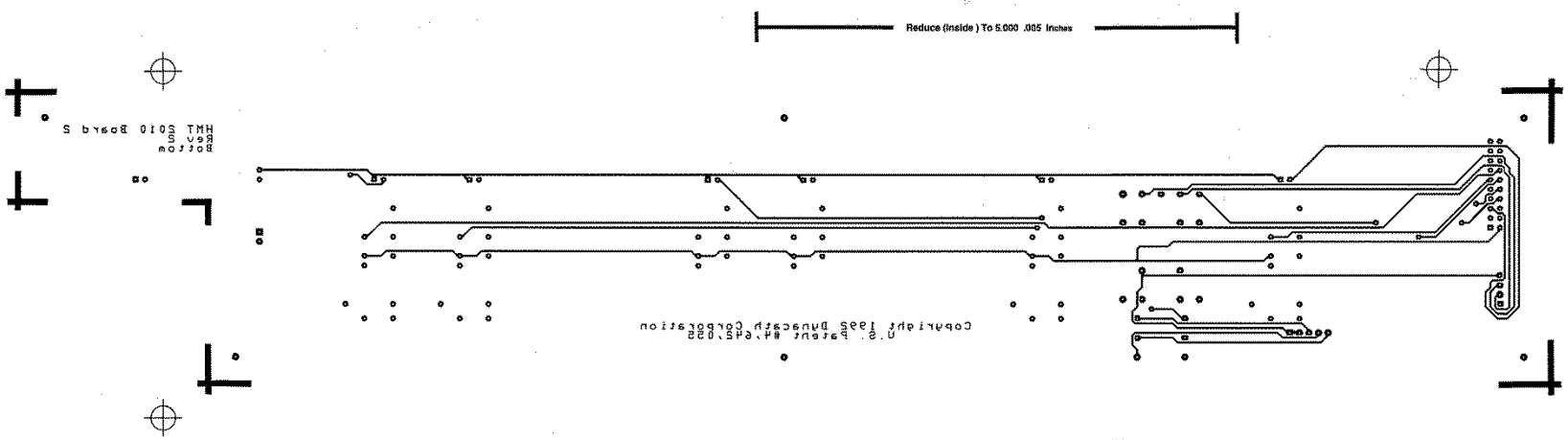
Dynacath Corporation FORD CENTRE, SUITE 370 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4266	TOLERANCES (EXCEPT AS NOTED) DECIMAL . FRACTIONAL . ANGULAR .	HMT 2010 SCALE 2X DRAWN BY T. TALITERMAN APPROVED BY TITLE COMPONENT LAYER (TOP)
MATERIAL TREATMENT FINISH		DATE 10/26/87 DRAWING NUMBER BOARD 2 #1



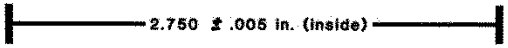
Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-330-4268	TOLERANCES (EXCEPT AS NOTED) DECIMAL . FRACTIONAL . ANGULAR .	HMT 2010 SCALE 2X DRAWING BY S. SALITERMAN APPROVED BY TITLE SOLDER LAYER (BOTTOM) DATE 10/26/87 DRAWING NUMBER BOARD 2 #2
MATERIAL TREATMENT FINISH		



Dynacath Corporation Meadowbrook Medical Building W-110 6490 Excelsior Blvd. Minneapolis, Minnesota 55426 (612) 920-8773	TOLERANCES (EXCEPT AS NOTED)	PROJECT: Critical Care Patient Simulator 2010	
	DECIMAL	SCALE: 2X	DRAWN BY: Steven S. Saltzman
MATERIALS: Specifications Attached	FRACTIONAL	TITLE: Component Layer (Top)	
TREATMENT	ANGULAR	DATE: 4/5/93	DRAWING NUMBER: Board 2-Rev 2 #1
FINISH			



Dynacath Corporation Meadowbrook Medical Building W-110 6490 Excelsior Blvd. Minneapolis, Minnesota 55426 (612) 920-8773	TOLERANCES (EXCEPT AS NOTED)	PROJECT: Critical Care Patient Simulator 2010	
	DECIMAL	SCALE: 2X	DRAWN BY: Steven S. Schlierman
MATERIALS: Specifications Attached	FRACTIONAL	TITLE: Solder Layer (Bottom)	
TREATMENT	ANGULAR	DATE: 4/5/93	DRAWING NUMBER: Board 2-Rev 2 #2
FINISH			



The Dynacath Critical Care & Hemodynamic Monitoring Training System™

Program	Cases	Subjects	Waveforms

Copyright 1988, Dynacath Corporation
Copyright 1983-1988, Apple Computer, Inc.

Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4298	TOLERANCES (EXCEPT AS NOTED) DECIMAL .	HMT 2010	
		2 3/4 x 1 3/4 RND CORNER	SCALE
			DRAWING BY S. SALITERMAN APPROVED BY
	FRACTIONAL .	TITLE DISKETTE LABEL	
MATERIAL WHITE HI GLOSS PERMANENT TREATMENT	ANGULAR .	DATE 5/14/88	DRAWING NUMBER DL001
FINISH VARNISH			

Dynacath Corporation
570 Ford Centre
420 N. 5th St.
Minneapolis, MN 55401
(612) 333-4298

- Do Not Insert Needles Or Infuse Fluids.
- For Educational Use Only.

U.S. Patent No. 4,642,055

This equipment complies with the requirements in Part 15 of FCC Rules for a Class A computing device. Operation of this equipment in a residential area may cause unacceptable interference to radio and TV reception requiring the operator to take whatever steps are necessary to correct the interference.

Connections:

Power Supply

Macintosh Computer

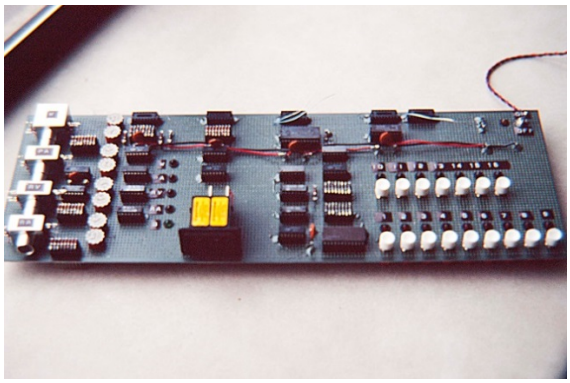
Ault, Inc. 5712-305-403E12 or equivalent UL Listed, 5 & 12 VDC input.

Serial Number:	**Model 2010**

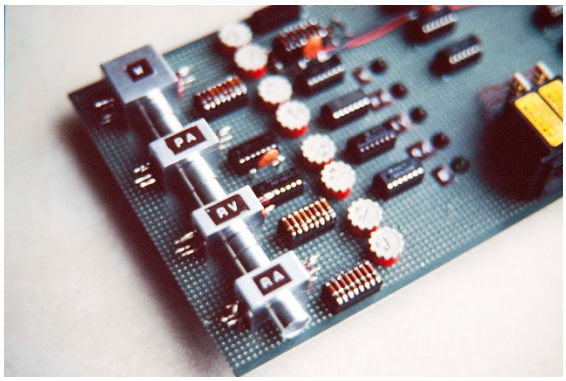
Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4298	TOLERANCES (EXCEPT AS NOTED) DECIMAL :	HMT 2010	SCALE DRAWING BY S. SALITERMAN APPROVED BY
MAX. DIM. = 2¼" x 3½"	FRACTIONAL :	TITLE BACK PANEL LABEL	
MATERIAL			
TREATMENT FINISH	ANGULAR :	DATE 5/14/88	DRAWING NUMBER BPL 001

Hardware Prototype A Photographs

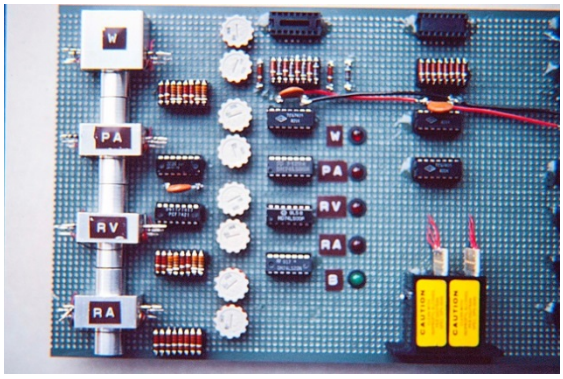
Apple ll Computer



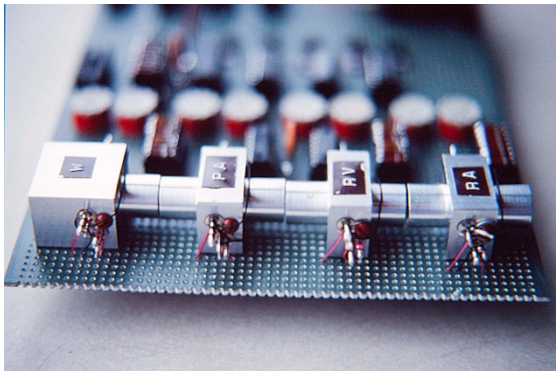
Prototype A Breadboard



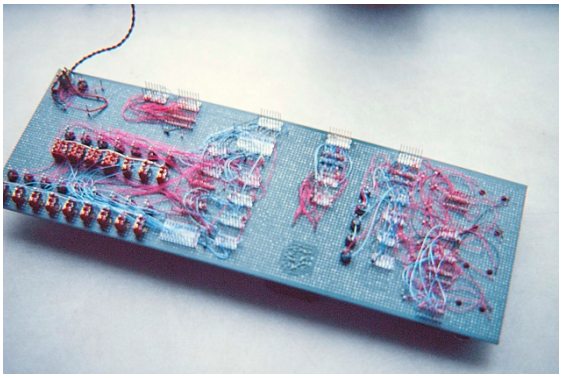
Closeup of Balloon Detector Blocks



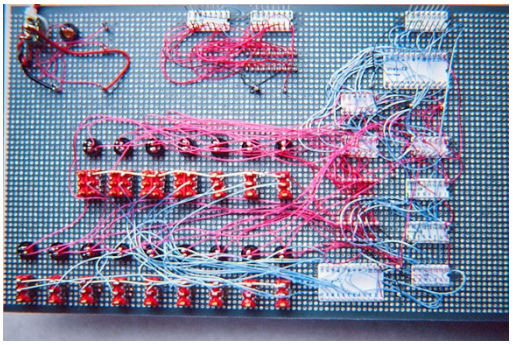
Closeup of Potentiometers



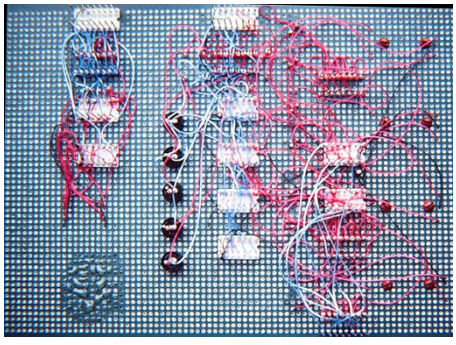
Photodiodes and LEDs



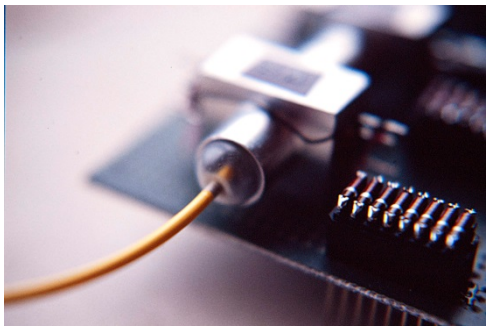
Bottom of Board Showing Wire Wrap



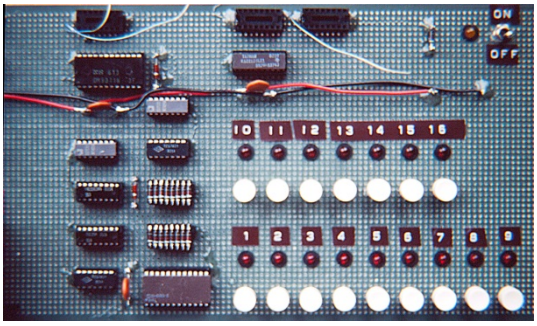
Closeup of Wire Wraps (1)



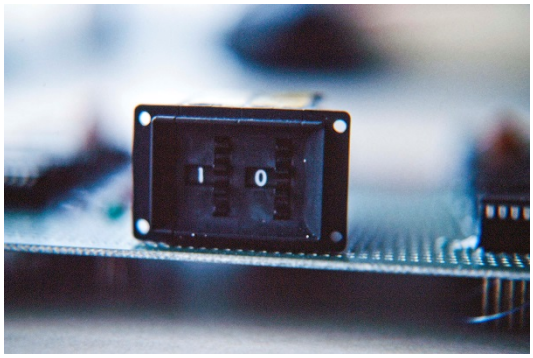
Closeup of Wire Wraps (2)



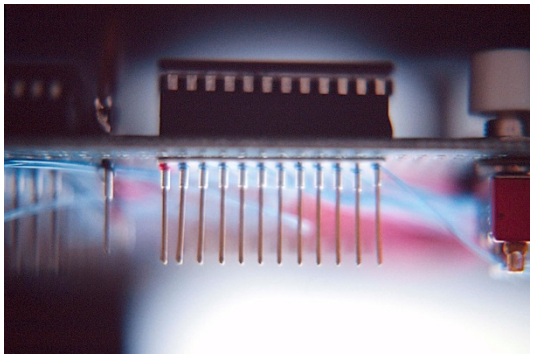
Catheter Balloon Entering Detectors



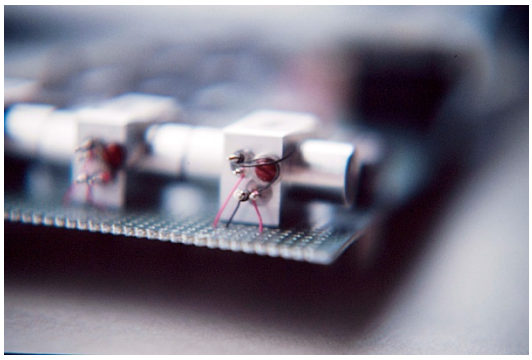
Button Controls



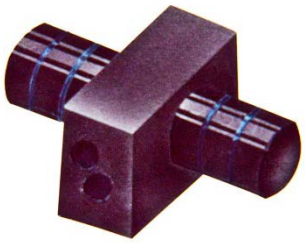
Thumbwheel Control



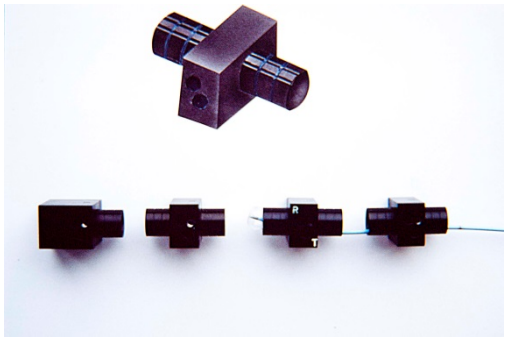
Wire Wrap Socket



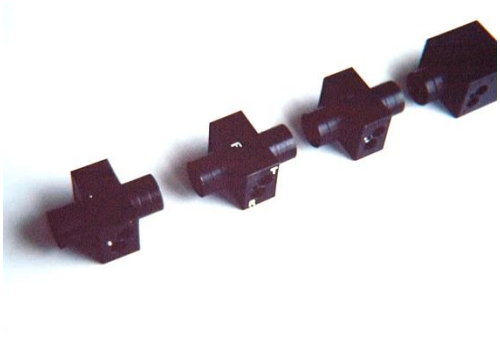
Closeup of Photodiode and LED



Airbrush of Concept Detector Block



Sequence of Detector Blocks

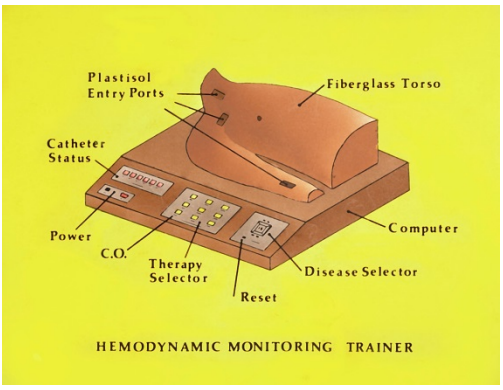


Oblique View of Detector Sequence

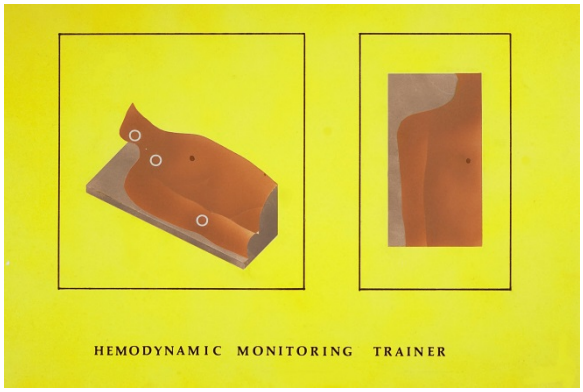
Hardware

Prototype B

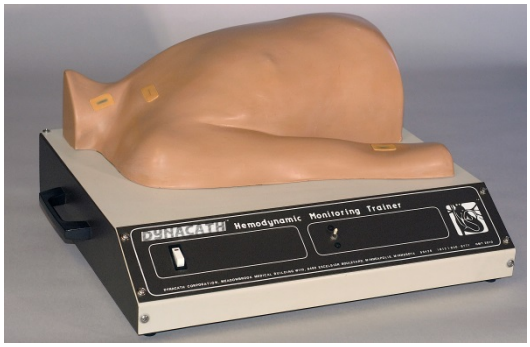
Photographs
Mechanical Drawings
Electronic Schematics



Airbrush of Concept Trainer

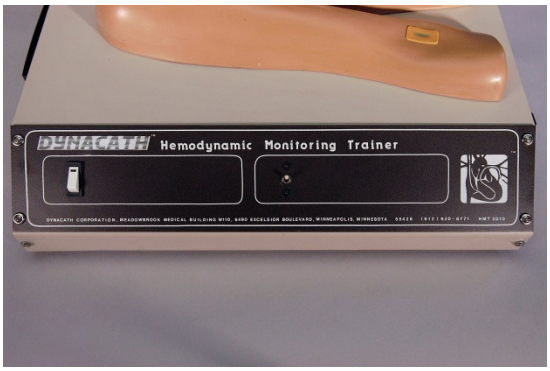


Airbrush of Concept Manikin



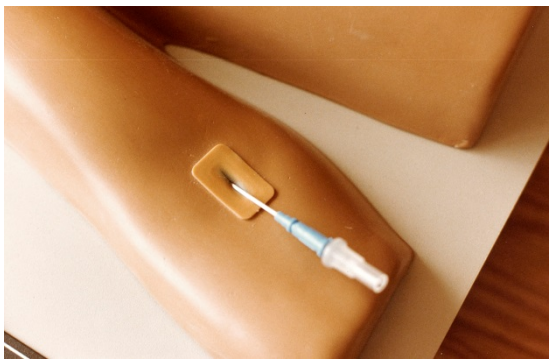
Prototype Dynacath Trainer

Prototype Backside

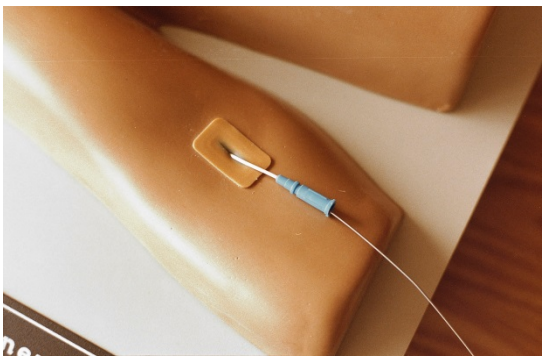


Prototype Front Panel

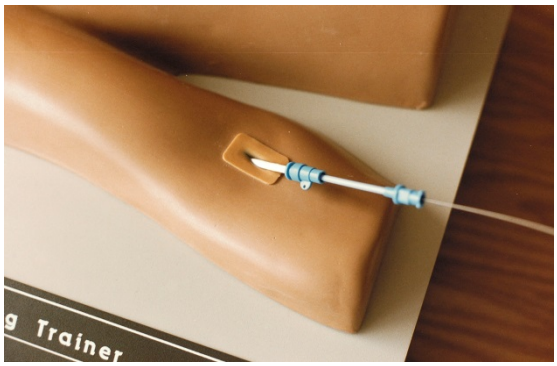
Prototype On/OFF Switch



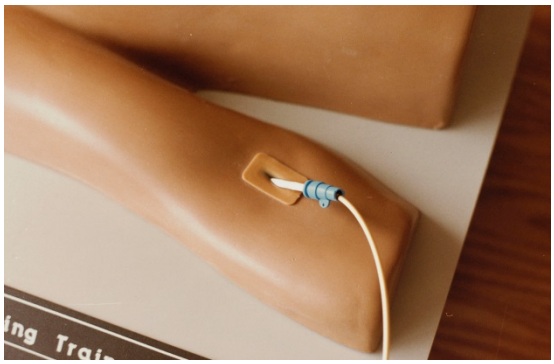
IV Needle Insertion



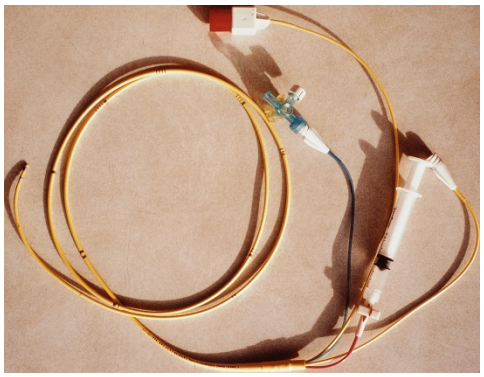
Spring Wire



Introducer, Dilator and Wire



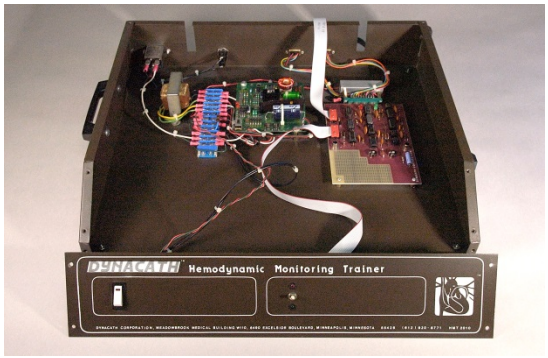
Catheter



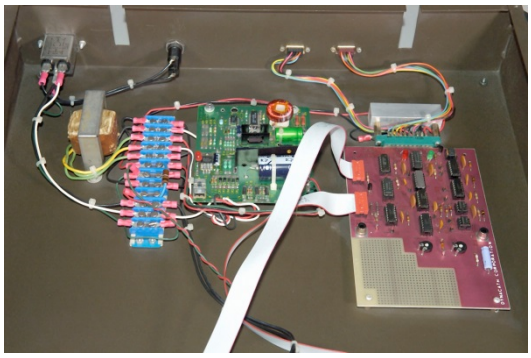
Pulmonary Artery Catheter

Prototype Workstation

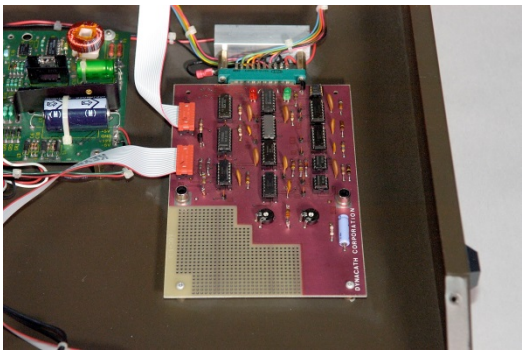
Software Development on Lisa Computer



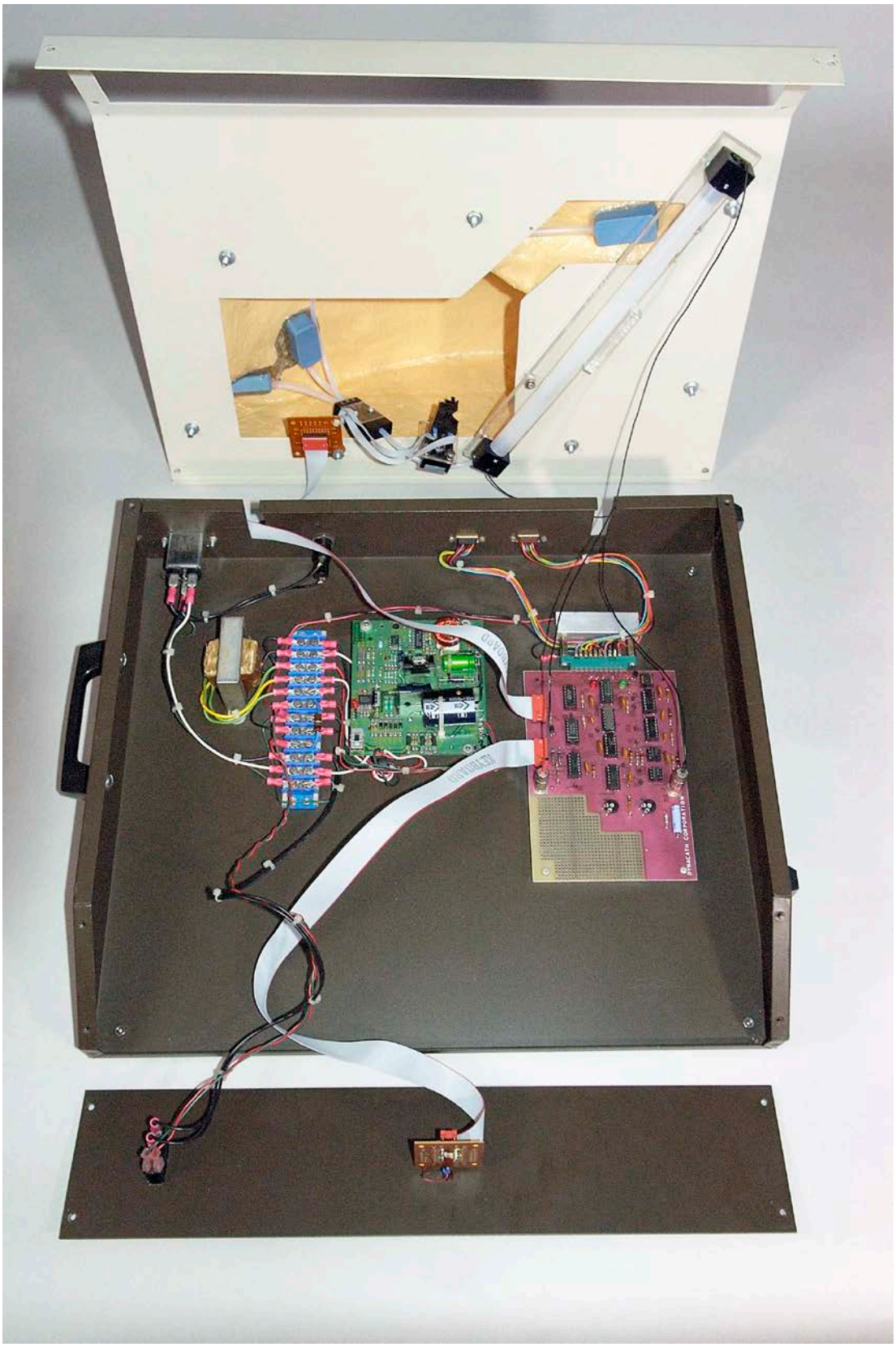
Prototype Inside View



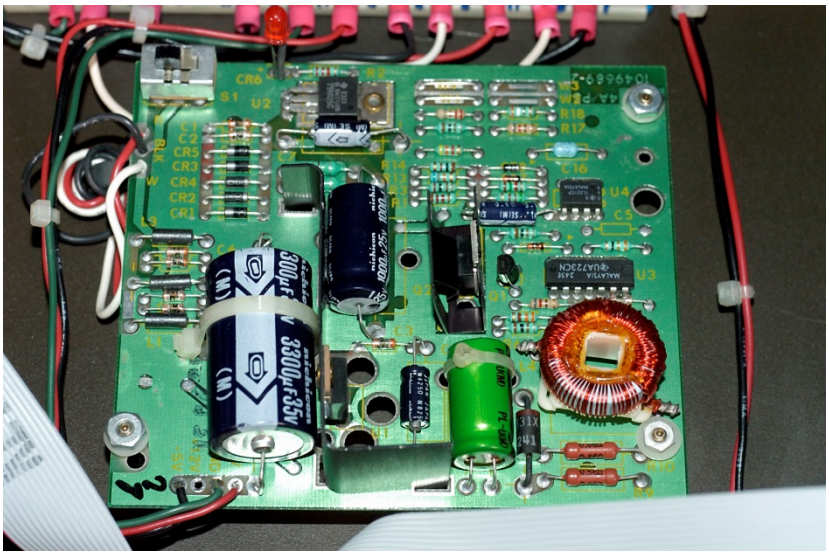
Power Supply & Main Circuit Board



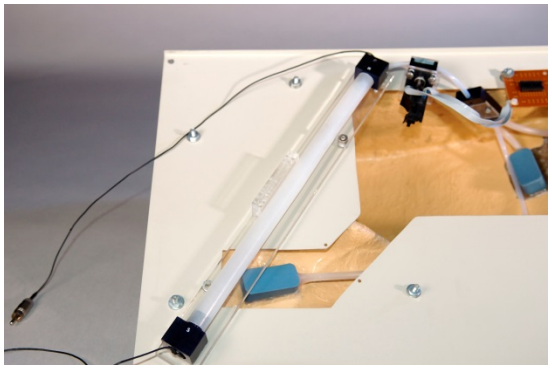
Main Circuit Board



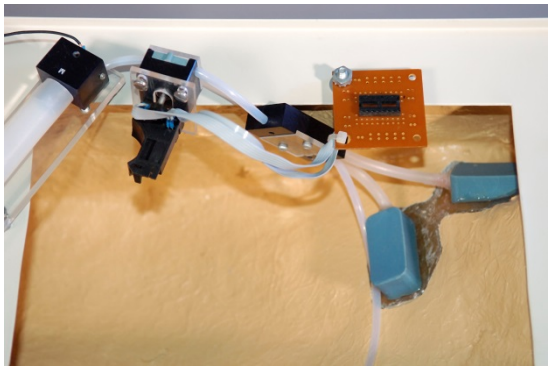
Prototype Inside View



Prototype Power Supply

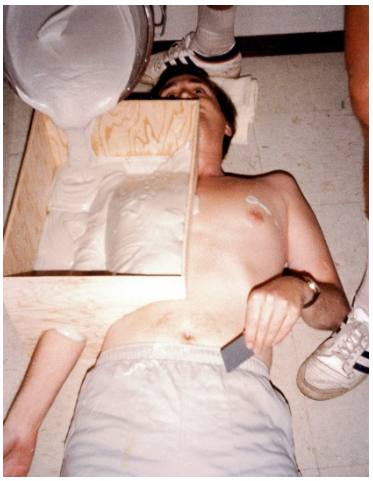


Prototype Acoustic Chamber



Prototype Catheter Guideway

Manikin Mold Plaster Splash Box



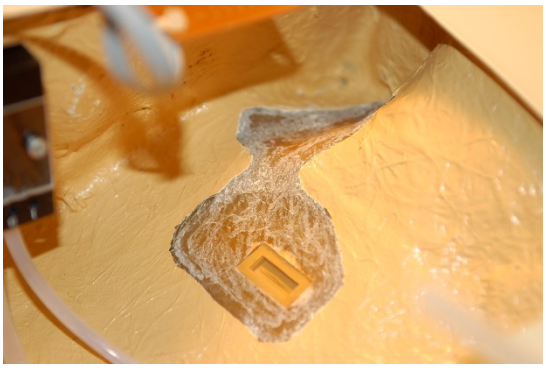
Pouring the Mold with Plaster

Plaster Torso Casting

Torso Mold and Fiberglass Casting

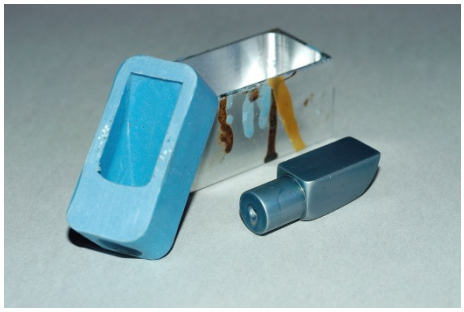
Prototype Fiberglass Torso

Inside View of Torso

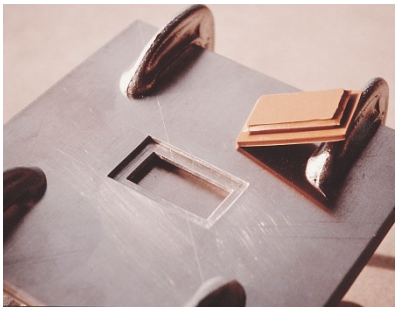


Prep for Gluing Coupler

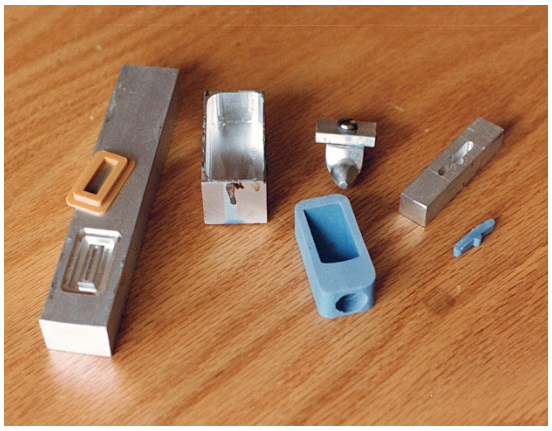
Catheter Coupler



Mold for Casting Plastisol Coupler

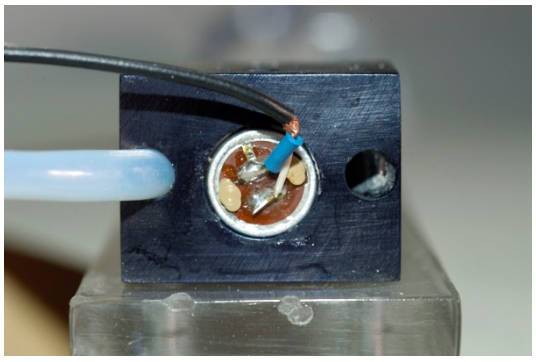


Mold and Plastisol Skin Port

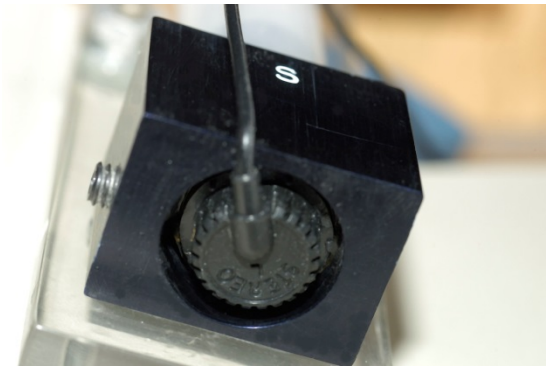


Various Prototype Molds & Castings

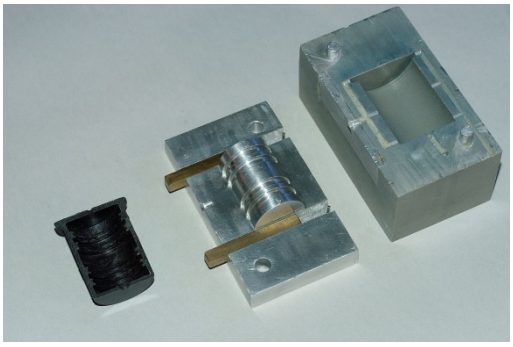
Prototype Cast Acoustic Coupler



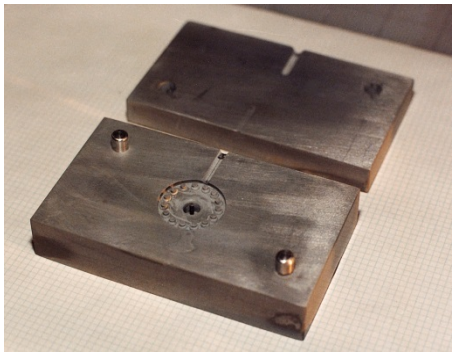
Acoustic Coupler Microphone



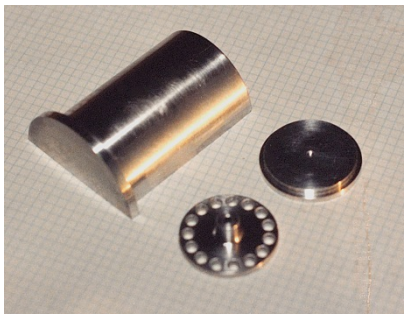
Acoustic Coupler Speaker



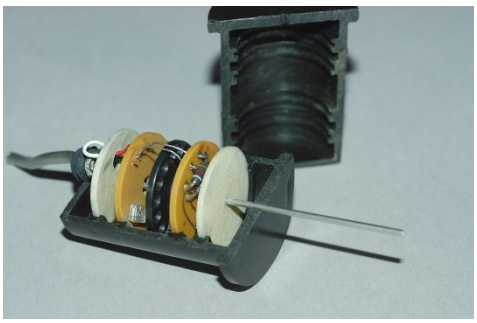
Casting & Mold of Optical Encoder Shell



Mold for Encoder Hole Wheel

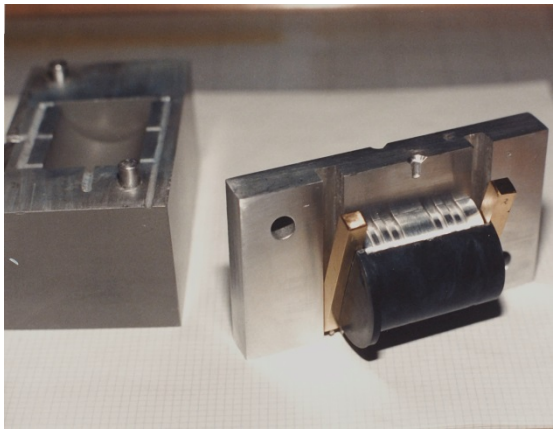


Models for Casting Molds

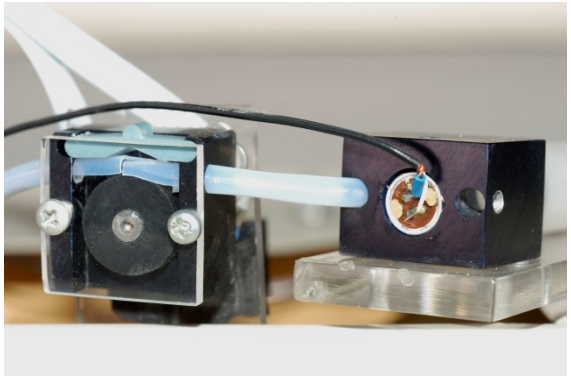


Assembled Optical Encoder

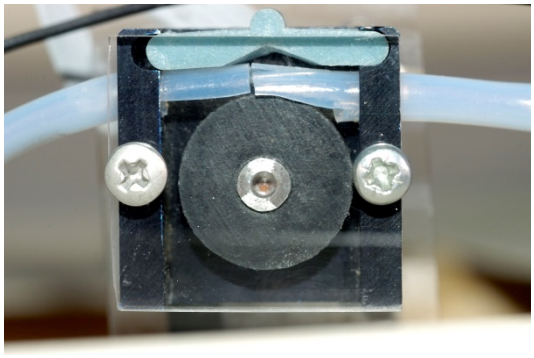
ABS Plastic Injection Molded Shells



Mold for Shells

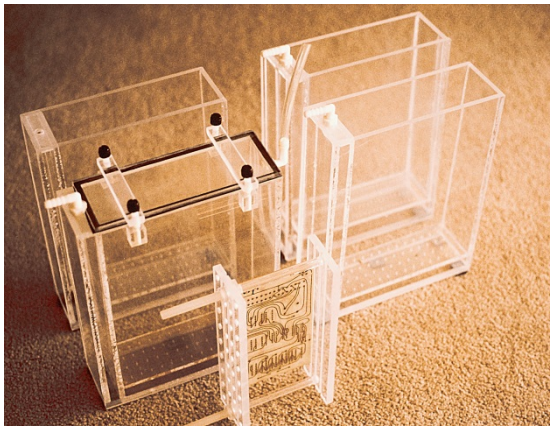


Encoder Roller & Guideway



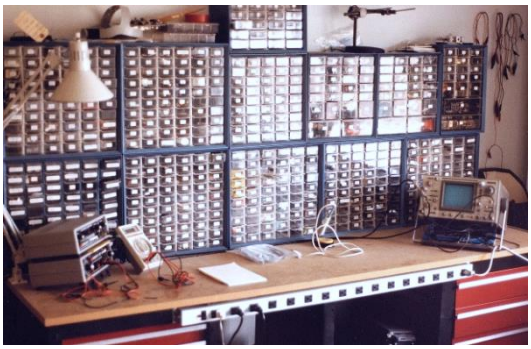
Optical Encoder Roller

Catheter Port Combiner



Fabricated Circuit Board Etching Tanks

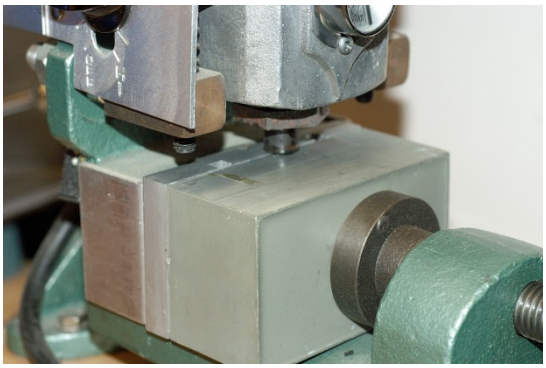
Drafting Area



Prototyping Bench

Front Panel Silk Screening

Plastic Injection Molding Machine



Plastic Injection Molding Machine

Plastic Injection Molding Machine

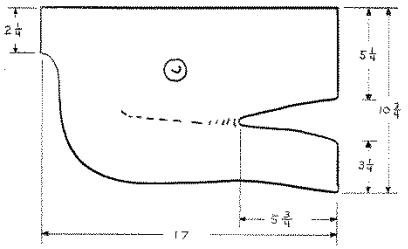
LISA Computer for Software Development

Later Software Development

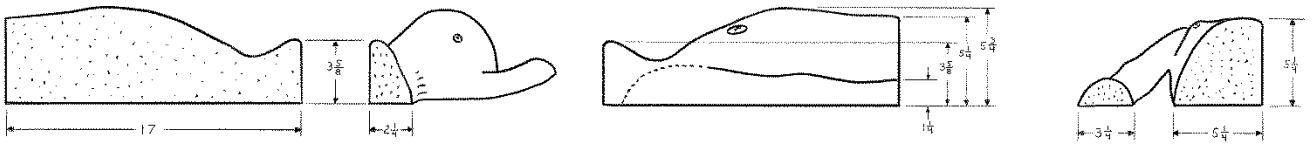
Prototype Software Diskette

NOTES
1. TONGUE AND GROOVE AL CAST ROTATIONAL MOLD TOOL
2. REMOVE SURFACE FLAWS
3. FILL SHELL HOLLOW
4 SQUARE SIDES BACK & BOTTOM
5 CREATE $\frac{1}{8}$" RADIUS ON BOTTOM
6. NUTS A-F PLACED IN TOOL PRIOR TO EACH ROTATIONAL MOLDING OPERATION
7. FINISH TOOL TO YIELD PART WITH MATTE TOP AND PEBBLE TEXTURE SIDES - SEE SAMPLES
8. DISCUSS LOCATIONS B & D

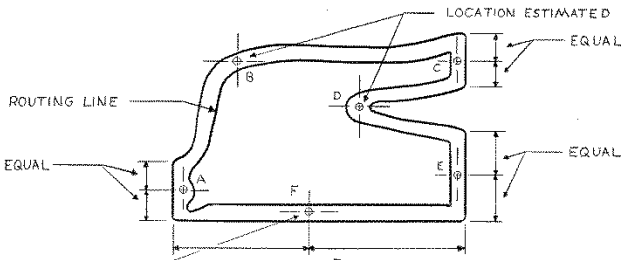
REVISIONS			
NO	DESCRIPTION	BY	DATE
1	NUTS MOVED IN $\frac{1}{2} \rightarrow \frac{5}{8}$	SSS	3/21/87



PATTERN MEASUREMENTS ≈ FROM FIBERGLASS SHELL



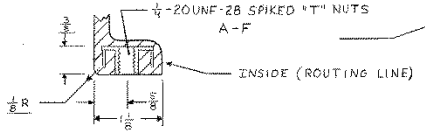
PATTERN VIEWS ABOVE ↑



PART DIM DEP ON ALCAST AND PLASTIC SHRINKAGE

BOTTOM VIEW MOLDED PART

CROSS SECTIONAL VIEW

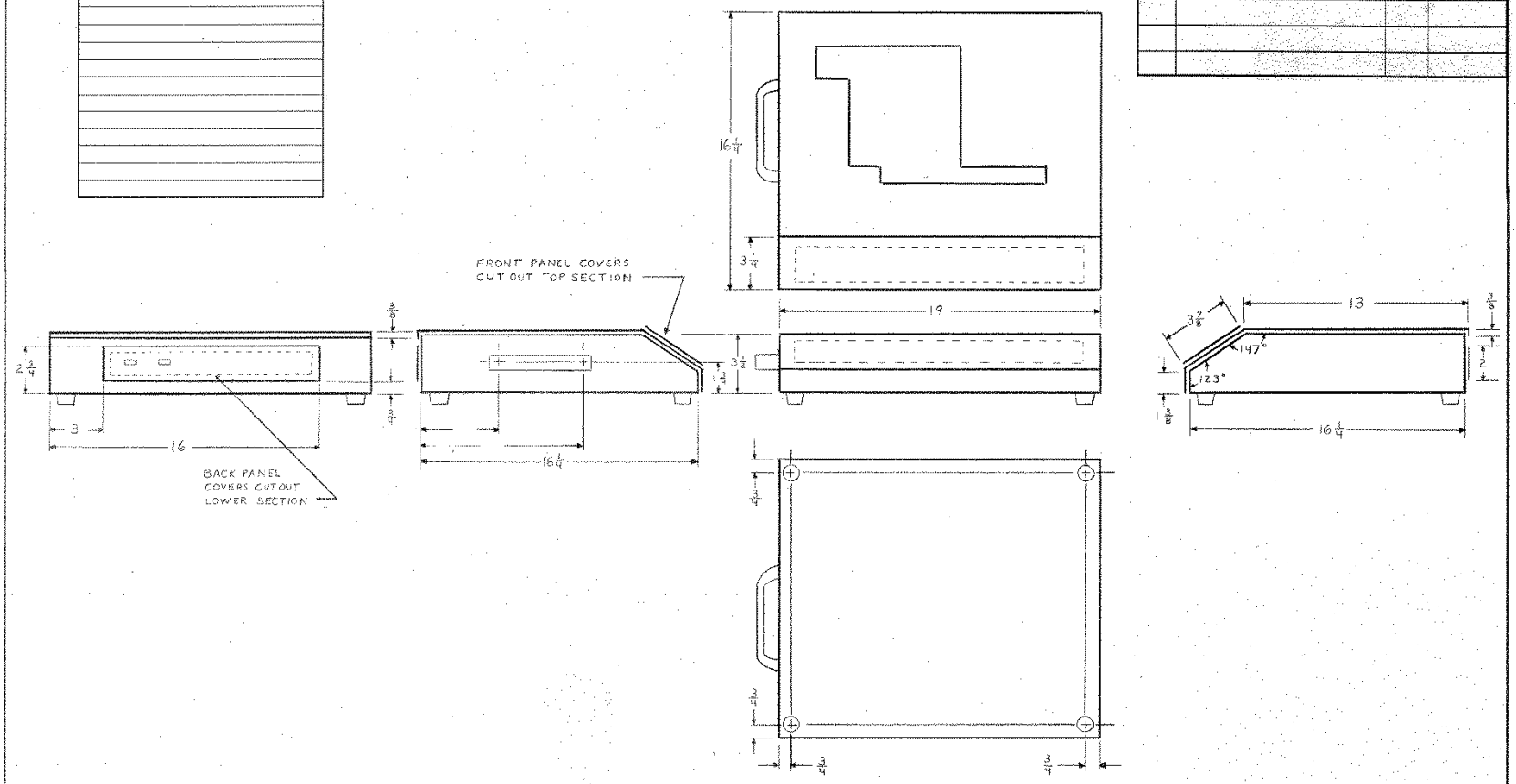


(FASTEN TO CHASSIS WITH $\frac{1}{4}$-20 UNF-2A $\frac{3}{8}$ RND HD MACH SCR)

Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4298	TOLERANCES (EXCEPT AS NOTED)	TRAINER 2010	
	DECIMAL .	SCALE 1/4	DRAWING BY S SALITERMAN APPROVED BY
	FRACTIONAL .	TITLE MANIKIN PATTERN/PART	
MATERIAL	ANGULAR .	DATE 1/30/87	DRAWING NUMBER HMT 001
TREATMENT			
FINISH			

NOTES

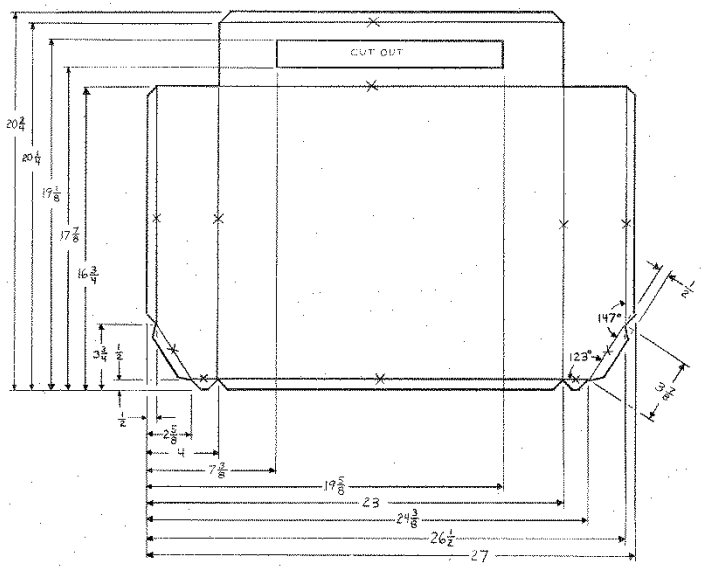
REVISIONS			
NO	DESCRIPTION	BY	DATE



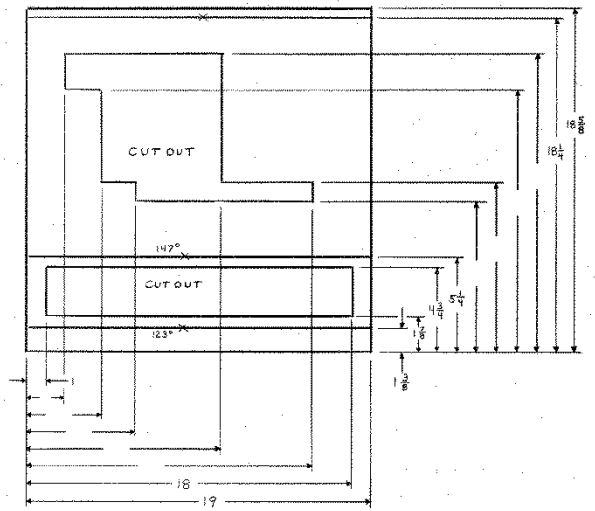
Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 512-333-4298	TOLERANCES (EXCEPT AS NOTED)	TRAINER 2010	
	DECIMAL	SCALE 1/4"	DRAWING BY S. SALITERMAN APPROVED BY
Prototype	FRACTIONAL	TITLE CHASSIS - OVERVIEW	
MATERIAL	ANGULAR	DATE 2/26/87	DRAWING NUMBER HMT 002
TREATMENT			
FINISH			

REVISIONS			
NO.	DESCRIPTION	BY	DATE

BOTTOM SECTION



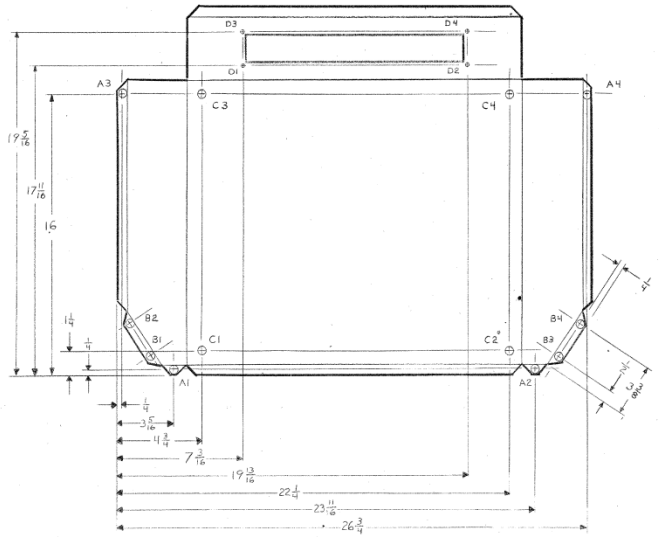
TOP SECTION

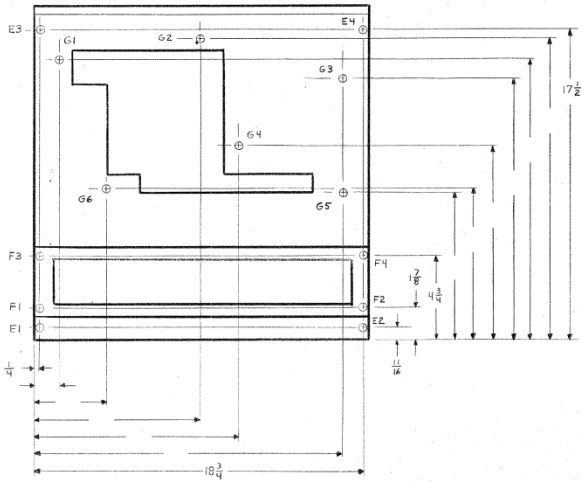


NOTES
1. X = 90° BEND UNLESS SPEC.
2. ADJUST TO FIT TOP TO BOTTOM

Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4298	TOLERANCES (EXCEPT AS NOTED) DECIMAL ±	TRAINER 2010	SCALE 1/4 in DRAWING BY S. SALITERMAN APPROVED BY
Prototype MATERIAL 16 GUAGE CR STEEL	FRACTIONAL 1/32 ANGULAR	TITLE CHASSIS - SHEAR + PUNCH	
TREATMENT FINISH		DATE 2/26/87	DRAWING NUMBER HMT 003

REVISIONS			
NO	DESCRIPTION	BY	DATE



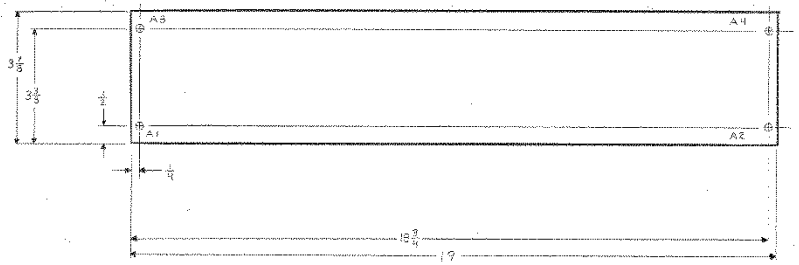


NOTES				
1 SELF-CLINCHING NUTS :				
A1 - A4	8-32	HS .213 OD	5/16	
B1 - B4	8-32	HS .213 OD	5/16	
D1 - D4	4-40	HS .166 OD	1/4	
2 HOLES :				
C1 - C4				
E1 - E4	5/16			
F1 - F4	5/16			
G1 - G6	5/16			

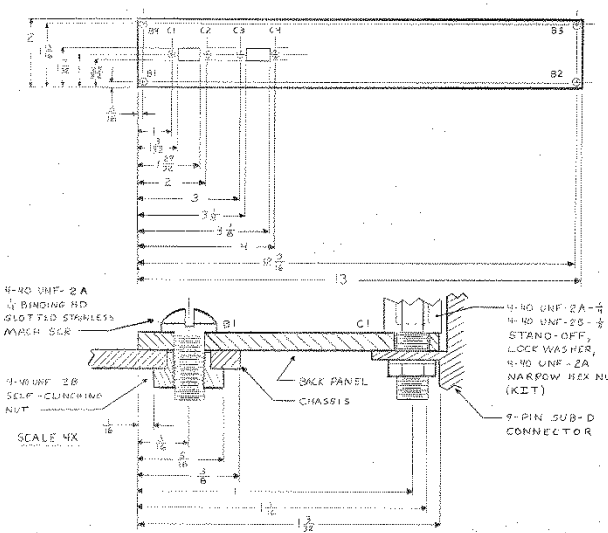
Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4298	TOLERANCES (EXCEPT AS NOTED)	TRAINER 2010	
	DECIMAL :	SCALE 1/4"	DRAWING BY S SALITERMAN APPROVED BY
Prototype	FRACTIONAL :	TITLE CHASSIS. - NUTS & HOLES	
MATERIAL	ANGULAR :	DATE 2/28/87	DRAWING NUMBER HMT 004
TREATMENT			
FINISH			

REVISIONS			
NO	DESCRIPTION	BY	DATE

FRONT PANEL



BACK PANEL

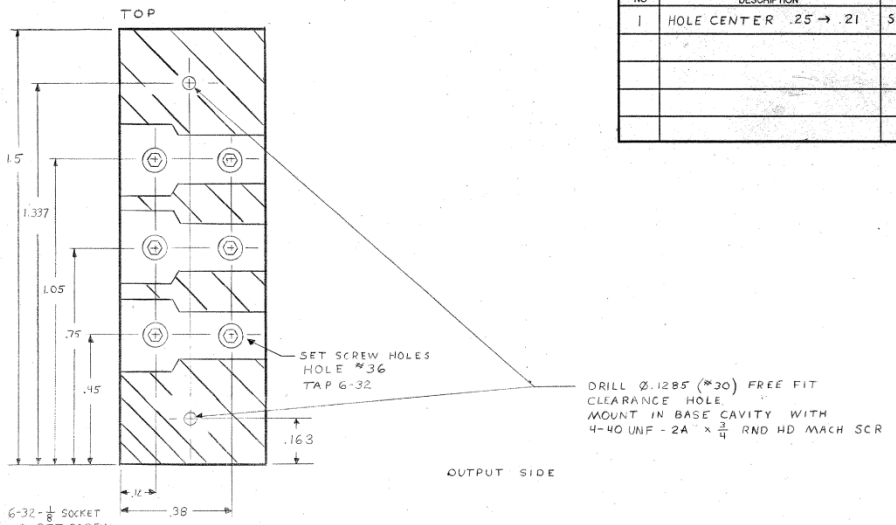


NOTES
FRONT PANEL:
1. HOLES A1-A4 ⅛
BACK PANEL:
1. HOLES B1-B4 ⅛ " TO MATCH NUTS
C1-C4 ⅛ " TO MATCH SUB-D

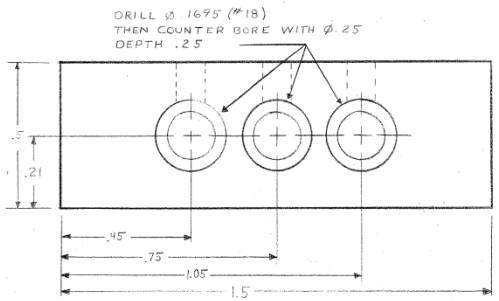
Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4298	TOLERANCES (EXCEPT AS NOTED)	TRAINER 2010	
	DECIMAL .		SCALE 1/2 / DRAWING BY S. SALITERMAN / APPROVED BY
Prototype	FRACTIONAL ±	TITLE FRONT & BACK PANELS	
MATERIAL 16 GAGE CR STEEL .0598"			
TREATMENT	ANGULAR .	DATE 2/28/87	DRAWING NUMBER HMT 005
FINISH			

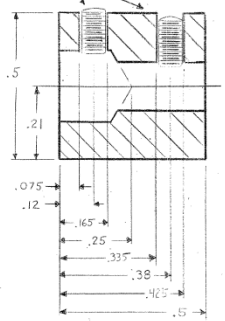
NOTES

REVISIONS			
NO	DESCRIPTION	BY	DATE
1	HOLE CENTER .25 → .21	SSS	4/19/87

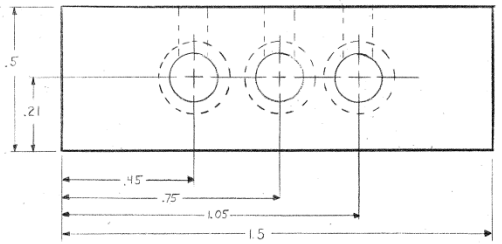


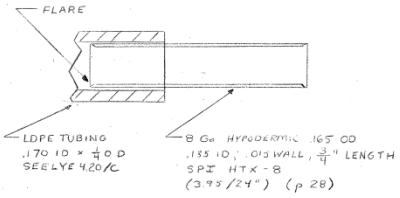
INPUT SIDE





OUTPUT SIDE



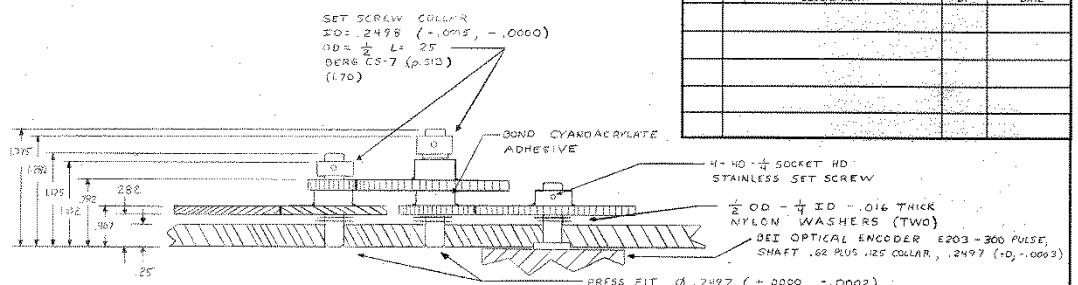


Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4298	TOLERANCES (EXCEPT AS NOTED)	TRAINER 2010	
	DECIMAL :	SCALE 4X"	DRAWING BY S. SALITERMAN APPROVED BY
Prototype	FRACTIONAL :	TITLE COMBINER CLAMP	
MATERIAL 6061 ALUMINUM OR DELRIN	ANGULAR :	DATE 3/2/87	DRAWING NUMBER HMT 006
TREATMENT FINISH			

NOTES

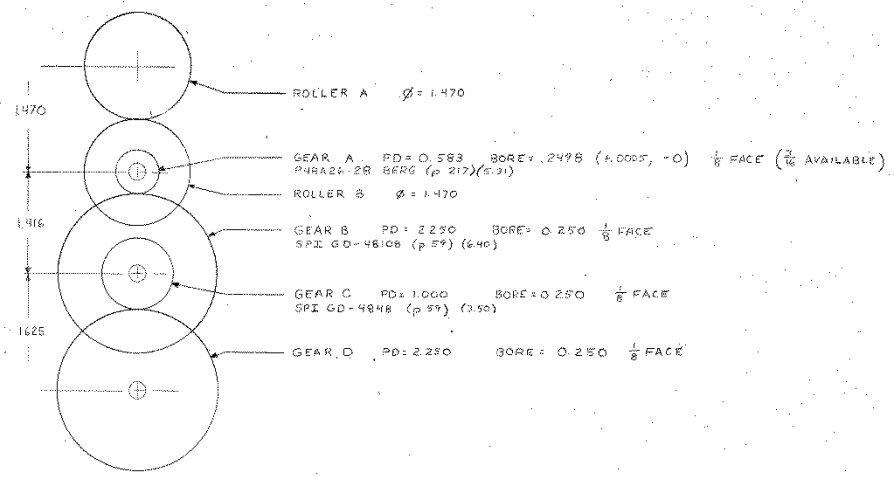
1. REAM GEARS & ROLLER Ø .2510

REVISIONS			
NO	DESCRIPTION	BY	DATE



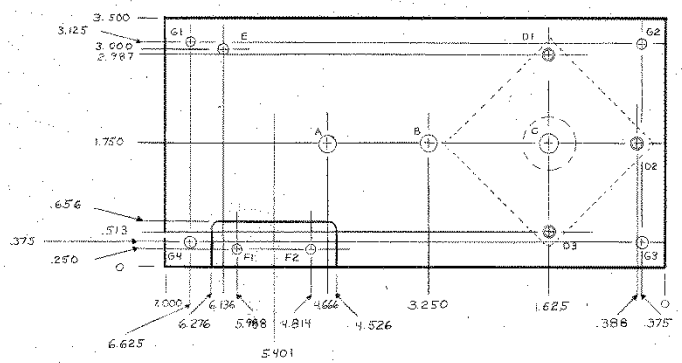
AVAILABLE REAMERS: (✓ = HAVE)

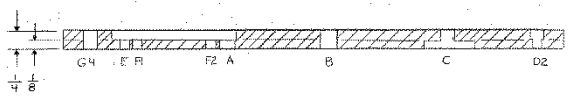
DO-ALL	.1590	.2480
	.1562	.2490 ✓
	.1570	.2495
		.2510 ✓
SATTERLEE	.1545	.2480
	.1550 ✓	.2493 ✓
	.1555	.2490
	.1560	.2495
	.1562	.2500
	.1565	.2505
	.1570	.2510
		.2515
		.2520



Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4266	TOLERANCES (EXCEPT AS NOTED)	TRAINER 2010	
	DECIMAL .	SCALE 1	DRAWING BY S. SALITERMAN APPROVED BY
Prototype	FRACTIONAL .	TITLE ROLLER-GEAR ASSEMBLY	
MATERIAL	ANGULAR	DATE 3/12/87	DRAWING NUMBER HMT 007
TREATMENT			
FINISH			

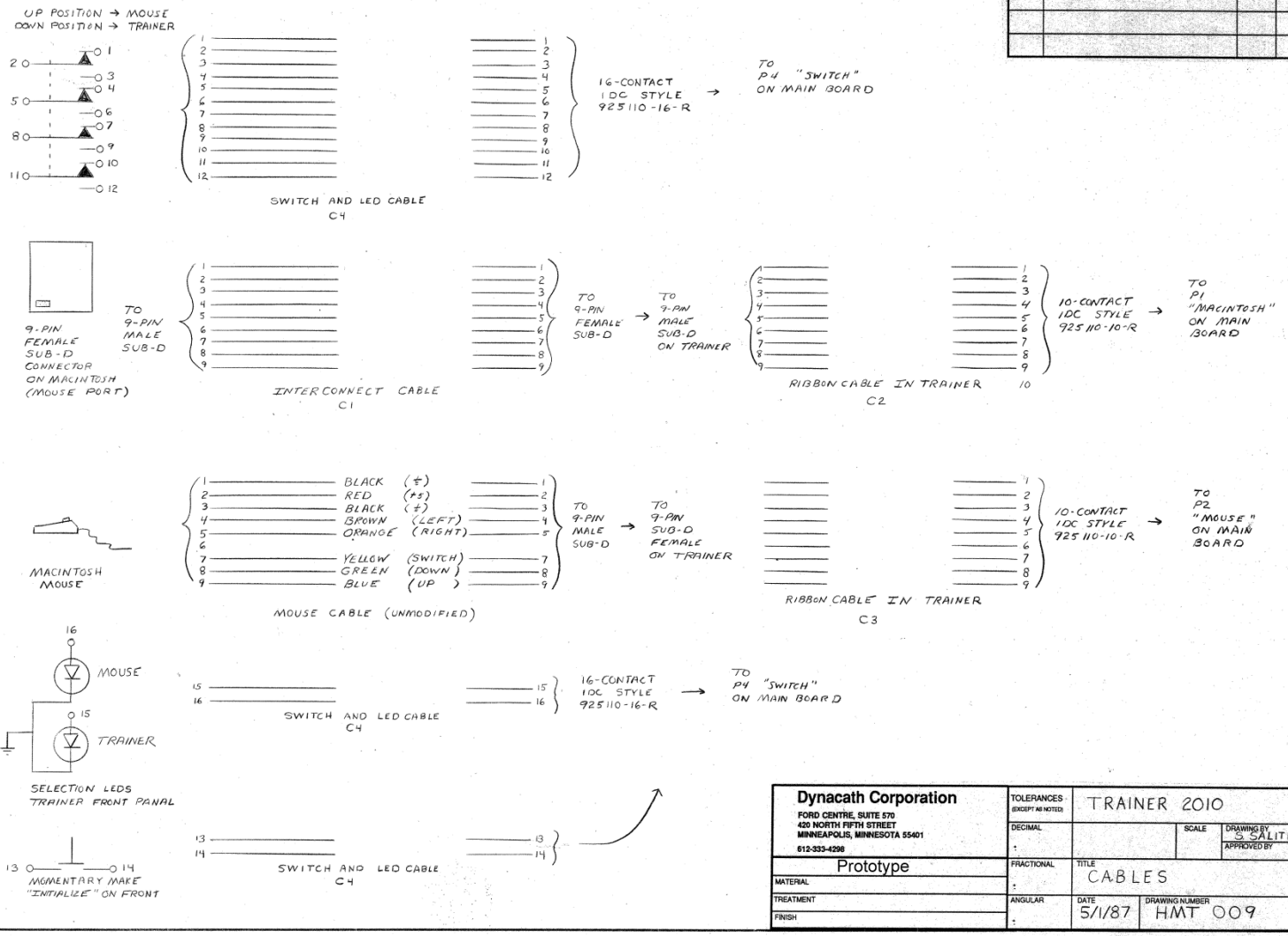
NOTES	
HOLES A =	.2490 (REAM)
B =	.2490 (REAM)
C =	19/32 / 11/16
D1-D3 =	15/64 / 5/64
E =	
F1-F2 =	.1285 (#30)
G1-G4 =	5/32
H =	
MILL COMBINER CLAMP CAVITY WITH	
3/32 RADIUS (1/16 END MILL)	





Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4296	TOLERANCES (EXCEPT AS NOTED)	TRAINER 2010	
	DECIMAL .	SCALE 1	DRAWING BY S. SALITERMAN APPROVED BY
Prototype	FRACTIONAL .	TITLE MOTION SENSOR BASE	
MATERIAL	ANGULAR .	DATE 3/19/87	DRAWING NUMBER HMT 008
TREATMENT			
FINISH			

REVISIONS			
NO	DESCRIPTION	BY	DATE



Dynacath Corporation FORD CENTRE, SUITE 570 420 NORTH FIFTH STREET MINNEAPOLIS, MINNESOTA 55401 612-333-4296	TOLERANCES (EXCEPT AS NOTED)	TRAINER 2010	
	DECIMAL ±	SCALE	DRAWING BY S SALITERMAN APPROVED BY
Prototype	FRACTIONAL ±	TITLE CABLES	
MATERIAL			
TREATMENT	ANGULAR ±	DATE 5/1/87	DRAWING NUMBER HMT 009
FINISH			

NOTES

BOARD LABELED VERSION 1

5/9/87 - DRAWING REPLACED BY HMT011

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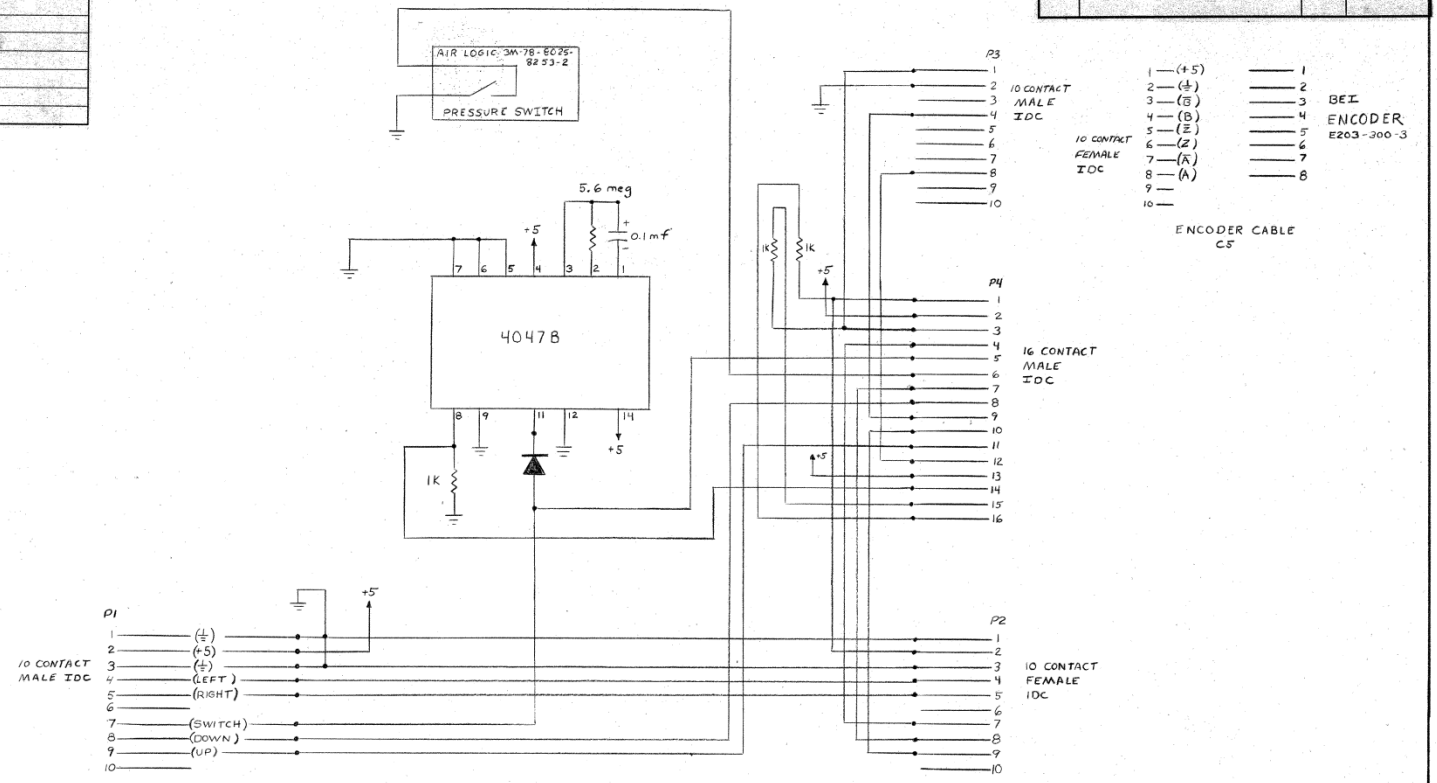

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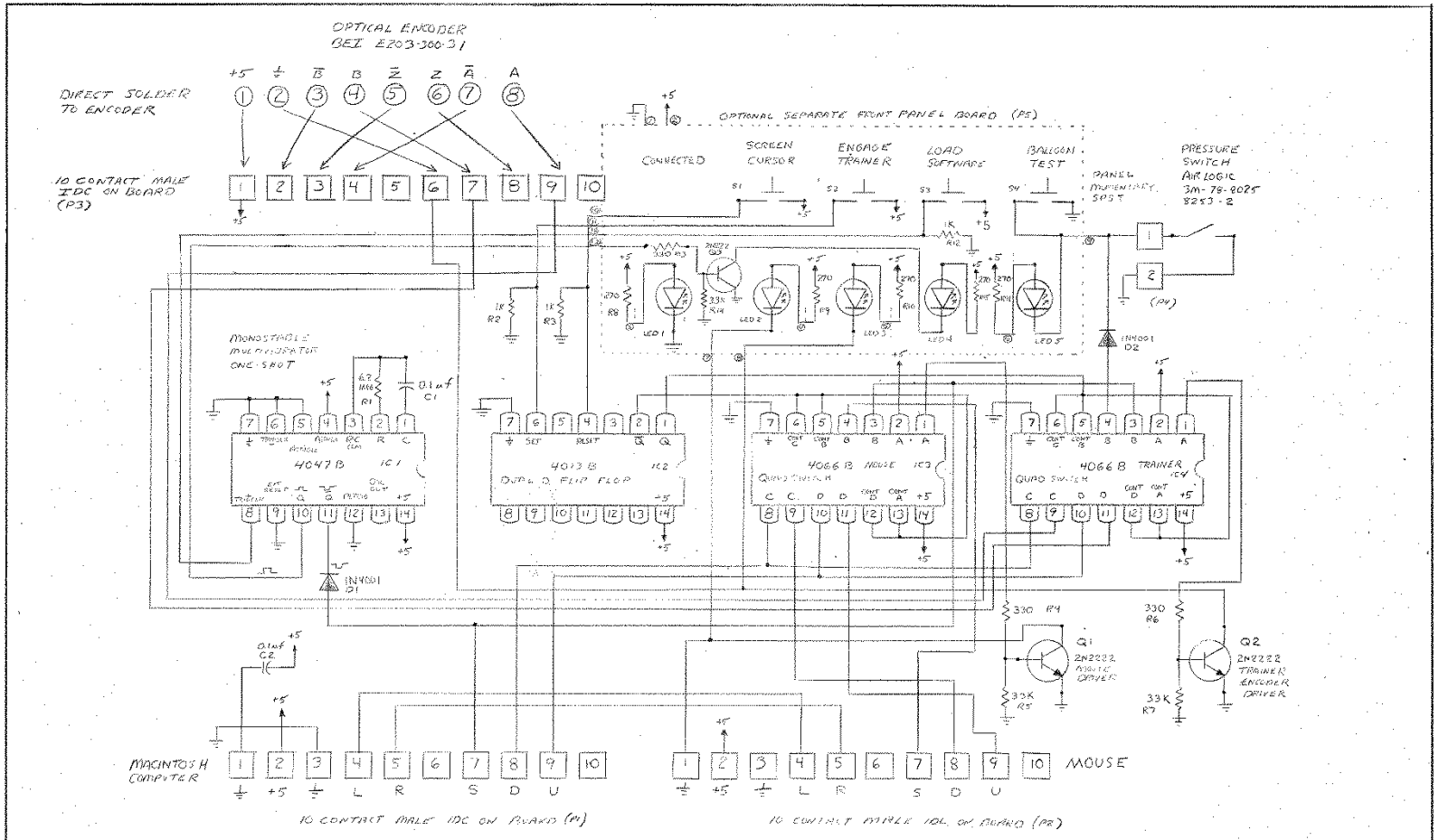

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TREATMENT			
FINISH			

United States Patent

United States Patent

United States Patent [19]

Saliterman

[11] **Patent Number: 4,642,055**

[45] **Date of Patent: Feb. 10, 1987**

[54] **HEMODYNAMIC MONITORING TRAINER**

[76] Inventor: **Steven S. Saliterman,** 1920 S. First, #1008, Minneapolis, Minn. 55454

[21] Appl. No.: **747,767**

[22] Filed: **Jun. 24, 1985**

[51] **Int. Cl.**[4] **G09B 23/32**

[52] **U.S. Cl.** **434/268**

[58] **Field of Search** 434/262, 265, 267, 268, 434/272, 273

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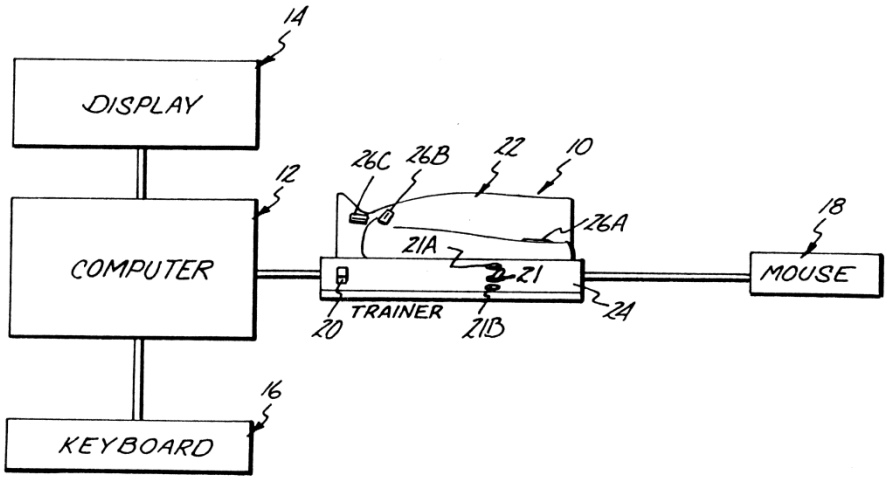
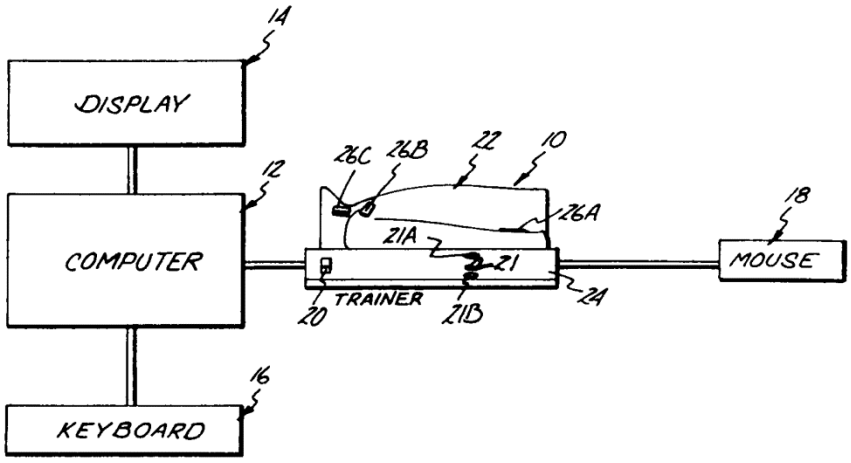
Primary Examiner—Harland S. Skogquist
Attorney, Agent, or Firm—Kinney & Lange

[57] **ABSTRACT**

A computerized training system allows physicians, nurses and other medical professionals to obtain substantial experience in hemodynamic monitoring without need to acquire all that experience with live, critically ill patients. The system simulates the entire process of hemodynamic monitoring, including the physical process of introducing the catheter through an insertion site in a manikin, feeding the catheter through the veins, the heart and into the pulmonary artery, inflating the balloon at the tip of the catheter, and interpreting the measured pressure and other information obtained.

33 Claims, 27 Drawing Figures

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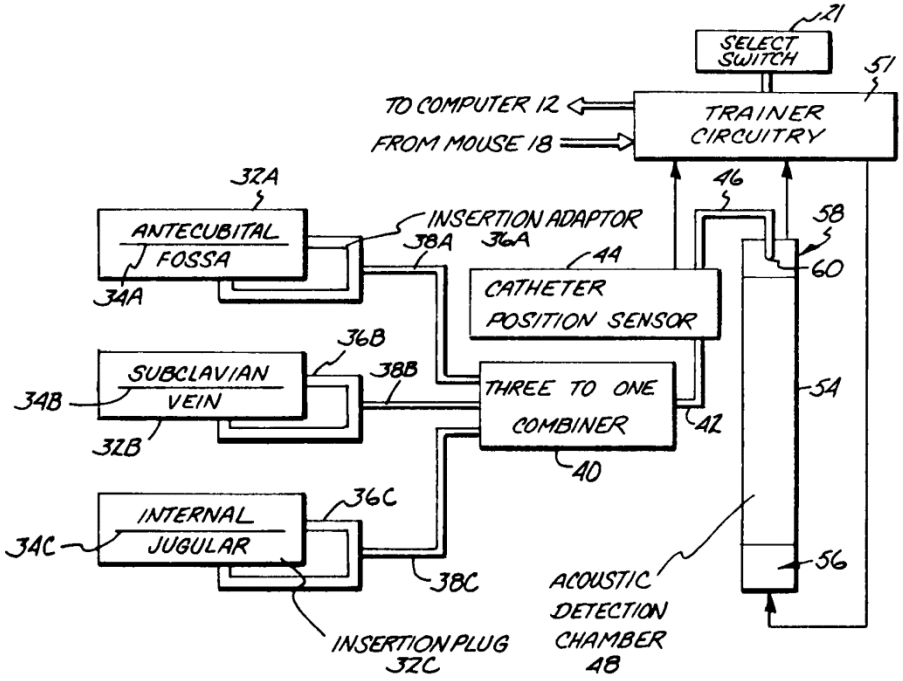
DISPLAY
12
COMPUTER
16
KEYBOARD
26C
26B
22
10
26A
21A
21
20
TRAINER
21B
24
18
MOUSE

Fig. 1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SELECT SWITCH
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TO COMPUTER 12
FROM MOUSE 18
TRAINER CIRCUITRY
32A
ANTECUBITAL FOSSA
34A
INSERTION ADAPTOR
38A
36A
46
58
60
44
CATHETER POSITION SENSOR
36B
SUBCLAVIAN VEIN
34B
32B
38B
THREE TO ONE COMBINER
42
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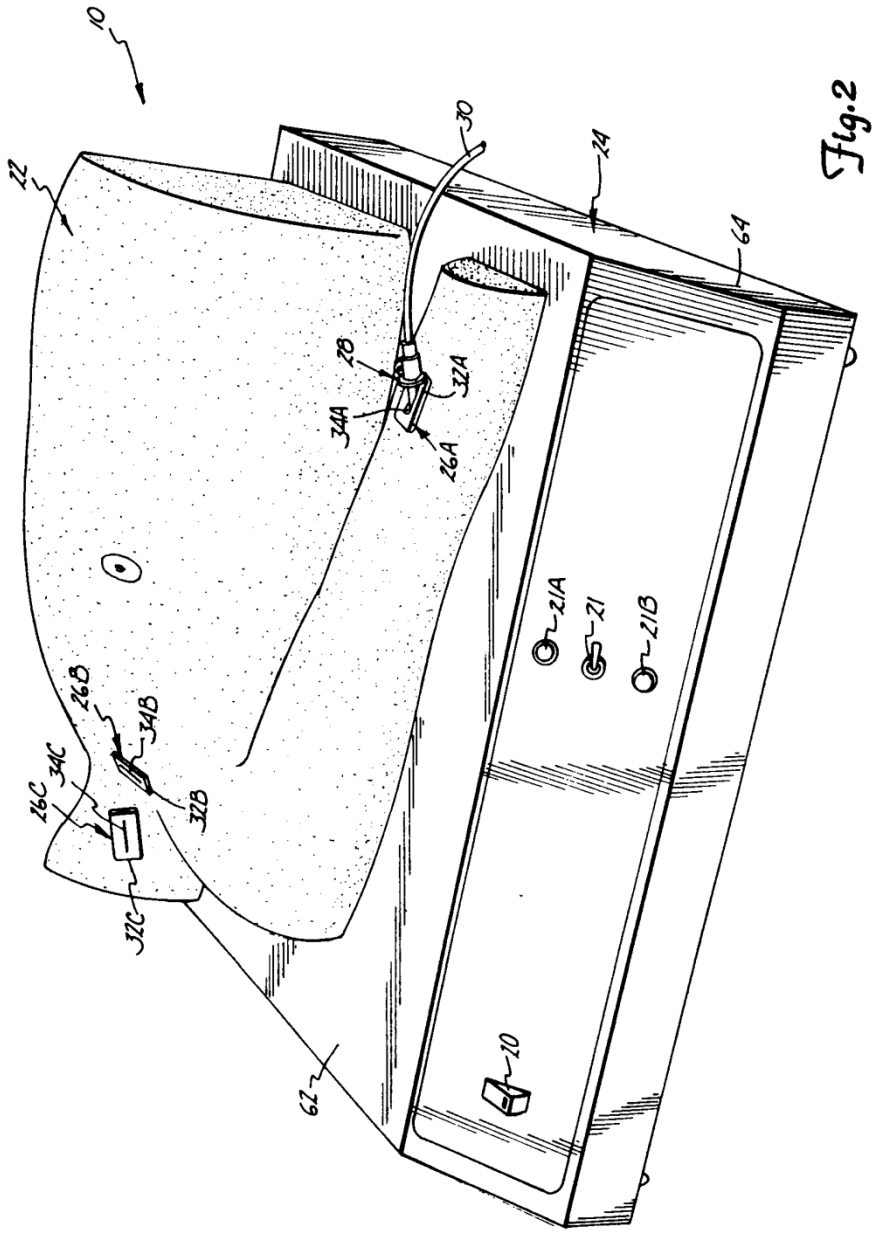
36C
INTERNAL JUGULAR
34C
38C
INSERTION PLUG
32C
ACOUSTIC DETECTION CHAMBER
48
56

Fig. 3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16C
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32C
21A
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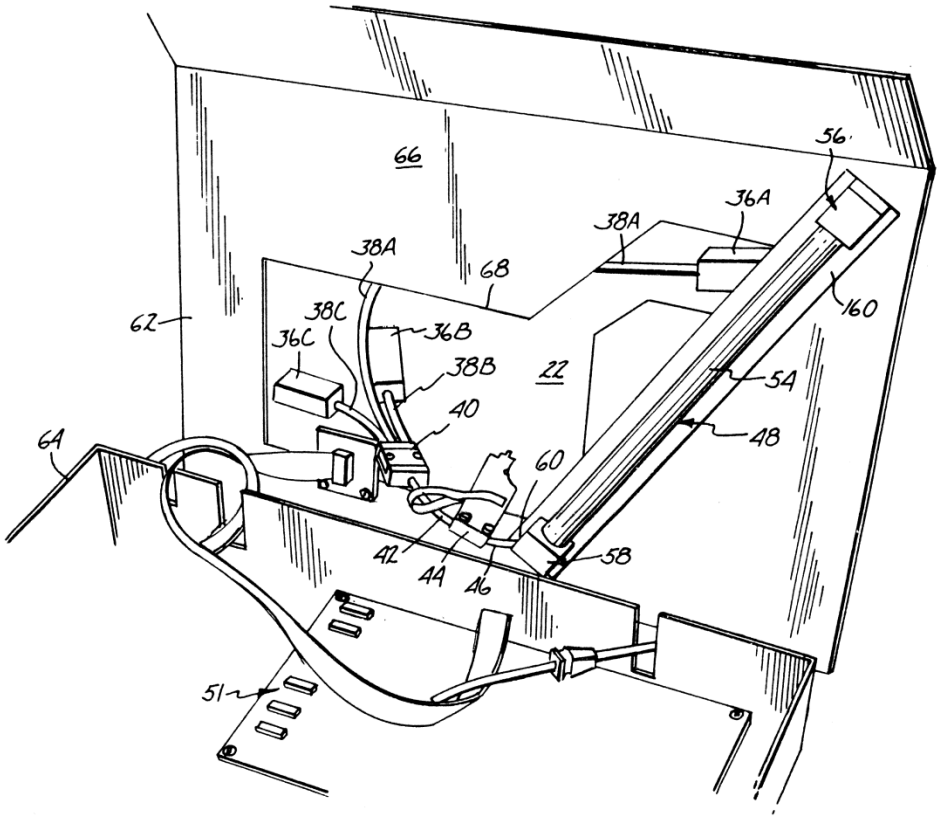
21B
10
62

Fig.2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36A
38A
38A
68
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38C
36B
36C
38B
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160
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40
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6A
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42
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58
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Fig.4

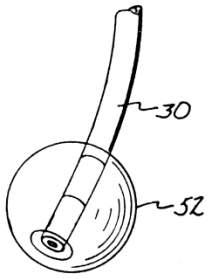
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Fig.5

Fig.6A

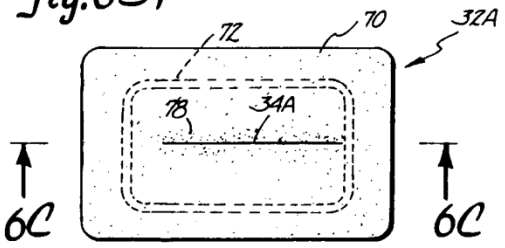


Fig.6C

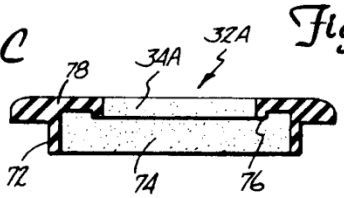


Fig.6B

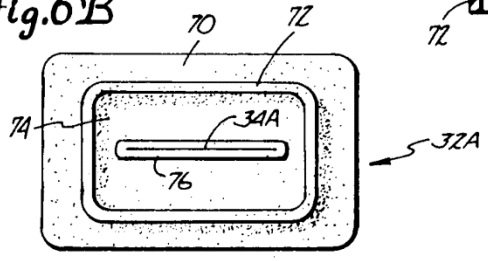


Fig.7A

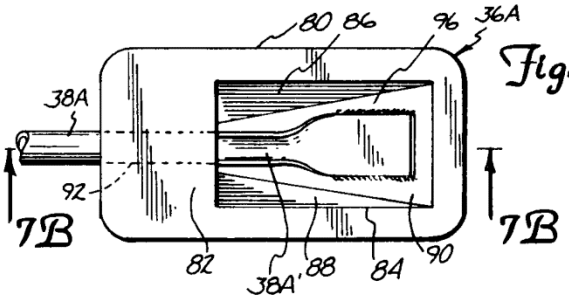


Fig.7B

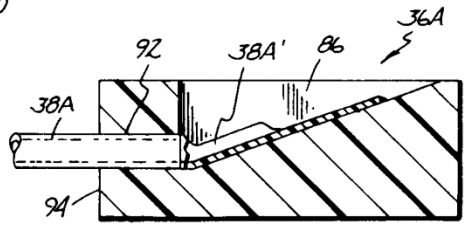
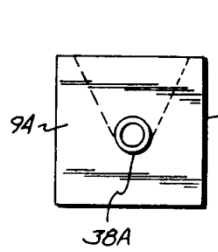
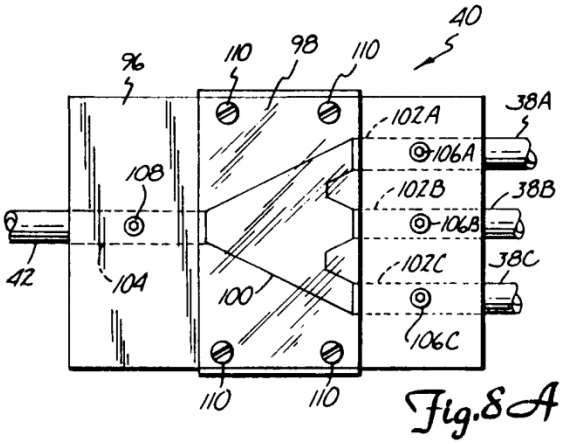


Fig.7C





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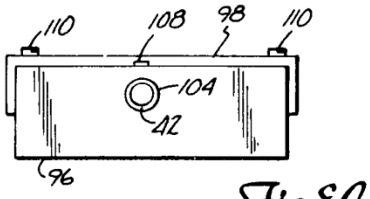

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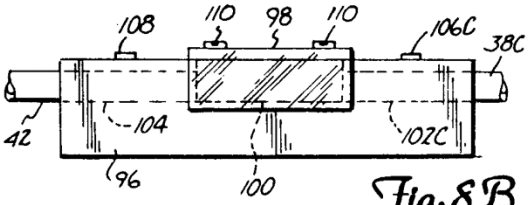


Fig.8B

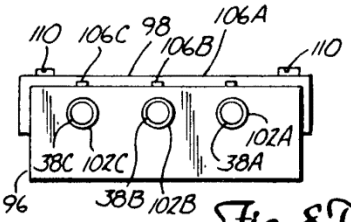
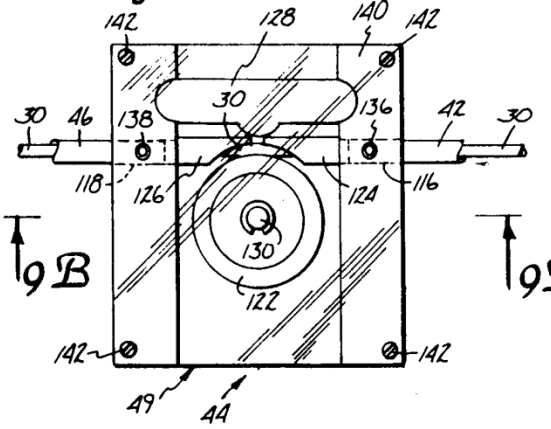


Fig.8D

Fig.9A



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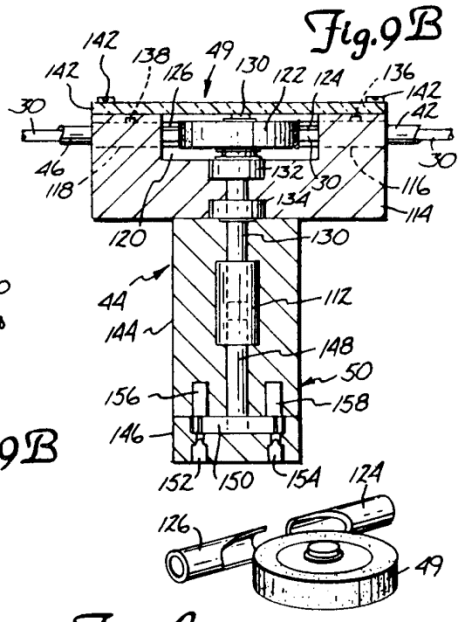
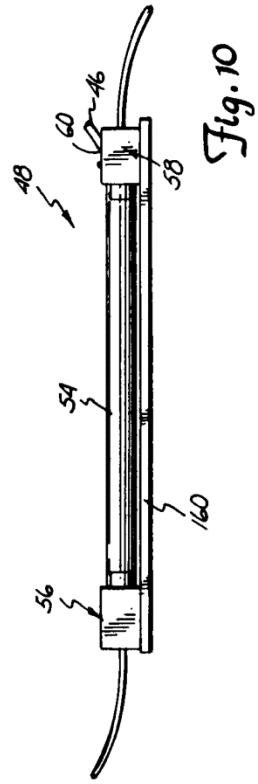


Fig.9C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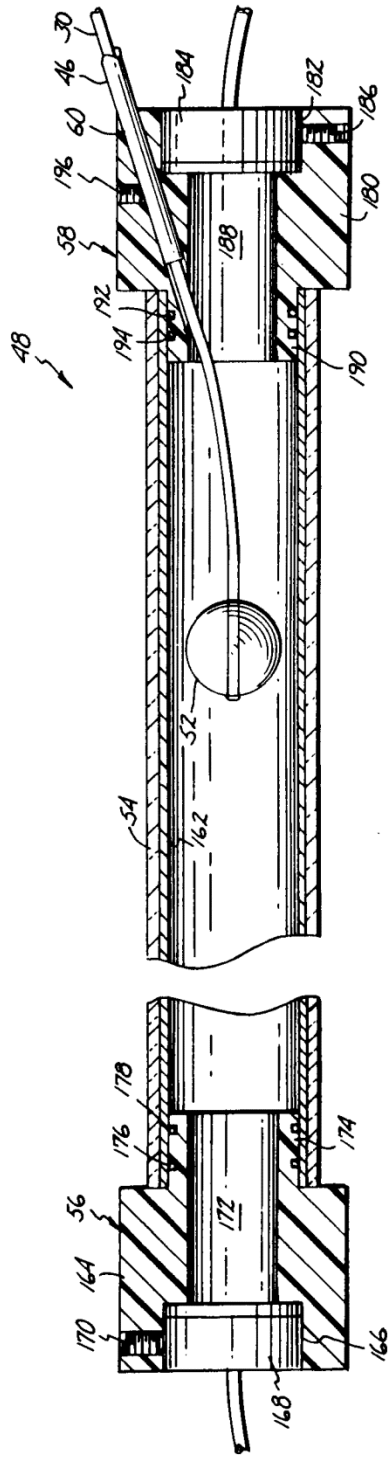
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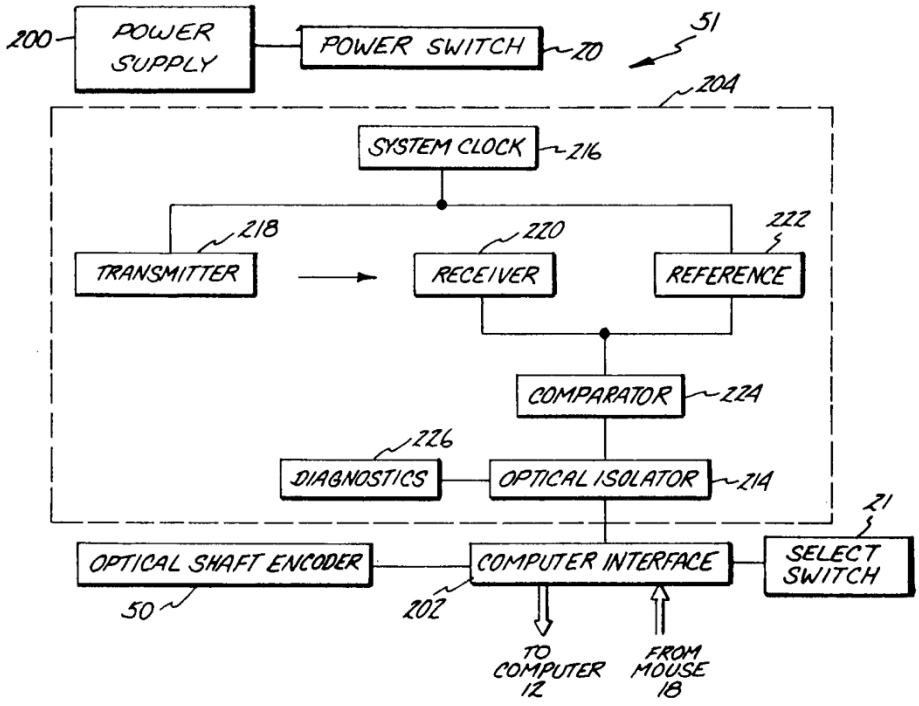
Fig. 11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TRANSMITTER
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RECEIVER
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REFERENCE
COMPARATOR
224
226
DIAGNOSTICS
OPTICAL ISOLATOR
214
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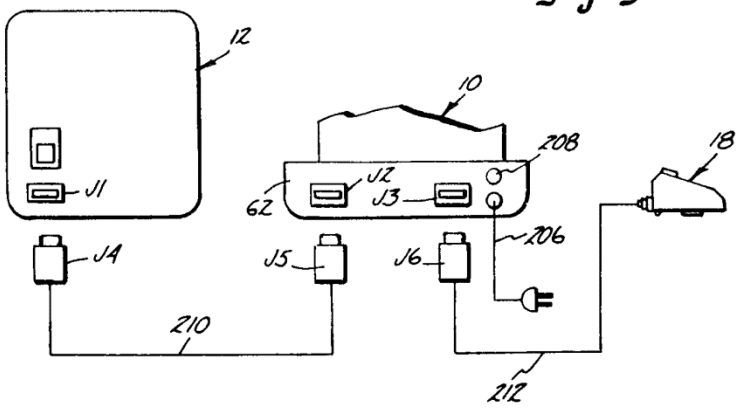
SELECT SWITCH
OPTICAL SHAFT ENCODER
50
COMPUTER INTERFACE
202
TO COMPUTER 12
FROM MOUSE 18

Fig. 12

Fig. 13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208
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62
J2
J3
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J4
J5
J6
210
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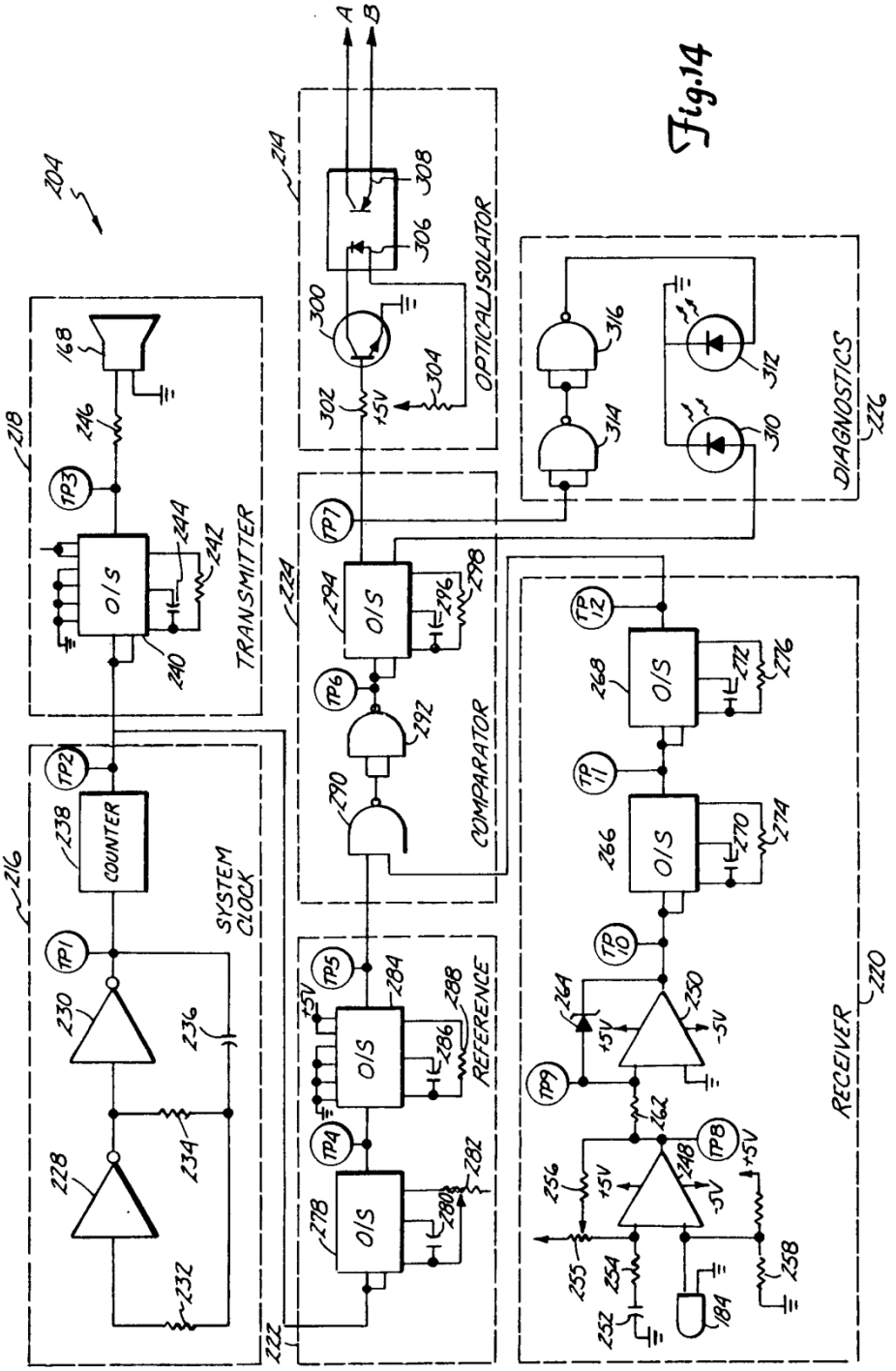

204
216
218
214
224
220
222
TRANSMITTER
SYSTEM CLOCK
COUNTER
OPTICAL ISOLATOR
COMPARATOR
REFERENCE
DIAGNOSTICS
RECEIVER
O/S
A
B
+5V
-5V

Fig.14

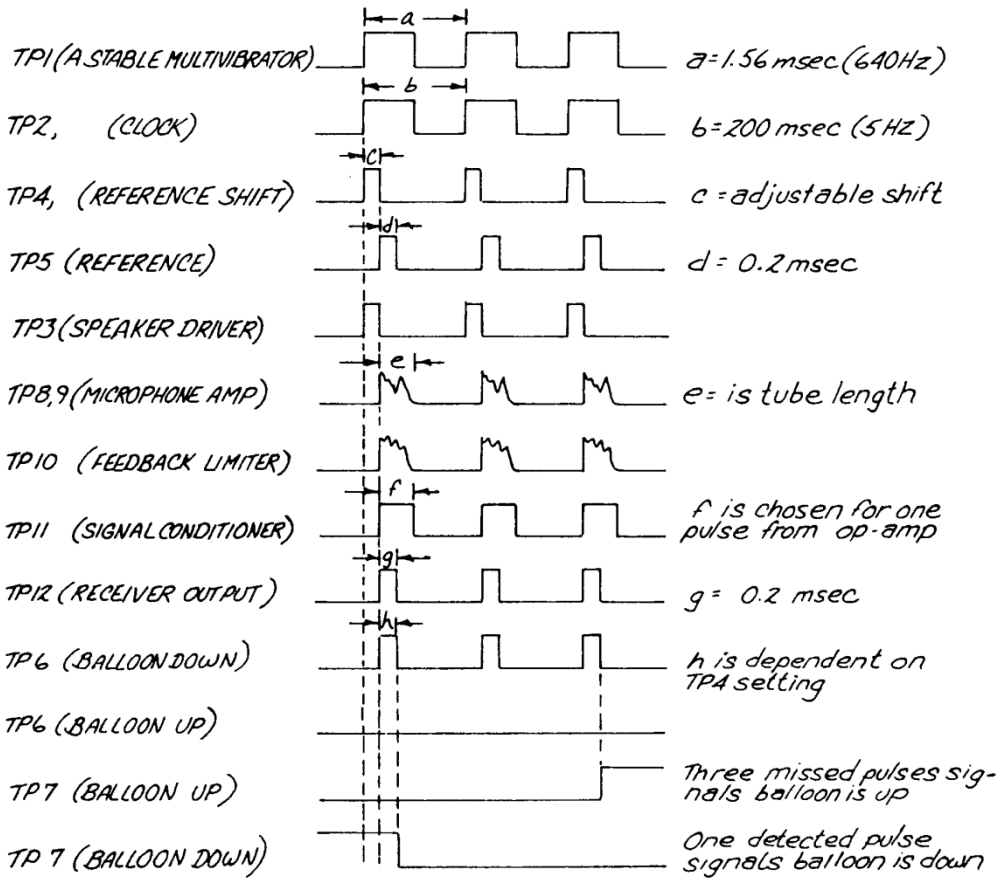
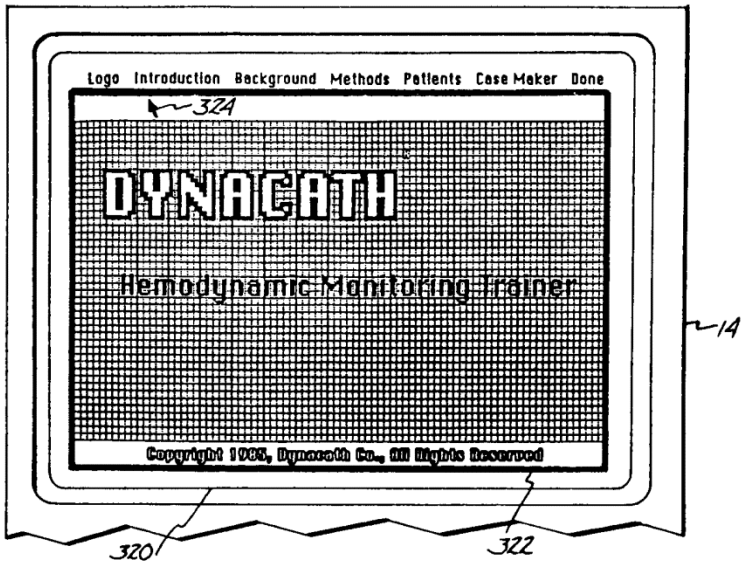

a
b
c
d
e
f
g
h
TP1 (A STABLE MULTIVIBRATOR)
a = 1.56 msec (640Hz)
TP2, (CLOCK)
b = 200 msec (5 HZ)
TP4, (REFERENCE SHIFT)
c = adjustable shift
TP5 (REFERENCE)
d = 0.2 msec
TP3 (SPEAKER DRIVER)
TP8,9 (MICROPHONE AMP)
e = is tube length
TP10 (FEEDBACK LIMITER)
TP11 (SIGNAL CONDITIONER)
f is chosen for one pulse from op-amp
TP12 (RECEIVER OUTPUT)
g = 0.2 msec
TP6 (BALLOON DOWN)
h is dependent on TP4 setting
TP6 (BALLOON UP)
TP7 (BALLOON UP)
Three missed pulses signals balloon is up
TP 7 (BALLOON DOWN)
One detected pulse signals balloon is down

Fig. 15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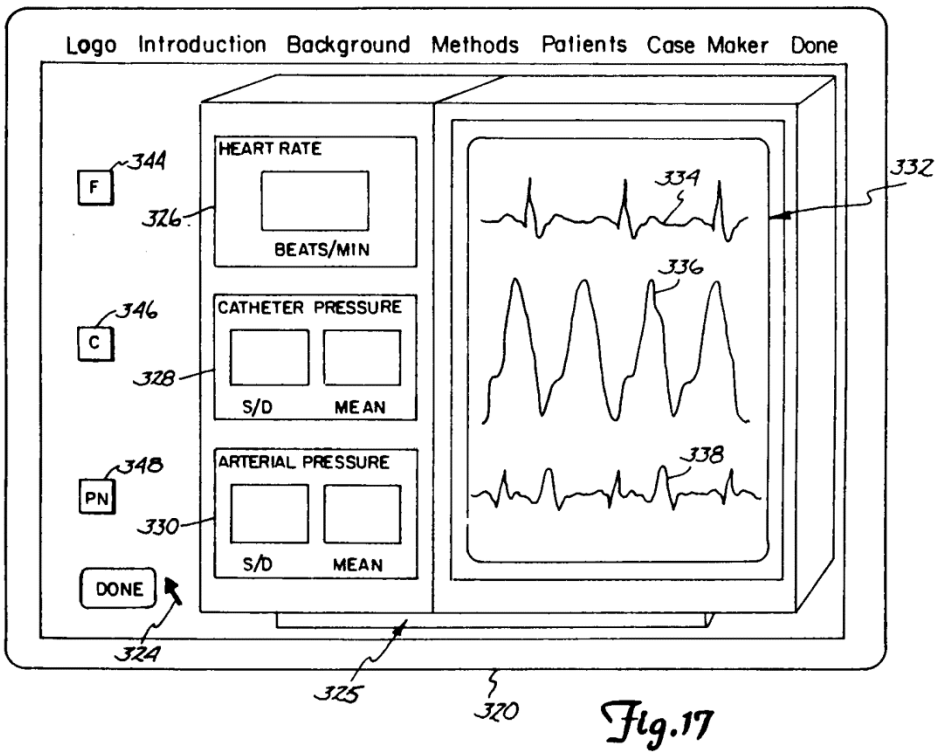
DYNACATH
Hemodynamic Monitoring Trainer
Copyright 1985, Dynacath Co., All Rights Reserved
14
320
322

Fig.16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CATHETER PRESSURE
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S/D
MEAN
PN
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ARTERIAL PRESSURE
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S/D
MEAN
DONE
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325
320
332
334
336
338

Fig.17

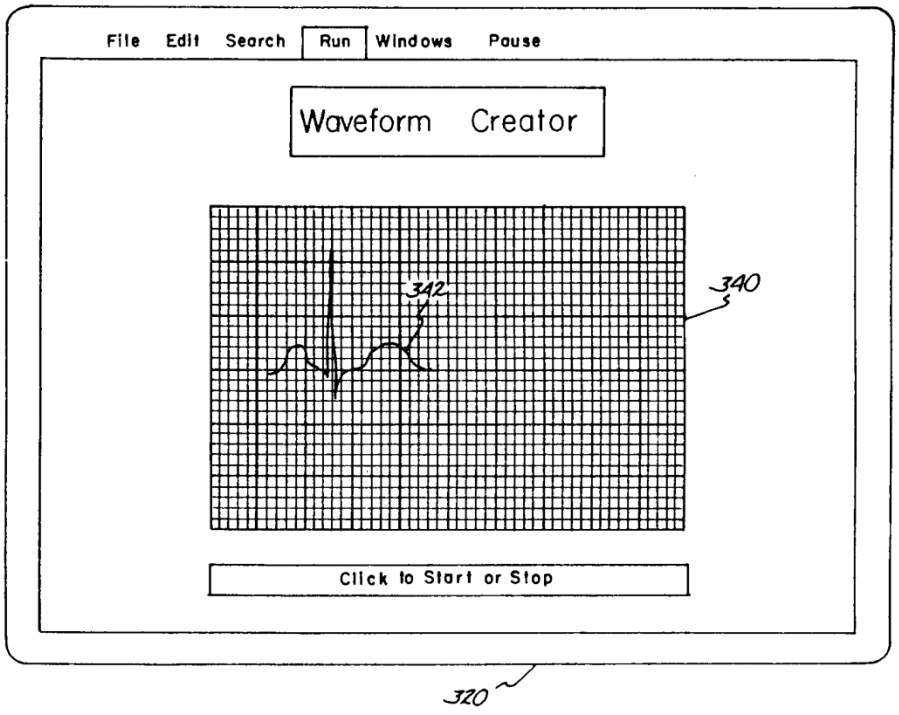
File
Edit
Search
Run
Windows
Pause
Waveform Creator
342
340
Click to Start or Stop
320

Fig.18

HEMODYNAMIC MONITORING TRAINER

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is related to a computerized training system for physicians, medical students, nurses and other medical professionals. In particular, the present invention relates to a system which teaches the purpose, indications, methods, complications and techniques for hemodynamic monitoring of patients.

2. Description of the Prior Art

Hemodynamic monitoring is the method whereby a patient undergoes placement of a catheter passed from a distant vein, through the heart to the pulmonary vasculature for the purposes of measuring intracardiac, pulmonary artery and wedge pressures. The measured pressure data is used by the physician to determine the type or extent of cardiopulmonary disease, to evaluate therapeutic measures, and to monitor cardiac function.

Hemodynamic monitoring is typically performed by a physician in an intensive care unit of a hospital, while caring for a critically ill patient. Among the diseases for which hemodynamic monitoring is useful are acute myocardial infarctions, heart valvular disorders, cardiomyopathies, pulmonary disorders and congenital defects.

The hemodynamic monitoring catheter is essentially a long synthetic polymer tubing which is small enough to be inserted into a peripheral vein of the body and which is long enough to extend through that vein and the heart to the pulmonary artery within the lungs. There are hollow tubes running the length within the catheter which provide a conduit for manometric measurement of the pressures within the heart and pulmonary artery. Electronic pressure transducers are connected to the end of the catheter outside the body, and these are in turn connected to an oscilloscope display which shows the instantaneous pressure data with time (i.e. a hemodynamic waveform). The catheter may also allow for simultaneous measurement of pulmonary artery and right atrial pressures. A thermister probe near the end of the catheter may be utilized for thermodilution derived measurement of the cardiac output. There is a balloon located at the distal end of the catheter that is inflated by the medical professional as the catheter enters the heart. This inflated balloon assists the catheter tip through the heart chambers into the pulmonary artery. It also may be inflated in the pulmonary artery to obtain a wedge pressure. The wedge pressure is a reflected pressure of the left chambers of the heart through the lung, rather than the direct pressures obtained from the right side of the heart as the catheter is advanced.

Traditionally, training in hemodynamic monitoring has taken place at the bedside, with a more experienced physician (often a cardiologist or internist) demonstrating the technique and methods of waveform interpretation to the inexperienced physician, medical student or nurse. The training process, therefore, has been dependent upon the availability of critically ill patients on which the inexperienced physician, medical student or nurse can practice.

Although the physical process of introducing a catheter into a patient can be simulated, in the past there has been no training system available by which physicians, medical students and other medical professionals can practice and be trained in the techniques of hemodynamic monitoring through simulation, rather than with live patients.

SUMMARY OF THE INVENTION

The hemodynamic monitoring training system of the present invention simulates the process of hemodynamic monitoring, so that a physician, medical student, nurse or other medical professional can obtain substantial experience in hemodynamic monitoring without having to acquire all that experience with live patients. The training system includes a manikin with one or more insertion sites through which a catheter can be inserted. Connected to each insertion site is the guide tubing which provides a passage through which the catheter passes as it is inserted into the manikin. Position sensing means provides an indication of the position of the catheter, and balloon state detecting means provides an indication of whether the balloon at the tip of the catheter is inflated.

The hemodynamic monitoring training system is capable of simulating the entire process of catherization, including the technical processes of site identification, skin preparation and catheter insertion, as well as the advancement of the catheter through a vein to the heart, through the chambers of the heart, and to the pulmonary vasculature. Based upon signals from the position sensing means and the balloon state detection means, outputs are provided which assist in the simulation process. The training system preferably includes a computer with a display which generates simulated waveforms corresponding to the various catheter locations (as indicated by the position sensing means). Simulated measurement of cardiac output and simulated fluoroscopy also are preferably provided. The student may interact with the training system through an input device to the computer to select various therapeutic options and then observe the consequences of those therapeutic options in the simulation.

The hemodynamic monitoring training system, therefore, increases both technical and cognitive skills of the student. In addition, it provides the capability of training a large number of students prior to actual patient contact.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of the hemodynamic monitoring training system of the present invention.

FIG. **2** is a perspective view of the hemodynamic monitoring trainer showing a hemodynamic monitoring catheter inserted through at an antecubital fossa site.

FIG. **3** is a mechanical and electrical block diagram of the trainer.

FIG. **4** is a perspective view of the trainer of FIG. **2** with the manikin and chassis top plate pivoted to an open position to reveal their bottom surfaces.

FIG. **5** is a perspective view of the distal end of a hemodynamic monitoring catheter with its balloon inflated.

FIGS. **6A-6C** are top, bottom and cross-sectional views of one of the insertion plugs of the trainer.

FIGS. **7A-7C** are top, cross-sectional and end views of one of the insertion adapters of the trainer.

FIGS. **8A-8D** are top, front and left and right end views of the three-to-one converter of the trainer.

FIG. **9A** is a top view of the optical encoder and pressure roller which senses position of the catheter within the trainer.

FIG. 9B is a sectional view along section 9B-9B of FIG. 9A.

FIG. 9C is a perspective view of the cutaway guides and roller wheel of the pressure roller of FIG. 9A.

FIG. 10 is a side view of the acoustic detection chamber used for balloon inflation sensing of the trainer.

FIG. 11 is a sectional view of the acoustic detection chamber of FIG. 10 with the catheter balloon inflated within the chamber

FIG. 12 is a block diagram of the trainer circuitry.

FIG. 13 is a diagram illustrating interconnection of the mouse, trainer and computer.

FIG. 14 is an electrical schematic diagram of the balloon detection circuitry.

FIG. 15 is a timing diagram showing waveforms produced at selected points within the circuit of FIG. 14, both with the balloon inflated and with the balloon deflated.

FIGS. 16-18 are images displayed by the computer in its interaction with the student or instructor who is using the training system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

I. System Overview

As shown in the block diagram in FIG. 1, the hemodynamic monitoring training system of the present invention is a computerized training system which includes trainer 10, computer 12, display 14, keyboard 16 and mouse 18. The system simulates the entire process of catherization, and provides the student with mouse driven menu displays and real time feedback of hemodynamic data, so that the student can be trained in all aspects of hemodynamic monitoring prior to any actual patient contact.

In a preferred embodiment, computer 12, display 14, keyboard 16 and mouse 18 are all part of an Apple Macintosh computer system. Trainer 10 interfaces with computer 12 through the mouse port of computer 12, and in turn mouse 18 is connected to trainer 10. Trainer 10 has a power switch 20 (which turns trainer 10 on and off) and a select switch 21 (which determines whether signals from mouse 18 or from the sensing circuitry of trainer 10 will be provided as inputs to computer 12). Indicator lights 21A and 21B, which flank select switch 21, indicate whether mouse 18 or trainer 10 is currently connected to computer 12.

As shown in FIG. 2, trainer 10 includes a life-like manikin 22 of a portion of an upper torso and right arm which is supported on chassis 24. Manikin 22 includes three sites at which a student can practice insertion of the catheter: antecubital fossa site 26A, subclavian vein site 26B, and internal jugular vein site 26C. For purposes of illustration in FIG. 2, catheter needle 28 is shown inserted at site 26A. Catheter tubing 30 is fed through needle 28 into the interior of manikin 22.

In order to simulate actual catheter insertion, each catheter site 26A-26C has an insertion plug 32A-32C with an insertion slit 34A-34C through which the catheter needle 28 is inserted.

As illustrated in FIGS. 3 and 4, each site 26A-26C has an insertion adapter 36A-36C positioned within manikin shell 22 to receive catheter needle 28 as it is inserted through insertion plugs 32A-32C, respectively. Insertion adapters 36A-36C provide a path for catheter tubing 30 into one of three guide tubes 38A-38C which simulate the veins running from sites 26A-26C, respectively, to the heart.

Guide tubes 38A, 38B and 38C are connected to three-to-one combiner 40 which guides catheter tubing 30 to a single guide tube 42, regardless of the particular guide tube 38A-38C through which the catheter tube 30 is passing.

From three-to-one combiner 40, the catheter tubing 30 passes through guide tube 42, catheter position sensor 44, guide tube 46, and into acoustic detection chamber 48. Catheter position sensor 44 measures how far the tip of catheter tubing 30 has advanced past sensor 44 to allow computer 12 to determine where anatomically the tip of catheter tubing 30 would be located within an actual human body. In the preferred embodiment which will be described in further detail later (in conjunction with FIGS. 9A-9C), catheter position sensor 44 preferably includes pressure roller 49 connected to optical shaft encoder 50. As the catheter tubing 30 passes through position sensor 44, it causes pressure roller 49 to rotate, thus causing movement of optical shaft encoder 50. Signals from optical shaft encoder 50 are supplied through trainer circuitry 51 to computer 12. Pressure roller 49 turns with sufficient torque to turn optical shaft encoder 50, while at the same time not adding much resistance to the movement of catheter tubing 30.

As described previously, hemodynamic monitoring catheter 30 includes a balloon 52 at its tip which can be inflated to assist the catheter tip through the heart chambers and into the pulmonary artery. Balloon 52 can also be inflated in the pulmonary artery to obtain a wedge pressure. FIG. 5 shows the distal end of catheter tube 30, with balloon 52 inflated.

Acoustic detection chamber 48 provides a means for sensing when balloon 52 is inflated or deflated. Acoustic detection chamber 48 preferably includes a cylindrical tube 54 with transmitter assembly 56 mounted at one end and receiver assembly 58 mounted at an opposite end. Catheter tubing 30 enters acoustic detection chamber 48 through inlet port 60 in receiver assembly 58.

Acoustic detection chamber 48 senses whether balloon 52 is inflated by sending sound pulses from transmitter assembly 56 down tube 54 toward receiver assembly 58. The condition of balloon 52 is determined based upon the amount of attenuation of the sound pulses received at receiver assembly 58.

When select switch 21 selects signals from trainer 10, trainer circuitry 51 provides signals to computer 12 which indicate whether the balloon 52 is inflated or deflated and also provides signals from catheter position sensor 44. Alternatively, when select switch 21 is in an opposite position, the signals provided to computer 12 are from mouse 18.

Based upon those signals, computer 12 interacts with the student by presenting information on display 14. That information includes a mouse driven menu by which the student can select one of a variety of different training modes, as well as necessary educational text. In one mode, computer 12 causes simulated waveform displays to be presented on display 14 which are a function of the position of the tip of catheter 30 and the state of balloon 52. In another mode computer 12 provides on display 14 a simulated fluoroscopic image, which allows the student to observe a simulation of the movement of the catheter through the heart and vasculature (based upon the signals from position sensor 44) much as it would appear if the student were actually inserting a

catheter into a live patient and observing it with the assistance of a fluoroscope.

The data storage capabilities of computer **12** also allow the storage of patient case histories, with simulated waveforms based upon catheter position. In these case histories, the student is required to select from a group of therapeutic options which are presented, and computer **12** then displays the consequences of that selected therapeutic option by showing the resulting simulated waveforms.

2. Mechanical Components

a. Manikin **22**

Manikin **22** is, in one preferred embodiment, made of fiberglass and polyester resinol. Other synthetic materials, such as polyvinyl can also be used.

Manikin **22** is, in the embodiment shown in FIG. **2**, a life size portion of the neck, upper torso and right arm of a human body, and is preferably flesh color with accurate anatomical markings.

Manikin **22**, together with insertion plugs **32A–32C**, provide an opportunity for the student to identify important anatomical landmarks for catheter insertion, to prepare the skin site as would be done in real-life, to utilize standard catheter insertion needle, sheath and dialator kits, and finally to insert the catheter tubing **30** as would be done on a real patient.

b. Chassis **24**

As shown in FIGS. **2** and **4**, chassis **24** includes cover **62** and base **64**. Manikin **22** is attached to top plate **66** of cover **62**. As best shown in FIG. **4**, top plate **66** includes a manikin access opening **68** to provide access to the components mounted within manikin **22**. All of the trainer circuitry **51** is located within chassis **24**.

c. Insertion Plugs **32A–32C**

FIGS. **6A–6C** show top, bottom and sectional views, respectively, of insertion plug **32A**, which is typical of all three insertion plugs **32A–32C**. Insertion plugs **32A–32C** are each bonded to the top surface of manikin **22** over a rectangular opening at sites **26A–26C**, respectively.

Insertion plug **32A** includes entry slit **34A**, plug top **70**, neck **72**, cavity **74** and entry lip **76**. Insertion plug top **70** has an area which is larger than the opening into which insertion plug **32A** is mounted in manikin **22**. Neck **72** is of a size to fit snugly within the opening in manikin **22**, so that insertion plug **32A** can be mounted securely to manikin shell **22** by application of an adhesive glue to the bottom surface of plug top **70** and the outer surface of neck **72**.

Hardened entry lip **76** adds strength to the surfaces of entry slit **34A**. This minimizes wear and tear on insertion plug **32A** with repeated insertions and removal of the insertion needle, sheath and dialator of catheter needle **28**.

Insertion plug **32A** preferably is flesh colored, and includes a vein coloration area **78** which is generally aligned with entry slit **34A**.

In a preferred embodiment, insertion plugs **32A–32C** are made of a combination casting of vinyl dispersions No. 65 and Plastisol and No. 90 Plastisol. Hardened inner lip **76** is made by placing a small amount of blue colored No. 90 Plastisol in a mold and precasting, and then adding the flesh-tone colored No. 65 Plastisol in the mold for full-time casting. The result is an insertion plug which is durable, flexible which provides natural coloration in both the skin and the underlying vein, and which simulates the natural feel of passing needle **28** into the human skin without destroying the insertion plug **32A–32C** with a single use.

A further advantage of insertion plugs **32A–32C** is that in the event any one of the plugs is damaged or worn out by repeated use, it can easily be removed and replaced.

d. Insertion Adapters **36A–36C**

Insertion adapters **36A–36C** serve as receiving ports for the catheter assembly **28** (which includes an insertion needle, introducer sheath, dialator, and tubing **30**). Each adapter **36A–36B** is bonded under a rectangular opening cut into manikin **22** at sites **26A–26C**, respectively. FIGS. **7A–7C** show top, sectional and end views of insertion adapter **36A**, which is representative of all three insertion adapters **36A–36C**.

Insertion adapter **36A** preferably has a plastic body **80** made from a casting of vinyl dispersion No. 90 plastisol. In its top surface **82**, body **80** has a rectangular cavity **84** with a pair of slanted side walls **86** and **88** and a slanted bottom surface **90** which form a funnel toward circular passage **92**, which extends from the lower end of cavity **84** out through end **94** of body **80**. Tubing **38A** extends through passage **92** and into cavity **84**. The portion **38A'** of tubing **38A** which is located within cavity **84** has its top half removed, and is bonded to slanted surface **90** by adhesive **96** (which is preferably a silicone cement).

The rectangular opening of cavity **84** is aligned with the generally rectangular cavity **74** of insertion plug **32A**. As a result, insertion slit **34A** of insertion plug **32A** is generally aligned with the center of cavity **84** and with passage **92**.

In a preferred embodiment in which insertion adapters **36A–36C** are castings of vinyl dispersion No. 90 plastisol, each adapter **36A–36C** is secured to the inner surface of manikin **22** first with cyanoacrylate glue, and then are secondarily sealed with a bead of silicone cement around the outer edge of body **80**.

e. Tubing **38A–38C**, **42** and **46**

Tubing **38A–38C**, **42** and **46** provide passageways for catheter **30** among the various mechanical components of trainer **10**. The tubing, therefore, must provide a relatively friction-free path for the catheter. Polytetrafluoroethylene tubing has been found to be particularly advantageous in allowing catheter **30** to pass with a minimum of friction and binding. Other tubing materials which have been used tended to cause binding between the deflated balloon **52** at the tip of catheter **30** and the inner walls of the tubing.

In the preferred embodiment, tubing **38A–38C**, **42** and **46** has an outside diameter of 0.175 inch, an inside diameter of 0.135 inch, and a wall thickness of 0.020 inch.

f. Three-to-One Combiner **40**

Three-to-one combiner **40** combines the three separate possible paths of catheter **30** into a single path which travels through catheter position sensor **44** and into acoustic detection chamber **48**. At its inlet end, three-to-one combiner **44** receives the ends of tubing **38A–38C**, and at its outlet it receives the inlet end of tubing **42**.

As shown in FIGS. 8A–8D, three-to-one combiner **40** includes base **96** and cover **98**. Base **96** has a generally V-shaped central channel **100** which connects at its inlet end to entry ports **102A–102C**, and which connects at its outlet end to exit port **104**. Tubing **38A–38C** extend through entry ports **102A–102C**, respectively, to the inlet end of channel **100**. Set screws **106A–106C** hold the outlet ends of tubing **38A–38C** securely in entry ports **102A–102C**, respectively.

Tubing **42** extends into exit port **104** so that its inlet end is located at the outlet end of channel **100**. Set screw **108** holds tubing **42** securely within exit port **104**.

Cover **98**, which is preferably a clear plastic plate, covers the otherwise open top of channel **100**, so that the catheter must pass from tubing **38A**, **38B**, or **38C**, through channel **100**, to tubing **42**. Cover **98** is held in place over channel **100** by screws **110**.

In other embodiments of the present invention, other or additional manikin insertion sites can be used. In those embodiments where more than three sites are used, combiner **40** simply includes a greater number of entry ports to receive tubing from additional insertion adapters. The function of combiner **40** remains unchanged: to cause a convergence of the possible paths of the catheter to a single path which will lead through catheter position sensor **44** and into acoustic detection chamber **48**.

g. Catheter Position Sensor **44**

Catheter position sensor **44** monitors movement of the catheter as it passes from three-to-one combiner **40** through tubing **42** and tubing **46** to acoustic detection chamber **48**. It provides the data necessary to establish how far catheter **30** has been advanced into manikin **22**. This data specifies the direction and extent of movement, so that computer **12** can determine which chamber of the heart or pulmonary vasculature the tip of the catheter **30** would be in, if it were in a human chest.

In the preferred embodiment illustrated in FIGS. **9A–9C**, catheter position sensor **44** includes pressure roller assembly **49** and optical shaft decoder assembly **50**, which are interconnected by shaft coupling **112**.

Pressure roller assembly **49** includes a housing **114** having an entry port **116** for receiving the outlet end of tubing **42** and an exit port **118** for receiving the inlet end of tubing **46**. Between ports **116** and **118** is a channel **120** in which roller wheel **122**, guides **124** and **126**, and counter pressure bar **128** are mounted. Wheel **122** is mounted on shaft **130**, which is rotatably supported by bearings **132** and **134** and is connected at its lower end to shaft coupling **112**.

As catheter **30** passes through pressure roller assembly **49**, it passes from tubing **42** through guide **124** to guide **126** and then to tubing **46**. Guides **124** and **126** are split and are cut away so that catheter **30** makes contact with wheel **122**. Thus, movement of catheter **30** in either direction will cause rotation of wheel **122** and shaft **130**. The direction of movement of catheter **30** determines the direction of rotation of wheel **122** and shaft **130**.

Pressure roller assembly **49** must accommodate catheters of different sizes and designs, including various balloon attachments. It must, therefore, allow these various catheters to slide easily across wheel **122** while not slipping or binding. For example, the deflated balloon **52** on the tip of catheter **30** provides a bumpy surface that ordinarily would not pass through a more rigid metering device. To accommodate both balloon **52** as well as the more smooth catheter tubing **30**, pressure roller assembly **49** causes catheter **30** to be guided closely along the wheel **122** as the result of the bias force which is exerted from counter pressure bar **128** to the guideway formed by guides **124** and **126**. This guideway is split to allow some flexibility as different diameter catheters pass through pressure roller assembly **49**.

Alternatively, the means for urging catheter **30** toward wheel **122** can take the form of a counter pressure wheel which is spring loaded to be urged in the direction toward wheel **122**. This allows the nip defined between the two wheels to vary depending upon the size of the catheter passing through, without adding significant friction or resistance to the motion of catheter **30**.

As shown in FIGS. **9A** and **9B**, the outlet end of tubing **42** is secured in entry port **116** by set screw **136**, and the inlet end of tubing **46** is secured in exit port **118** by set screw **138**. A clear plastic cover **140** preferably covers the entire top surface of pressure roller assembly **49** and is secured in place by screws **142**.

Encoder assembly **50** includes a two-piece housing **144** and **146**, in which is mounted encoder shaft **148**, encoder wheel **150**, a pair of photodiodes **152** and **154**, and a pair of phototransistors **156** and **158**. Encoder shaft **148** is connected by shaft coupler **112** to shaft **130** of pressure roller assembly **49**. As wheel **122** of pressure roller assembly **49** rotates, encoder shaft **148** rotates, thus causing rotation of encoder wheel **150**. The slits of encoder wheel **150** move past photodiodes **152** and **154** to allow light to pass to phototransistors **156** and **158**. By the use of two photodiodes **152** and **154** and two phototransistors **156** and **158**, both incremental movement and the direction of movement can be determined by decoding the output signals from phototransistors **156** and **158**.

In one embodiment of the present invention, encoder assembly **50** is the same assembly used in the mouse of the Apple Macintosh computer. This is particularly advantageous when computer **12** is an Apple Macintosh computer, since the signals from encoder assembly **50** can be decoded by computer **12** without the need for any additional special circuitry.

h. Acoustic Detection Chamber **48**

Acoustic detection chamber **48** represents the end of the pathway for catheter **30**. Once the tip of catheter **30** has reached acoustic detection chamber **48**, balloon **52** can be inflated, and a determination will be made automatically as to whether or not balloon **52** has in fact been inflated.

As illustrated in FIGS. **10** and **11**, acoustic detection chamber **48** preferably includes cylindrical tube **54** with transmitter assembly **56** mounted at one end, and receiver assembly **58** located at the opposite end. The entire acoustic detection chamber **48** is preferably supported by support plate **160**, which in turn is mounted on the bottom side of top plate **66** (as illustrated in FIG. **4**).

In a preferred embodiment, tube **54** is preferably a PVC cylinder with a coating **162** of polytetrafluoroethylene on its inner surface. Coating **162** reduces friction between balloon **52** and the inner surface of cylinder **54**. In addition, powder may be added inside cylinder **54** to further decrease friction between balloon **52** and coating **162**.

Transmitter assembly **56** includes transmitter fitting **164** which has a recessed cavity **166** for receiving miniature audio speaker **168**. Set screw **170** holds speaker **168** securely in position within transmitter fitting **164**. Internal passage **172** extends from cavity **166** through fitting **164** to the interior of cylinder **54**. Fitting **164** has a neck portion **174** with a pair of snug fit grooves **176** and **178**, which allow neck **174** to be press fit mounted in the transmitter end of cylinder **54**.

Receiver assembly **58** is located at the opposite end of cylinder **54**, and is of generally similar construction to transmitter assembly **56**. Receiver fitting **180** has a recess **182** into which miniature microphone **184** is inserted. Set screw **186** holds microphone **184** securely in place within cavity **182**. Passage **188** provides communication between the interior of cylinder **54** and microphone **184**. Neck **190** of fitting **180** has a pair of snug fit grooves **192** and **194**, which assist in providing a press fit mounting of neck **190** in the receiver end of cylinder **54**.

One further difference between receiver assembly **58** and transmitter assembly **56** is the presence of entry port **60** which receives the outlet end of tubing **46** and provides a passageway through which catheter **30** enters cylinder **54**. Set screw **196** holds the outlet end of tubing **46** securely in place in entry port **60**.

As shown in FIG. **11**, the entrance of catheter **30** through entry port **60** is at an angle, and does not significantly block the communication between microphone **184** and the interior of cylinder **54**.

In operation, speaker **168** periodically chirps at a rate of, for example, five times a second (5Hz). At the opposite end of cylinder **54**, microphone **184** listens for each chirp, including the main signal and reverberation set up inside cylinder **54**. It has been discovered that when balloon **52** is inflated and much of interior of cylinder **54** is blocked, a detectable attenuation of the primary chirp and the reverberations occurs. The circuitry associated with microphone **184** conditions each received chirp, temporally compares it with a tuned, phase-shifted reference pulse from the speaker driver circuitry, and determines whether balloon **52** is inflated or deflated.

3. Trainer Circuitry **51**

FIG. **12** shows a block diagram of the trainer circuitry **51**. Basically, trainer circuitry **51** can be described as four separate units: power supply **200**, optical shaft encoder **50**, computer interface **202**, and balloon detection circuitry **204**.

Traniner **10** has its own power supply circuitry **200** which converts the incoming AC line voltage to the necessary DC voltage levels required for operation of the various components within trainer circuitry **51**. Power supply circuitry **200** typically includes a power cord **206** and a circuit breaker **208** (which are shown in FIG. **13**) as well as a step-down transformer and a direct current supply (which are not shown). The direct current supply provides ± 5 V as well as ground for operation of operational amplifiers within balloon detection circuitry **204**. Power switch **20** is connected in the power supply circuitry to turn trainer **10** on and off.

Optical shaft encoder circuitry **50** is, in the preferred embodiment, the same encoder which is used in the Apple Macintosh computer mouse. This device requires a five volt supply voltage for operation of phototransistors **156** and **158** and photodiodes **152** and **154**. This supply voltage preferably is obtained directly from computer **12** by an arrangement in which either mouse **18** or optical shaft decoder **50** is connected through computer interface **202** to computer **12**, depending on the position of selection switch **21**. In this embodiment, the optical shaft encoder **50** operates by taking the place of mouse **18**. Rather than providing encoded data about mouse movement, computer interface **202** provides encoded data about movement of catheter **30**. The output of optical shaft encoder **50** is subsequently decoded by the already existing hardware within computer **12** and is available for further data processing and interpretation.

Computer interface **202** is shown diagramatically in FIG. **13**. Jack **J1** is located at the rear of computer **12**, while jacks **J2** and **J3** are located at the back of chassis **62** of trainer **10**. Multiconductor cable **210** has jack **J4** at one end for connection to jack **J1** of computer **12**, and jack **J5** at its opposite end for connection to jack **J2** of trainer **10**. Mouse **18** is connected through multiconductor cable **212** to jack **J3** of trainer **10**. Jack **J6** at the end of cable **212** mates with jack **J3**. In a preferred embodiment, jacks **J1** and **J3** are nine pin subminiature-D female chassis connectors, jack **J2** is a nine pin subminiature-D male chassis connector, jacks **J4** and **J6** are nine pin subminiature-D male line connectors, and jack **J5** is the nine pin subminiature-D female line connector.

Computer interface **202** selectively routes through jack **J2** to computer **12** either (a) signals from optical encoder **50** and optical isolator **214** of balloon detection circuitry **204**, or (b) signals to mouse **18**. In addition, power to mouse **18** and optical encoder **50** is received from computer **12** and is supplied selectively either to optical encoder **50** or mouse **18**.

The selection of the signals to be routed to computer **12** is made by select switch **21** which in one embodiment is a four-pole, double-throw switch. In one position, mouse **18** is connected to computer **12**. In the opposite position, signals from optical isolater **214** and optical encoder **50** will be routed to computer **12**. Computer interface **202** also causes the appropriate indicator **21A** or **21B** to be lit depending on the position of select switch **21**.

Balloon detection circuitry **204** is shown in block diagram in FIG. **12** and in schematic diagram in FIG. **14**. It includes optical isolator **214**, system clock **216**, transmitter **218**, receiver **220**, reference **222**, comparator **224**, and diagnostics circuit **226**.

Clock **216** includes an astable multivibrator formed by inverting buffers **228** and **230**, resistors **232** and **234**, and capacitor **236**. The 640 Hz output of the astable multivibrator is divided by divide-by-N counter **238** to provide the 5 Hz clock signal which is supplied to transmitter **218** and to reference **222**.

Transmitter **218** includes a positive triggered one-shot multivibrator **240** with associated timing resistor **242** and capacitor **244**, current limiting resistor **246** and speaker **168**. The output of transmitter **218** is an acoustic signal which sends quiet chirps at a frequency of five per second down cylinder **54** of acoustic detection chamber **48**.

The acoustic signals produced by transmitter **218** are detected by receiver **220**. The received signals from microphone **184** are amplified by an amplifier and unipolar feedback limiter circuit formed by operational amplifier (op amp) **250**, capacitor **252**, potentiometer **255**, resistors **254**, **256**, **258**, **260** and **262**, and Zener diode **264**. The output of op amp **250** is supplied to a signal processor formed by two positive triggered one-

shot multivibrators **266** and **268**, capacitors **270** and **272**, and resistors **274** and **276**.

The output of receiver **220** is supplied to comparator **224**, where it is temporally compared with a reference signal from reference circuit **222**. Reference circuit **222** includes a positive triggered one-shot multivibrator **278**, with associated timing capacitor **280** and potentiometer **282** and a negative triggered one-shot multivibrator **284** with associated timing capacitor **286** and resistor **288**.

The receiver and reference signals are supplied to dual input NAND gate **290** of comparator **224**. The output of NAND gate **290** is inverted by inverter **292** and supplied to retriggered one-shot multivibrator **294**, whose period is determined by capacitor **296** and resistor **298**.

One output of one-shot **294** is supplied to optical isolator **214**, which includes drive transistor **300**, resistors **302** and **304**, photodiode **306**, and phototransistor **308**. The output of optical isolator **214** is supplied to computer interface **202** and is in turn sent to computer **12** whenever select switch **21** has selected signals from trainer **10** as opposed to signals from mouse **18**.

The outputs of one-shot **294** of comparator **224** are also supplied to a diagnostic circuit which includes a pair of light-emitting diodes **310** and **312**, and a pair of inverters **314** and **316**.

In FIG. **14**, twelve different test points labeled TP1 through TP12 are shown. FIG. **15** illustrates timing of signals within balloon detection circuit **204** of FIG. **14** by showing the signals at the various test points. For test points TP6 and TP7, two different waveforms are illustrated, one in which balloon **52** is inflated ("balloon up") and the other in which balloon **52** is deflated ("balloon down").

As can be seen from FIG. **15**, if there are three successive pulses in which a reference signal was produced but no receiver output signal was received, the output of one shot **294** goes high, indicating that balloon **52** is up. As soon as a detected pulse results in a receiver output which corresponds to a reference signal, the output of one shot **294** goes low, indicating that balloon **52** is down. The requirement of multiple missed pulses before the balloon is identified as being inflated greatly reduces the likelihood of any erroneous output from balloon detection circuit **204**.

Table **1** shows the components used in one successful embodiment of balloon detection circuit **204**.

TABLE 1

Buffer	228	4049	Hex Inverting Buffer
Buffer	230	4049	Hex Inverting Buffer
Counter	238	4020	14-Stage Binary Ripple Counter
One Shot	240	4047	Multivibrator
One Shot	246	4047	Multivibrator
One Shot	268	4047	Multivibrator
NAND/Inverter	290	4011	Quad 2-Input Nand
NAND/Inverter	292	4011	Quad 2-Input Nand
NAND/Inverter	314	4011	Quad 2-Input Nand
NAND/Inverter	316	4011	Quad 2-Input Nand
Op Amp	248	NE5534	Operational Amplifier
Op Amp	250	NE5534	Operational Amplifier
Photodiode	306	MCT2	Optical Isolator
Phototransistor	308	MCT2	Optical Isolator
Capacitor	236	470	Picofarad
Capacitor	244	1000	Picofarad
Capacitor	252	100	Microfarad
Capacitor	270	01	Microfarad
Capacitor	272	1000	Picafarad
Capacitor	280	01	Microfarad
Capacitor	286	1000	Picafarad
Capacitor	296	0.1	Microfarad
Resistor	232	2 M	Ohms
Resistor	234	1.2 M	Ohms
Resistor	242	47K	Ohms
Resistor	246	470	Ohms
Resistor	254	100	Ohms
Resistor	256	33K	Ohms
Resistor	258	10K	Ohms
Resistor	260	100K	Ohms
Resistor	262	4.7K	Ohms
Resistor	274	560K	Ohms
Resistor	276	100K	Ohms
Resistor	288	47K	Ohms
Resistor	298	12 M	Ohms
Resistor	304	330	Ohms
Zener Diode	264	IN752A	5 Volt Zener Diode
Potentiometer	255	22K	Ohms Potentiometer
Potentiometer	282	500K	Ohms Potentiometer
Transistor	300	2N2222	NPN Transistor
LED	310	5 VDC	Red Light Emitting Diode
LED	312	5 VDC	Green Light Emitting Diode
Microphone	184	High Impedance	Miniature Crystal Microphone
Speaker	168	8 Ohm	Miniature Headphone Speaker

4. User Interaction—Computer **12**

Computer **12** performs three main functions. First, it monitors internal circuits of trainer **14** and determines what event is taking place based upon signals from optical shaft encoder **50** and from balloon detection circuit **204**.

Second, computer **12** provides a user friendly environment for the student, which eases the learning of the manual and cognitive skills required in hemodynamic monitoring. To accomplish this, the student may easily scan several topics concerning hemodynamic monitoring, much like reading a text book, but faster and tailored to the student's needs.

Third, computer **12** simulates events which would actually take place if the hemodynamic monitoring were being performed on a live patient. For example, computer **12** preferably recreates a cardiac monitor, similar to that found in a clinical setting, and shows waveforms of the various chambers of the heart and pulminary vasculature as the catheter **30** is advanced into manikin **22**.

In this third major function, computer **12** simulates a variety of different diseases, and the student may interactively select therapeutic options and observe the consequences. The diseases are presented in the form of case studies, which include a brief medical history (complete with history, physical and laboratory for each patient), presented on display **14** in the form of a familiar looking hospital chart. Once a decision has been made to place a catheter, the chart is removed from the display, and an image of a simulated cardiac monitor appears. In addition, if elected, the student may observe on display **14** a simulation of a chest fluoroscopic display and thereby watch catheter **30** advance into the chest as it is being advanced into manikin **22**.

FIG. **16** shows an image which is displayed on display **14** which appears whenever a student or an instructor is selecting the function to be performed. Appearing on screen **320** of display **14** is a rectangular image **322** which has, along its top edge, titles for the various operating sections: "Logo", "Introduction", "Background", "Method", "Patients", "Casemaker", and "Done". The user selects one of these sections by

moving cursor 324 to the appropriate title and pressing the ENTER key or button on mouse 18.

"Logo", when selected, displays a menu of some subsections which can then be selected by the user again by locating cursor 34 at the particular subsection of interest. Under "Logo" the subsections include "About the Dynacath System" (which provides general information); "Dynacath Hardware Tester" (which allows diagnostic testing of the system hardware to be performed); and "Instructional Text Editor" (which is a word processing program used whenever an instructor is creating text material to be read by students in one of the other sections).

"Introduction" displays a menu which includes subsections entitled "Getting Started", "About the Dynacath Hardware", and "About the Dynacath Software". Selecting any one of these three subsections causes computer 12 to display introductory text material on screen 320. This includes general instructional material which familiarizes the user with the operating principles of the hardware and software, as well as the theory of operation and uses of the system.

"Background" has four subsections which are displayed in a menu: "Principles of Hemodynamic Monitoring", "Waveform Characteristics and Identification", "Disease Determination and Therapeutic Options" and "Further Reading". Each of these four subsections contain textual material to be read by a student in order to familiarize the student with the process and techniques of hemodynamic monitoring. The student will normally review this material before attempting a simulated catheter insertion and monitoring.

The "Methods" section includes three subsections entitled "Review of Technical Skills", "Understanding the Instrumentation", and "Common Problems and Complications". Each of these sections include text material and appropriate graphics which instruct the student on the techniques used in the catheterization process, in understanding the information which is derived from hemodynamic monitoring, and problems and complications which can be encountered during hemodynamic monitoring.

The "Patients" section is used by the student when simulating the entire hemodynamic monitoring process. The "Patients" section accesses files which contain data necessary to simulate the hemodynamic monitoring process as the student inserts the catheter into manikin 22. The student can select a patient file by name or by disease category, or may allow computer 12 to select the patient at random for study.

The "Casemaker" section allows the instructor to create a new patient file, to edit an existing patient file, or to delete an existing patient file. The instructor can, for example, enter new information about the patient, create new or different waveforms which will be displayed during the simulated monitoring, or select and store complications which will occur during the simulation in order to test the manual and cognitive skills of the student.

The "Done" section allows the student or instructor to signal the computer 12 that he or she is done with a particular section, or is done using the system entirely.

FIG. 17 shows screen 320 during a simulation of hemodynamic monitoring. This simulation (which occurs when the student has selected a patient from the "Patients" section and has performed the catheterization procedure) results in an image of a simulated hemodynamic monitoring instrument 325. Simulated instrument 325 includes a simulated heart rate display 326, a simulated catheter pressure display 328, a simulated arterial pressure display 330, and a simulated oscilloscope display 332.

Heart rate display 326 displays a numerical value representing beats per minute. This value is, of course, stored in memory corresponding to the particular patient file. The heart rate which is displayed is representative of a measurement which can typically be made from an electrocardiogram signal.

Catheter display 328 displays two numerical values which simulate measurements made by cathether 30 when inserted in the patient and when balloon 52 is inflated. One value is alternatively the systolic or the diastolic pressure, and the other value is a mean pressure. These values are stored in the patient file and are dependent upon whether balloon 52 is inflated and the sensed position of the catheter within manikin 22 (based upon the position signals from catheter position sensor 44). Computer 12 selects the appropriate values to be displayed in catheter pressure display 328 based upon those inputs from trainer 10.

Arterial pressure sensor display 330 also displays systolic or diastolic pressure and a mean pressure. These pressures are typically measured by a separate sensing device (i.e. they are not read using catheter 30). Once again, the values which are displayed on simulated arterial pressure display 330 are stored in the patient file by computer 12, and are retrieved for display when the display mode showing instrument 325 is selected by the student.

Simulated waveform display 332 shows, in the preferred embodiment illustrated in FIG. 17, three separate waveforms 334, 336 and 338. Waveform 334 is an electrocardiogram (ECG) waveform. Waveform 336 is a waveform which represents pressure measured by catheter 30. Depending on the position of the cathether within manikin 22, computer 12 selects one of four previously stored waveform types: a right atrial, a right ventrical, a pulmonary artery, or a wedge pressure waveform.

Waveform 338 is an arterial pressure waveform. Like the pressure values displayed on simulated arterial pressure display 338, a waveform like the one displayed on arterial pressure waveform 338 would be derived in actual practice from a separate sensing device.

Waveforms 334, 336 and 338 preferably are created by the instructor using the Casemaker section. One of the functions which can be performed in the Casemaker section is entitled "Waveform Creator". In this mode, a display like the one shown in FIG. 18 appears on screen 320. The display includes a simulated graph paper 340 on which the instructor draws a waveform section 342. This waveform section can be created using mouse 18. When the instructor has completed drawing the waveform section, the instructor signals computer 12 using the key on mouse 18. Computer 12 treats waveform section 342 as one period of the waveform, and replicates section 342 to produce a multiperiod waveform like the one shown in FIG. 17. In this particular example, section 342 of FIG. 18 is one period of the ECG waveform 334 shown in FIG. 17.

In preferred embodiments of the present invention, the instructor can store a set of waveforms for each of several different scenarios. The particular set which is selected to be displayed on simulated instrument 324 depends upon the particular treatment option which is selected by the student. In this way, the student is able

to observe the consequences of particular treatment options and learn to expect and interpret changes in waveforms and readout values which can occur during hemodynamic monitoring.

Also shown on screen **320** in FIG. **17** are icons **344**, **346** and **348**. Icon **344** represents the fluoroscopic display mode, in which a simulated fluoroscopic image of the patient's chest showing the location of the tip of catheter **30**, is displayed on screen **320**. The location of the tip of catheter **30** as shown in the fluoroscopic display is dependent upon the signals from catheter position sensor **44**. The student selects the fluoroscopic display by placing cursor **324** adjacent icon **344** and supplying an EXECUTE command through mouse **18**.

Icon **346** represents a mode in which cardiac output using thermodilution is selected. In this mode, a cardiac output value (which would be measured in actual conditions using catheter **30**) is displayed on screen **320**. The cardiac output mode is selected by placing cursor **322** adjacent icon **346**, and supplying an EXECUTE command.

Icon **348** represents a progress note mode. When this mode is selected, a progress note is displayed in text form on screen **320**. The progress note describes the status of the patient at that time. The progress notes are previously prepared by the instructor and stored in memory by computer **12**. The progress note allows the student to determine at any time the current status of the patient, and thus allows the student to confirm conclusions which the student may have made about the patient's current status based upon the information displayed by simulated instrument **325**.

5. Conclusion

The hemodynamic training system of the present invention represents an extremely powerful yet user friendly and simple-to-use system for teaching the purpose, indications, methods, complications and techniques of hemodynamic monitoring of patients. This system provides a full simulation of the hemodynamic monitoring process, and in fact provides more information to the student than can be obtained conveniently using traditional training methods which take place at bedside using real, critically ill patients.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

What is claimed is:

1. A training system comprising:

a manikin having an insertion site at which a catheter may be inserted into the manikin;

means positioned at the insertion site for receiving a catheter as it is inserted into the manikin at the insertion site;

means for guiding the catheter along a path from the insertion site;

position sensing means for providing signals from which a location of a tip of the catheter can be determined; and

means for providing an output as a function of the signals from the position sensing means.

2. The system of claim **1** wherein the position sensing means is positioned along the path and wherein signals provided by the position sensing means indicate movement of the catheter along the path.

3. The system of claim **2** wherein the position sensing means comprises:

roller means for engaging the catheter and rotating as a function of movement of the catheter along the path; and

encoder means for providing signals as a function of rotation of the roller means.

4. The system of claim **3** wherein the position sensing means further comprises:

means for urging the catheter into contact with the pressure roller.

5. The system of claim **1** wherein the catheter is a hemodynamic monitoring catheter having an inflatable balloon at its tip, and wherein the system further comprises:

balloon state detecting means located adjacent an end of the path for providing signals which indicate when the balloon is inflated and deflated.

6. The system of claim **5** wherein the means for providing an output provides the output as a function of the signals provided by the position sensing means and the balloon state detecting means.

7. The system of claim **6** wherein the balloon state detecting means comprises an acoustic detection chamber connected at the end of the path and into which the tip of the catheter is advanced, and wherein the acoustic detection chamber detects inflated and deflated states of the balloon within the chamber based upon transmission of acoustic signals within the chamber.

8. The system of claim **7** wherein the acoustic detection chamber comprises:

a cylinder having an inner diameter large enough to permit inflation of the balloon within the cylinder;

transmitter means positioned at a first end of the cylinder for transmitting acoustic signals;

receiver means positioned at a second end of the cylinder for receiving acoustic signals;

port means for permitting passage of the catheter into the cylinder; and

means for deriving a balloon state signal as a function of signals from the receiver means.

9. The system of claim **8** wherein the means for deriving a balloon state the signal comprises:

means for providing a transmitter drive signal to the transmitter means;

means for deriving a reference signal from the transmitter drive signal;

means for deriving a receiver signal from the receiver means; and

means for comparing the reference signal and the receiver signal to produce the balloon state signal.

10. The system of claim **1** wherein the manikin comprises a hollow shell representing a portion of a human body, the manikin having an opening at the insertion site.

11. The system of claim **10** and further comprising:

an insertion plug positioned over the opening opening in the manikin, the insertion plug having a flexible top with an entry slit therein through which the catheter may be inserted and withdrawn.

12. The system of claim **11** wherein the insertion plug has a neck extending from an inner surface of its top which extends into the opening in the manikin to position the insertion plug at the insertion site.

13. The system of claim **12** wherein the insertion plug further includes, on the inner surface of its top, a hardened entry lip surrounding the entry slit.

14. The system of claim 13 wherein the insertion plug has a flesh color, with a vein coloration area generally aligned with the entry slit.

15. The system of claim 11 wherein the means for defining a path includes a first guide tube having an inlet and an outlet end; and wherein the means for receiving the catheter comprises an insertion adapter mounted at the insertion site below the insertion plug, the insertion adapter having a cavity which is generally aligned with the entry slit of the insertion plug for guiding the catheter from the entry slit into the inlet end of the guide tube.

16. The system of claim 15 wherein the cavity of the insertion adapter has slanted surfaces which form a funnel toward the inlet end of the guide tube.

17. The system of claim 1 wherein the means for providing an output comprises:

means for deriving a catheter tip position based upon the signals from the position sensing means; and

means for displaying a simulated waveform based upon the catheter tip position.

18. The system of claim 1 wherein the means for providing an output comprises:

computer means for receiving the signals from the position sensing means, the computer means including means for storing data from which simulated output information can be generated as a function of location of the catheter tip; and

display means controlled by the computer to display output information selected by the computer from the stored data based upon the location of the catheter tip.

19. The system of claim 18 wherein the computer means stores data for each of a plurality of hypothetical patients, the data including output information to be displayed when a particular one of the patients is selected.

20. The system of claim 19 wherein the computer means stores data representing hemodynamic monitoring waveforms.

21. The system of claim 20 wherein the computer means stores data from which a simulated chest fluoroscopic display is produced by the display means, the simulated fluoroscopic display providing a visual indication of the location of the catheter tip within the chest as a function of the derived catheter tip location.

22. The system of claim 1 wherein the manikin has a plurality of insertion sites; wherein the means for defining a path includes a plurality of guide tubes, each guide tube having an inlet end adjacent one of the insertion sites; and combiner means connected to outlet ends of the guide tubes for causing a convergence of individual paths defined by the guide tubes to a single path.

23. The system of claim 22 wherein the position sensing means is positioned along the single path.

24. A training system comprising:

a manikin representing a portion of a human body, the manikin having a first insertion site at which a catheter may be inserted into the manikin;

a chamber;

guide means for guiding the catheter along a path between the first insertion site and the chamber to simulate movement of the catheter to a desired location within the human body;

means for determining a position of a tip of the catheter; and

means for displaying a waveform which represents a simulation of a parameter measured using the catheter when the tip is located within the human body at a location corresponding to the position of the tip within the manikin.

25. A training system comprising:

a manikin representing a portion of a human body, the manikin having a first insertion site at which a catheter may be inserted into the manikin;

a chamber;

guide means for guiding the catheter along a path between the first insertion site and the chamber to simulate movement of the catheter to a desired locaton within the human body;

means for providing encoder signals representing incremental motion of the catheter along the path; and

means for determining a position of the tip based upon the encoder signals; and

means for providing an output as a function of the position.

26. A training system for training in the use of a catheter of a type having an inflatable balloon at its tip, the system comprising:

a manikin representing a portion of a human body, the manikin having a first insertion site at which the catheter may be inserted into the manikin;

a chamber;

guide means for guiding the catheter along a path between the first insertion site and the chamber to simulate movement of the catheter to a desired location within the human body;

transmitter means positioned at a first end of the chamber for transmitting acoustic signals;

receiver means positioned at a second end of the chamber for receiving acoustic signals; and

means for deriving a balloon state signal as a function of signals from the receiver means.

27. The system of claim 26 wherein the means for deriving the balloon state signal comprises:

means for providing a transmitter drive signal to the transmitter means;

means for deriving a reference signal from the transmitter drive signal;

means for deriving a receiver signal from the receiver means; and

means for comparing the reference signal and the receiver signal to produce the balloon state signal.

28. A training system comprising:

a manikin representing a portion of a human body, the manikin having an opening at a first insertion site at which a catheter may be inserted into the manikin;

a chamber;

guide means for guiding the catheter along a path between the first insertion site and the chamber to simulate movement of the catheter to a desired location within the human body;

an insertion plug positioned over the opening in the manikin, the insertion plug having a flexible top with an entry slit therein through which the catheter may be inserted and withdrawn;

wherein the insertion plug has a neck which extends into the opening in the manikin to position the insertion plug at the first insertion site;

wherein the insertion plug further includes a hardened entry lip surrounding the entry slit;

wherein the insertion plug has a flesh color, and a vein coloration area generally aligned with the entry slit; and

wherein the guide means comprises:

a first guide tube having an inlet and an outlet end; and

an insertion adapter mounted at the first insertion site below the insertion plug, the insertion adapter having a cavity which is generally aligned with the entry slit of the insertion plug for guiding the catheter from the entry slit into the inlet end of the first guide tube; wherein the cavity of the insertion adapter has slanted surfaces which form a funnel toward the inlet end of the first guide tube.

29. A training system comprising:

a manikin representing a portion of a human body, the manikin having first and second insertion sites at which a catheter may be inserted into the manikin;

a chamber;

guide means for guiding the catheter along a path between the first insertion site and the chamber to simulate movement of the catheter to a desired location within the human body; wherein the guide means comprises:

a first guide tube leading from the first insertion site;

a second guide tube leading from the second insertion site;

combiner means connected to the first and second guide tubes for causing a convergence of separate paths defined by the guide tubes to a common path which leads to the chamber.

30. A training system for training in the use of a catheter which has an inflatable balloon at its tip, the system comprising:

a manikin representing a portion of a human body, the manikin having an insertion site at which the catheter may be inserted into the manikin;

guide means for guiding the catheter along a path from the insertion site;

means for sensing position of the catheter tip along the path;

means for sensing whether the balloon is inflated; and

means for providing a simulated output based upon the position of the catheter tip and whether the balloon is inflated.

31. A training system for training in the use of a catheter, the system comprising:

a manikin having an opening at an insertion site;

an insertion plug positioned over the opening, the insertion plug having a flexible top with an entry slit through which the catheter may be inserted and withdrawn; wherein the insertion plug has a neck which extends into the opening in the manikin to position the insertion plug at the insertion site; wherein the insertion plug further includes a hardened entry lip surrounding the entry slit; and

guide means for guiding the catheter from the entry slit along a path to simulate movement of the catheter to a desired location within a human body; wherein the guide means includes a guide tube having an inlet end and an outlet end; and an insertion adapter mounted at the insertion site below the insertion plug, the insertion adapter having a cavity which is generally aligned with the entry slit of the insertion plug for guiding the catheter from the entry slit into the inlet end of the guide tube; wherein the cavity of the insertion adapter has slanted surfaces which form a funnel toward the inlet end of the guide tube.

32. The system of claim **31** and further comprising:

means for determining a position of the catheter along the path; and

means for providing an output as a function of the position.

33. The system of claim **31** wherein the insertion plug has a flesh color, and a vein coloration area generally aligned with the entry slit.

* * * * *

Correspondence

Methodist Hospital
Medical Staff

November 29, 1985

Steven Saliterman, M.D.
W110 Meadowbrook Medical Building
St. Louis Park, MN 55426

Dear Steve:

RE: Internal Medicine Subspecialty Conference - "Introduction to the Hemodynamic Monitoring Trainer"

This is simply a brief note to give you some feedback on your presentation of November 20, 1985. I think we were all struck by the ingenuity of the model. It obviously represented a great deal of work over a number of years. All the attendees rated the talk as excellent. I must say, for my part, I thought it was a clever, innovative, and superb presentation.

Yours sincerely,

David

David N. Williams, M.D.
Coordinator, Medical Education

DNW/ln

cc: Thomas Slack, M.D.

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May 13, 1986

Dr. Steven Saliterman
6490 Excelsior Blvd.
St. Louis Park, MN 55426

Dear Steve:

RE: Hemodynamic monitoring trainer

I would like to express my personal appreciation for your presentation of the hemodynamic monitoring training device at our surgical conference. I think it is an extraordinary bit of training aid and obviously has taken lots of thought and work to develop this and to what I believe to be a first class training aid. It is a unique trainer, since there is no good way to teach people about the introduction of Swan Ganz catheters and what the different parameters and values may mean in terms of the hemodynamics of the patient with cardiorespiratory aberrations. The trainer is a significant teaching aid, since one can get different data into the system so that you can train critcal care nurses and residents realistically with therapeutic maneuvers and endeavors.

I commend you for the tremendous effort you have put in to this and thank you for your demonstration and help. I am sure that this will be a significant training tool nationwide for those people who are involved in critical care medicine.

Most sincerely,

Earl G. Young

Earl G. Young, M.D., Ph.D.
Clinical Professor of Surgery
University of Minnesota

mg

UNIVERSITY OF MINNESOTA
TWIN CITIES

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Box 508 Mayo Memorial Building
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(612) 625-9100

June 19, 1986

Steven S. Saliterman, M.D.
Meadowbrook Medical Building, Stuie W-110
6490 Excelsior Blvd.
Minneapolis, MN 55426

Dear Steve:

I am sorry I had to leave so quickly on the day you were here to show us the Hemodynamic Monitoring Trainer. Since I did not have adequate time to talk to you about it, I wanted to let you know that I was extremely impressed by its potential. I cannot think of a better way to teach the concepts of hemodynamic monitoring to students and residents. From my discussions with Bruce and Jay, they were equally enthusiastic. If I can be of any help to you with the trainer, please let me know.

Sincerely,

Jeffrey S. Schwartz, M.D.
Associate Professor of Medicine

JSS:ds

9 (L-JSSS)

Mayo Clinic Rochester, Minnesota 55905 Telephone 507 284-2511

Charles P. Taliercio, M.D.
Cardiovascular Diseases
and Internal Medicine

May 26, 1988

Steven S. Saliterman, M.D.
Meadowbrook Medical Building
Suite W-110
6490 Excelsior Boulevard
Minneapolis, MN 55246

Dear Steve:

I was happy to see you recently in Rochester. I must admit that I was quite impressed with the Dynacath Critical Care & Hemodynamic Monitoring Training System. It has an appealing appearance and was quite user friendly. After just a couple of cases I felt quite capable of using the system on my own. I think the system will be very useful in medical education at the medical student, resident and trainee level. It will be important to maintain a large library of cases such that the system can be used many times by the same individual. Its primary market should be medical centers with training programs.

Thank you for allowing me to review this exciting educational tool. Try not to forget some of the people you trained with after you become rich and famous.

Sincerely,

Charlie

Charles P. Taliercio, M.D.

CPT/jml

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January 11, 1988

Steven S. Saliterman, M.D.
Meadowbrook Medical Bldg., Suite W-110
6490 Excelsior Blvd.
Minneapolis, Minnesota 55426

Dear Steve,

It was great to here from you! I apologize for the delay in getting back to you but the holidays got in the way.

I have reviewed the information you sent on the Dynacath training system fairly carefully since it hits interests of mine at a couple of points - namely hemodynamic monitoring, computers in cardiology and just plain good, creative ideas. In short I think this is a terrific development. I agree with you that this is the most effective way to teach this material and it seems, from looking over the manual, that you have implemented it very well indeed.

I don't have responsibility for the Coronary Care Unit here, or mu;ch direct interaction with the teaching of hemodynamics. I have passed the materials on, however, to Dr. Chatterjee and Dr. Wolfe who do run the unit. I will have them respond to you or your company directly with their interests.

I would love to hear about the origins of Dynacath and how you have grown it up in more detail. I will probably be in Minnesota next summer and will try to reach you then. Please also contact me if you're out in the Bay area. I can be reached best by the page operator (415) 476-2155; my office number is (415) 476-1326 and the home number is (415) 469-7841.

I am looking forward to hearing from you - all the best for the new year!

Yours sincerely,

Paul G. Yock, MD
Assistant Professor of Medicine
Associate Director Catheterization Lab

Mayo Clinic Rochester, Minnesota 55905 Telephone 507 284-2511

Guy S. Reeder, M.D.
Cardiovascular Diseases
and Internal Medicine

May 26, 1988

Steven S. Saliterman, M.D.
Meadowbrook Medical Building
Suite W-110
6490 Excelsior Boulevard
Minneapolis, MN 55426

Dear Steve:

It was a pleasure to visit with you again and also to see your innovative device. This certainly is a nice appearing package and, I think, eminently marketable. I feel the main targets would be residents in training and perhaps medical students. While the manikin generates some instant appeal for those wanting to gain experience with heart catheterization, the "staying power" of the device will likely reside in the software. Perhaps you will offer a library of cases exemplifying common clinical cardiologic problems. I think this would strengthen the salability of the device.

Good luck.

Sincerely,

G. S. Reeder, M.D.

GSR:lg

Mayo Clinic Rochester, Minnesota 55905 Telephone 507 284-2511

Mahlon K. Burbank, M.D.
Cardiovascular Diseases
and Internal Medicine

May 31, 1988

Steven S. Saliterman, M.D.
Meadowbrook Medical Building, Suite W-110
6490 Excelsior Boulevard
Minneapolis, MN 55426

Dear Steve:

I certainly enjoyed watching the Dynacath Training System while you were demonstrating it. I am amazed at what can be done by a system such as this. As you know, I do not work in the cath lab, but I do recall the difficulties when I did take some training in the cath lab doing all the calculations and figuring out the values that we needed. Clearly, with such a system as yours, anyone training in the catheterization laboratory could understand why it was so important to make the correct calculations.

I would think that besides for use in training in the cath lab, such apparatus might be very useful in the intensive care unit to demonstrate to the noncardiac residents the significance of changes and why such data that is being acquired is of value.

I wish you luck with your project and was most impressed by your knowledge and ability to produce such a technical marvel.

Yours truly,

Mahlon

Mahlon K. Burbank, M.D.

MKB:rjk

Mayo Clinic Rochester, Minnesota 55905 Telephone 507 284-2511

Mark J. Callahan, M.D.
Cardiovascular Diseases
and Internal Medicine

June 1, 1988

Steven Saliterman, M.D.
Meadowbrook Medical Building
Suite W-110
6490 Excelsior Boulevard
Minneapolis, MN 55426

Dear Steve:

I enjoyed seeing you again and was certainly impressed by the Dyna-Cath training system. Certainly, its appearance as well as its flexibility are ideal for hemodynamic/ICU teaching. Its marketability would, I believe, only be limited by the ultimate price attached. I would be happy to consider the unit formally for our position at Mayo when it is commercially available. However, I must warn you that there will probably be some divisional resistance to an expensive item in this year of financial retrenchment. Nevertheless, let's both remain optimistic.

Sincerely yours,

Mark

Mark J. Callahan, M.D.

MJC:jmh

Mayo Clinic Rochester, Minnesota 55905 Telephone 507 284-2511

David A. Ahlquist, M.D.
Gastroenterology
and Internal Medicine

December 16, 1988

Steven S. Saliterman, M.D.
Meadowbrook Medical Bldg.
Suite W-110
6490 Excelsior Blvd.
Minneapolis, MN 55426

Dear Steve:

Thank you for sending me the brochure on your Dynacath Trainer. This is high tech and most impressive, especially considering the fact that you have done this on your own.

Best wishes to you over the New Year---all the success with Dynacath!

With warm regards,

David A. Ahlquist

David A. Ahlquist, M.D.

DAA:ssl

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Arkady Synhavsky, M.D.
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Nephrology
Internal Medicine
Transplantation
Critical Care
Apheresis

May 10, 1989

Steven Saliterman, M.D.
Meadowbrook Medical Building
6490 Excelsior Boulevard
Minneapolis, Minnesota 55426

Re: Dynacath Trainer

Dear Steve:

Thank you very much for allowing me to utilize the Dynacath Trainer over the past three months. I am quite impressed with its ease of use and quick ability to program cases and monitor tracings into the equipment.

I think at Methodist it will turn out to be invaluable in both nurse and physician education regarding hemodynamic monitoring in the Critical Care Unit. I hope to use it in the future in the certification of physicians in the use of Swan-Ganz catheterization.

Thank you again.

With kind regards,

Michael G. Somermeyer, M.D.
Methodist Director of Critical Care
MGS:MTS:sl

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January 26,1988

Mr. Steven S. Saliterman, M.D.
President
Dynacath Corporation
Ford Centre, Suite 570
420 North Fifth Street
Minneapolis, Mn. 55401

Dear Dr. Saliterman,

I would like to congratulate you on behalf of Apple Computer, Inc. on your selection by the National Patent and Trademark Office to exhibit at the National Inventors Expo '89.

The Dynacath Critical Care & Hemodynamic Monitoring Training System™ is an outstanding example of innovation for medical education and patient care that maximizes the ease-of-use and intuitive capabilities of the Apple Macintosh personal computer.

In the era of cost containment, I believe products such as the Dynacath Trainer, integrating computer technology into patient management, will be necessary to continue to raise the quality of patient care. We are proud that the Macintosh provided the appropriate platform to be an integral part of the Dynacath Trainer. Congratulations again on this achievement and I wish you tremendous success.

Very truly yours,

John E. Luff
Manager, Healthcare Market

Apple Computer, Inc.
20525 Mariani Avenue
Cupertino, California 95014
408 996-1010
TLX 171-576

Methodist Hospital

June 20, 1988

Steven S. Saliterman, M.D.
Meadowbrook Medical Building
Suite W. 110
6490 Excelsior Boulevard
Minneapolis, MN 55426

Dear Dr. Saliterman:

Thank you for the time you spent showing us your hemodynamic trainer. We all felt very enthusiastic about its potential uses in the medical/nursing field and about the opportunity you are offering Methodist Hospital in becoming involved. The years of time and hard work you have invested in this project were obvious, but we were especially impressed with the magnitude of your talents.

We specifically felt the realistic "feel" of the system and its ease of use by the true computer novice were outstanding. Its number of practical potential uses seem almost unlimited and range from technician training, critical care nurse training, and physician training - at all levels, from beginner to advanced. To our knowledge this is the only system available that allows for "hands-on" experience with the procedure of pulmonary artery catheter placement with a computer based learning center for interpretation and intervention of hemodynamic data.

We are definitely interested in a follow-through of your original offer to serve as a pilot test site for your product. Please let us know as soon as you have a system available for our use.

Sincerely,

Candace Lano
Candace Lano
Nurse Educator

Pat Robertson
Pat Robertson
Vice President, Patient Care Services

Pat Christie
Pat Christie
Director of Nursing

CL, PR, PC/gw

THE UNIVERSITY OF TENNESSEE
MEMPHIS
The Health Science Center

College of Medicine
Department of Anesthesiology
800 Madison Avenue, Memphis, TN 38163
(901) 528-5892

31 May 1990

Steven S. Saliterman, M.D.
Meadowbrook Medical Bldg.
Suite W-110
6440 Excelsior Blvd.
St. Louis Park, MN 55426

Dear Dr. Saliterman:

Thankyou very much for your participation in the SCA Education Workshop in Orlando, Florida. Your presentation on Anesthesia Simulators and Training Devices was very well received. In spite of having a time slot after the official end of the scientific meeting, I believe that the workshop overall was a success and very worthwhile for those who attended.

You should have submitted your travel expenses to the SCA for reimbursement. In addition, you will receive a per diem of $200, and an honorarium if you are a non-SCA member or are not eligible to become one. Again, thankyou for your effort.

Sincerely yours,

Daniel F. Grum, M.D

Daniel F. Grum, M.D.
Associate Professor

UNIVERSITY OF MINNESOTA

Health Computer Sciences
Laboratory Medicine and
Pathology
Box 511 UMHC
Minneapolis, Minnesota 55455
(612) 625-8440

October 24, 1990

Steven Saliterman, MD
Meadowbrook Medical Bldg. W-110
6490 Excelsior Blvd.
Minneapolis, MN 55426

Dear Dr. Saliterman:

I would like to thank you for your Biomedical Engineering Seminar presentation on the critical care patient management simulator. Your overview of the problem and discussion of your research and development efforts was most interesting and informative. The large audience and many questions attests to the widespread interest in this work.

Thanks again for your contribution to our seminar program.

Sincerely,

Stanley M. Finkelstein, PhD
Professor
Director, Biomedical Engineering Seminar Series

SF:dg

THE JOHNS HOPKINS UNIVERSITY
SCHOOL OF MEDICINE

James F. Schauble, M.D.
Department of Anesthesiology
& Critical Care Medicine

Please address reply care of
THE JOHNS HOPKINS HOSPITAL
BALTIMORE, MARYLAND 21205
(301) 955-6482

November 8, 1991

Steven Saliterman, M.D.
Meadowbrook Medical Building
6490 Excelsior Boulevard, Suite W110
Minneapolis, MN 55426

Dear Steven:

On behalf of myself and everyone who worked with you at the recent Hemodynamic Course, I would like to convey our pleasure in working together with you and gratitude for your immensely helpful contribution to the Course. I was chatting on the telephone yesterday with Frank Booth who will be co-directing the Course at the session October 31 - November 1, 1992 and we both earnestly hope that you will accept an invitation to participate in that session.

It is my understanding that we should be sending you a purchase order from Hopkins within a few days, and I believe Frank plans to order a simulator as well. The two of us are hoping to exchange operating room and ICU cases and build a joint teaching file based on the experience in Buffalo and Baltimore.

One of the thoughts that has crossed my mind (and which is a little a part from the concept of using the simulator with a small group of people or one on one) is to take some of the digitized waveforms and some of the cases with branching treatment algorithms and project them onto a large screen in the amphitheater as a way of encouraging group participation and interchange between speaker and audience.

I would very much be interested in any comments you have to make about the teaching.

Again, let me thank you for your contribution.

With warm personal regards. I am,

Sincerely,

James F. Schauble, M.D.

JFS/sdb
cc: Frank Booth, M.D.

Medtronic

Medtronic, Inc.
7000 Central Avenue, N.E.
Minneapolis, MN 55432-3576
Telephone: (612) 574-4000
Cable: Medtronic Telex: 29-0598
Telecopy: (612) 574-4879

December 10, 1991

Dr. Steven S. Saliterman
Dynacath Corporation
Meadowbrook Medical Bldg., W-110
6490 Excelsior Blvd.
Minneapolis, MN 55426

Dear Dr. Saliterman:

As follow-up to our December 5 telephone conversation, I would like to confirm Medtronic's ongoing interest in your technologies and how they might assist us in achieving our goal of providing physicians and other pacing healthcare professionals a learning model to simulate the implantation of pacing leads.

My estimate at this time would be that Medtronic would potentially acquire initially up to 25 or 30 of these systems at a cost range of $3,000 to $5,000. Whether we would like to acquire exclusive distribution rights is uncertain at this time, but we would like consideration for this if the opportunity arose.

Again, Dr. Saliterman, Medtronic was extremely impressed with you and your technologies. I sincerely hope that we will have the opportunity to collaborate further on this concept and potentially other ventures in the future.

Regards,

Paul S. Behl

Paul S. Behl
Sr. Account Executive

PB/dgs

UNIVERSITY OF MINNESOTA

Division of Cardiology
Department of Medicine
Medical School

Hennepin County Medical Center
701 Park Avenue South
Minneapolis, MN 55415
612-347-2875
Fax: 612-337-7495

December 3, 1992

Steve Saliterman, M.D.
Meadowbrook Medical Building
W110
6490 Excelsior Blvd.
St. Louis Park, MN 55426

Dear Steve:

Your presentation to us was a big hit. I received many favorable comments about your presentations. The hand-outs were especially popular. The teaching device you have developed is really quite extraordinary. The real challenge is to use it to the full extent of its capabilities. Mary Tahnk-Johnson remains enthused about developing further cardiology cases and I will be working closely with her on that project. We at Hennepin County Medical Center very much appreciate your taking time out of a busy schedule to speak to us and to demonstrate your work. I am sure that we will be in touch soon.

Sincerely,

Scott

Scott W. Sharkey, M.D.
Director, Cardiac Care Unit
Hennepin County Medical Center

Assistant Professor of Medicine
University of Minnesota

SWS/rr

725 S. Dellwood
Cambridge, MN 55008
Local 612-689-1500
Metro 612-434-6123
Greater MN 1-800-252-4133
Fax 612-689-7739

Cambridge
Memorial Hospital
A HealthSpan Organization

April 1, 1994

Dr. Steven Saliterman
6490 Excelsior Blvd., Room 110
St. Louis Park, MN 55426

Dear Steve:

Once again, sincere thanks for joining us in Cambridge this morning for the CME exercise on pulmonary artery monitoring and pulmonary intensive care.

This talk was truly "world class" and was greatly appreciated by our medical staff.

We are seriously considering obtaining the Swan Ganz simulator for physician and nursing staff education purposes.

I would like to request that additional copies of the brochure describing this equipment be sent to the following individuals at Cambridge Memorial Hospital:

Marly Dolezal, RN ICU
Liz Larson, Medical Education Department
Clayton Peterson, President

In an institution where frequency of Swan is somewhat low, it would appear that this device could greatly enhance physician and nursing staff comfort level and sense of competence by being able to practice interpretation of data and insertion procedures.

Once again, sincere thanks for joining us. I look forward to seeing you in the near future.

Cordially, — Don

Donald L. Deye, M.D./bkl

CC: C. Peterson, L. Larson

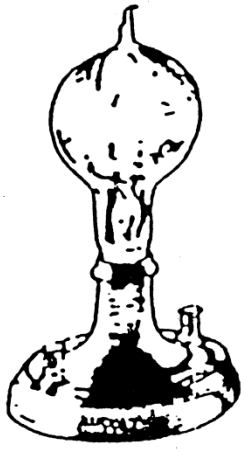
Great to see you again!

Presentations

17th Annual

INVENTORS EXPO

February 11
1 - 5 pm



February 12
10 am - 5 pm

PATENT & TRADEMARK OFFICE
PUBLIC SEARCH ROOM
CRYSTAL PLAZA BUILDING 3

2021 JEFFERSON DAVIS HWY.
ARLINGTON, VIRGINIA

★★★ INVENTOR EXHIBITS ★★★

BOOTH #

1	Weekly Reader (Young Inventors)	21	John A. Jakimas (Collapsible Crab Trap)	41	Eldon E. Larson (Seal-Greasing Apparatus)
2	George Cornelius (Brick and Block Pattern Form)	22	Manuel Cornrich (Pet Food Dispenser)	42	Jan Casner (Project XL)
3	J.A. Davidson (Rectangular Cutout Cutting Device)	23	John Fenton (Internal Combustion Engine)	43	Jan Casner (Project XL)
4	Alvin Blum (Joint and Muscle Activity Device)	24	Grant Barker (Air Conditioned Apron)	44	Herschel W. Crump (Sound Muffling System)
5	Robert P. Herbert (Game Board)	25	Frank McCarthy (Three Year Calender)	45	Allen Bruce Mage (3-D Display Device)
6	S. Pal Asija (Computer)	26	Jules A. Sandor (Fire Escape Ladder)	46	Alfred B. Riley (Manuel Gear Wrench)
7	Russel P. Gorsha (Work Support)	27	Donald F. Kennedy (Level)	47	Roger F. Moisdon (Verticle Ship)
8	Mary Ann Fallis (Pocket Seat Cushion)	28	Brian Vantosh (Vinyl Siding Repair)	48	John Soumenis (Rearview Mirror Assembly)
9	Tom Drake (Extension Handles for Trimmers)	29	Allie E. Orr (Illuminating Device Support)	49	J.Craig Yacoe (Geotangent Dome System)
10	Jim Hudson (Gas Chamber Animal Trap)	30	Steven S. Saliterman, M.D. (Hemodynamic Monitoring)	50	L. John Grenzer (Portaging Device)
11	Nancy G. Abt (Therapeutic Cooling Wrap)	31	Ken L. Yost (Pump Filter Apparatus)	51	Daniel Fermaglich (Baby Seat)
12	Peter J. Weyland (Mouse Trap)	32	William V. Duggan (Aerobic Exercise Machine)	52	Adam Sebalos (Pressure Liquid Dispenser)
13	Carl D. Keith (Camera Support)	33	Russell A. Byrd (Automated Garage System)	53	Lawrence L. Lee (Perforated Splint)
14	Dr. Arnold Rosenberg (Diet Game)	34	Alma Williamson (Beverage Cooler)	54	Frederick L. Jones (Boat Cover/Winch; Bag Holder)
15	Joseph L. Knight (Scribing Rule Guide)	35	Bozena Kucera (Mini Seeder)	55	Earnest J. Callahan (Stove Damper)
16	Robert Moyer (Portable Ladder Step)	36	Jerry Nitzberg (Accessory For Hammers)	56	Chrissellene Petropoulos (Cold Protective Garment)
17	William A. Krut (Magnetic Spinning Device)	37	James B. Reswick (Bicycle Transmission)	57	Evangelos A. Papadatos (Chord Selector)
18	Lloyd E. Wessel (Lawnmower Edger and Trimmer)	38	Gary W. Roberts (Vinyl Window Seal)	58	John G. Bjorklund (Water Purification Device)
19	Warren L. Erwin (Truck Coupling Arrangement)	39	Harry S. Bloch (Baby Sensor)	59	Robert E. Willis (Door Brace)
20	Arnold A. Buehler (Fingernail Cleaning Device)	40	Dr. Vinzi Laguna (Vehicle Anti-Theft Device)	60	Frank O. Price (Quarterback Football Game)

Peg Saliterman at the US Patent Office

Peg Saliterman at the US Patent Office Expo

ANNOUNCEMENT - PLEASE POST

BIOMEDICAL ENGINEERING SEMINAR

Fall Quarter
Tuesday, October 23, 1990

3:35-4:35 PM
Eustis Amphitheater, D230 Mayo

Critical Care Patient Management Simulation

Steven S. Saliterman, M.D.
Methodist Hospital
Minneapolis

A patient simulator has been developed for training, certification, modeling, and demonstrating problems in the management of critical care patients. The Dynacath Critical Care Patient Simulator consists of a personal 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.

Authors build a library of informative cases by using hardware and software tools provided.

For questions or further information, please call or write Doreen Gruebele, Box 5ll UMHC, 420 Delaware Street SE, Univeristy of Minnesota, Minneapolis, MN 55455, 612-625-8440.

This Seminar program is sponsored by the Biomedical Engineering Center, in conjunction with the Graduate Program in Biomedical Engineering.

Eric Lance at Park Nicollet Meeting

Annual Meeting of the Society of Critical Care Medicine

Feature Articles

MEDICAL RESEARCH

Dogs vs. Bytes

Computer models may soon replace some live animal experiments

BY DAVID STAMPS

IT PROBABLY SAYS SOMETHING ABOUT THE LEVEL OF concern for laboratory animals in this country that no one knows for sure how many are sacrificed each year for research, training, or testing of new drugs and consumer products. The best estimates put the figure at about 70 million, which includes 250,000 dogs, 100,000 cats, 25,000 primates, 750,000 rabbits, and 60 million rodents. The most distressing thing about the total number of animals used, say animal rights activists, is that it is increasing every year. Ironically, this increase comes at a time when more and more Americans are beginning to believe that the number of animals used in laboratory experiments is excessive.

Animal rights groups like People for the Ethical Treatment of Animals (PETA) have aroused public support by calling attention to research projects that duplicate one another or, in some cases, expose animals to treatment that is nothing short of cruel. Last year, in one of its more publicized actions, PETA obtained some 60 hours of videotape showing experiments performed at the University of Pennsylvania Medical School's Head Injury Lab. The tapes, seized from Dr. Thomas Gennarelli's lab by the Animal Liberation Front, an underground group that stages raids on research facilities, showed unanesthetized baboons being subjected to violent head injuries. (The tapes also revealed some distressingly unprofessional procedures—a lab technician suturing a wound while smoking a cigarette, and injured baboons being subjected to cavalier, even mocking, treatment by laboratory staff.)

Exposure of such abuses is starting to do more than grab headlines. According to Alex Pacheco, PETA chairman and cofounder, the animal rights movement is beginning to broaden its base of support.

"We're starting to see more professional groups like the Animal Legal Defense Fund and Psychologists for Ethical Treatment of Animals," says Pacheco. He views this growing grassroots support as the movement's greatest stride forward in recent years—one that may outweigh even the potential benefit from bills recently introduced in Congress that attempt to tighten controls on the conditions under which animal experiments can be performed.

"I'd be more enthusiastic about the legislation if it stood a chance of passing in anything but watered-down form," says Pacheco. "Trying to out-lobby the AMA [American Medical Association] is pretty hopeless, but we're starting to win support for future battles. There is even a new group called the Physicians Committee for Responsible Medicine."

Closer to home, the Animal Rights Coalition (ARC), a national organization based in the Twin Cities, cites figures that it claims illustrate both the growing influence of the animal rights movement and the difficulty of effecting change in the medical and research establishment. The University of Minnesota's Research Animal Resources Department, which supplies animals to most university labs, has within the last two years reduced its purchases of dogs and cats by 17 and 24 percent, respectively.

"That's a victory for dogs and cats, the animals that people identify with," says Vonnie Thomasberg, ARC cofounder and spokeswoman. However, the total number of live animal experiments done at the university is increasing at a rate the ARC finds alarming. Because of a dramatic rise in rat and mice experiments, the number of animals purchased by the university has doubled from 65,000 in 1982 to more than 131,000 in 1984.

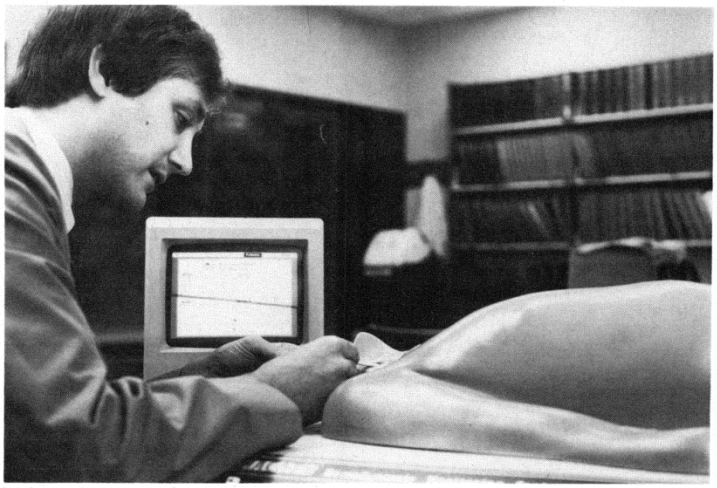
"Animal research is a for-profit business and as such will be slow to change its ways," says Thomasberg.

There may indeed be resistance to change within the research community, but part of the reluctance to abandon live animal testing and training may also stem from the fact that alternatives are becoming available very slowly at best. One of the possible alternatives cited by animal rights groups is the use of computer models in place of some experiments. Yet despite the availability of relatively powerful but inexpensive computers, useful simulations of live animal experiments are still few and far between.

Since 1982 Dr. Steven Saliterman has been dividing his time between his internal medicine practice in St. Louis Park and what amounts to a one-man research and development effort aimed at producing a computer model for teaching a procedure called hemodynamic monitoring. Hemodynamic monitoring involves passing a catheter (which has an inflatable balloon at one end) from a distant vein through the heart and into the pulmonary vasculature. Pressures detected by the balloon catheter are displayed as wave forms on an oscilloscope. The procedure is performed in a coronary care unit, where the type of wave form displayed can help a cardiologist determine if a patient is suffering from simple heart failure, a misfunctioning valve, or some other heart disorder.

For the past two years, Saliterman has invested an average of five to six hours a day—plus a fair amount of his own money—on design, programming, and research for the project. The result, he believes, is the first sophisticated computer model for teaching hemodynamic monitoring techniques.

The system, a prototype of which will be unveiled to cardiologists and medical schools later this month, is actually both a physical and a computer model, since it includes the upper torso and right arm of a mannequin. Electronic sensing devices in the mannequin



Dr. Steven Saliterman with the computerized model he designed to help teach hemodynamic monitoring. The mannequin, which is attached to an Apple Macintosh computer, was molded after Saliterman's own torso and right arm.

PHOTOGRAPH BY JAMES SCHINDLER

MMCC

Minnesota Medical Computing Consortium

NEWSLETTER **no. 7**

October 1985

COMPUTERIZED SWAN-GANZ INTERFACE

Next MMCC Meeting

November meeting, Wednesday, Nov. 13, 7:30 pm
Health Associations Center Bldg
2221 University Ave SE Mpls.

A Minneapolis internist has created an unusual training and testing tool for intensive care units. Steven Saliterman MD was heavily into digital electronics before attending Mayo Medical School. His interest has continued with the development of a mannequin connected to a MacIntosh. This allows Swan-Ganz users to demonstrate and learn skills in intensive care monitoring and treatment of patients in shock and heart failure.

The Swan-Ganz pulmonary artery monitor is used to determine the arterial pressure in the lungs and in the left atrium of the heart before the blood is pumped to the lungs. The left atrial pressure measurement is critical when treating the hypotension and low cardiac output of shock victims. Swan-Ganz catheters are the only way to measure this.

The multiple lumen catheter is threaded through a major vein to the superior vena cava. The tiny balloon at the tip is then inflated. This pulls the catheter along with the blood flow through the right side of the heart. Pressure measurements are taken in the atrium and ventricle and shown in wave form. Following the flow of blood the catheter enters the lungs through the pulmonary artery, travels down the branching of blood vessels until it wedges in an artery that is too small to allow further passage. When the balloon is inflated it closes off blood flow creating a situation where wedge arterial pressure can be measured. The pressure thus measured is actually a pressure reading from the left atrium of the heart or the main pooling chamber just before the main muscle of the heart, the left ventricle.

Gaining proficiency at the use of the Swan-Ganz monitor is a difficult task even in busy intensive care units where these devices are used with much frequency. Furthermore, it is difficult to demonstrate proficiency in the use of this technique for purposes of malpractice risk management and hospital procedure approval. Aside from actually taking care of acutely ill patients there has been no adequate way of learning or demonstrating facility with this monitor.

This is where the mannequin interface is useful. The position of the catheter tip in a simulated vein is transmitted to the MacIntosh. Appropriate waveform feedback is presented on the screen. The system is sufficiently flexible that actual patient data can be entered by end users to recreate actual intensive care unit waveforms on the simulated device. These waveforms can be programmed to show response to changes in medications, IV fluids, etc, that would mimic a patient's response in various clinical conditions. This allows for rather sophisticated training and testing in interpreting and responding to the data presented.

Dr. Saliterman will be presenting a demonstration of this device at the November meeting of the MMCC, Wednesday, Nov. 13, 7:30 pm at the Health Associations Center, 2221 University Ave SE, Mpls. Attendance is open to all interested persons.

It is very likely that Dr. Saliterman's MacIntosh Swan-Ganz simulator of patient care problems will become standard training equipment in medical schools and hospital ICUs.

This article was written by Donald Deye, MD, an internist in Cambridge, MN. Dr. Deye is president of the Minn. Medical Computing Consortium.

COMPUTER USER November 1985

Medical computing

Learning invasive techniques without invasion.

by Donald L. Deye

A Minneapolis internist has created an unusual training and testing tool for intensive-care units using an Apple Macintosh computer. Later this year Steven Saliterman is scheduled to demonstrate his uniquely equipped human mannequin interfaced to a Macintosh. This configuration will allow physicians to demonstrate and learn skills involved in intensive-care monitoring and treatment of patients in shock and heart failure...without having to invade a human body.

My beautiful balloon

The Swan-Ganz (pulmonary artery) monitor is a tool with nearly universal application in medical intensive-care units. This is a device that allows the attending physician to gain essential information about fluids and medications for patients in shock or with congestive heart failure.

The Swan-Ganz monitor also determines the blood pressure in the lungs and, specifically, what the blood pressure is in the left atrium of the heart (the chamber the blood enters after leaving the lungs). This left-atrial pressure is impossible to obtain by any other means and is very important information for the physician attempting to improve the blood pressure and circulation of a patient in shock.

Here's how the Swan-Ganz monitor works: The physician introduces a special flexible catheter with more than one channel into a vein in the forearm or under the collarbone. The catheter is then threaded into the main vein of the upper part of the body (the superior vena cava) at which point a ¼-inch diameter balloon is inflated on the tip of the catheter.

The balloon acts as a hydraulic anchor pulling the catheter tip along with the blood flow into the right side of the heart, the side which pumps blood from the veins of the body into the lungs. As the balloon is carried along through the heart with the flow of blood, the physician is able to measure the blood pressures and obtain pressure wave forms from the catheter tip, located in the right atrium, right ventricle and finally, the artery of the lungs (pulmonary artery).

The tip of the catheter is further advanced down the tree-like branching network of successively smaller arteries in the lungs until finally the balloon tip wedges the catheter into an artery which is too small to allow further passage.

The pressure is then measured beyond this balloon, which is closing off blood flow from behind. The pressure thus measured is actually a pressure reading from the left atrium of the heart, or the main pooling chamber just before the main muscle of the heart, the left ventricle.

Becoming proficient

Gaining proficiency at the use of Swan-Ganz monitor is a difficult task, even in busy intensive-care units where these devices are used with much frequency. Furthermore, demonstrating proficiency in the use of this technique for purposes of malpractice risk management and hospital procedure approval for specific physicians is also difficult.

Kate Brennan Hall

Aside from actually use with acutely ill patients, there has been no adequate way to learn or demonstrate knowledge involved with this device—and this is where the utility of Saliterman's Swan-Ganz monitor simulator is so valuable.

Using this device, the physician in training introduces the catheter into a simulated vein on the arm of the mannequin. The mannequin is wired in such a way that the location of the catheter tip within the vein or heart is transmitted through the interface to the Macintosh computer, triggering appropriate responses in terms of simulated wave forms on the monitor.

The physician is graded on whether he inflates and deflates the balloons at the correct positions and finally, after having demonstrated the manual skill of successfully passing the catheter, the physician is given wave forms which would be identical to those he would see in an intensive-care setting.

Actual patient data can be entered by end users to recreate actual intensive-care unit wave forms on the simulation device. These wave forms can be programmed to show response to changes in medications, intravenous fluids, etc., that would mimic an actual patient's response in various clinical conditions. This allows for rather sophisticated training and testing in interpreting and responding to the data presented.

Saliterman will present a demonstration of this device at the November meeting of the Minnesota Medical Computing Consortium, Nov. 13 at 7:30 p.m., at the Health Associations Center, 2221 University Av. SE., Minneapolis. Attendance is open to all interested persons.

It is very likely that Saliterman's Macintosh simulator of Swan-Ganz patient-care problems will become standard training equipment in medical schools and hospital intensive-care units. **CU**

(Donald Deye, an internist in Cambridge, Minn., is president of the Minnesota Medical Computing Consortium.)

Cath Lab In a Box

By Brian Goldman, MD

The medical student holds the end of the "j" wire like it's a slippery eel. Having missed the right subclavian vein twice before, she's not going to let this one get away. Her patient, a 65-year-old man with pulmonary edema of unknown etiology, can't afford it. Nervously, she threads an introducer, then a flexible catheter over the wire. So far, so good. The intern slowly and carefully advances the catheter toward what she thinks is the right heart. But on the monitor, all is not well. Even though she's advanced the catheter more than 15 centimeters, all she sees is a peripheral venous pressure tracing. She withdraws the catheter and advances it, praying that it will head due south toward the right heart. Twice more, she tries and fails. Beads of sweat form on her forehead. Suddenly, the patient moans and loses consciousness; his ECG monitor shows asystole. Despite vigorous resuscitative efforts, the patient dies.

"Back to the drawing board," offers the student's preceptor as he shuts off the Dynacath patient simulator. "Fortunately, there's plenty of time to work out the bugs before we let you practice on real patients."

"This patient wasn't real?" she asks, pointing to the molded plastic torso. "Could've fooled me."

This isn't science fiction. A Minneapolis-based internist and computer programmer has developed a patient simulator that makes "Resusci-Annie" look like a Barbie™ doll. It's called the Dynacath Trainer™, and it's the brainchild of Steven S. Saliterman, ACP Member, a critical care specialist at Methodist Hospital, in Minneapolis.

Dr. Saliterman has an eclectic background. He studied physiology at college. A self-taught "whiz kid" in computers, in the late 1960s he built his own personal computer that went on to win numerous recognition awards, and used concepts that Steven Jobs would successfully market years later at Apple Computer, Inc.

In the 1970s, Dr. Saliterman parlayed his early success with computers into an externship at the National Aeronautics and Space Administration (NASA), while studying medicine at Mayo Medical School in Rochester, Minn. He even qualified as a NASA flight surgeon for shuttle missions, but gave up the position when he bought a Minneapolis-based practice in internal medicine. Since then, Dr. Saliterman has divided his time between a busy medical practice and research in cardiovascular medicine.

He got the idea for the Dynacath Trainer™ from his experiences as an instructor in advanced cardiac life support at the Mayo Clinic.

"One of the things I thought was missing in that course was some way of actively involving a student in a real-time decision-making process," says Dr. Saliterman.

"After that teaching experience, I decided I would create a device that would allow a total management simulation. That is, where you would be presented with a history and physical, and have to make clinical decisions."

The result is the Dynacath Trainer™. It consists of a Macintosh SE (or Macintosh II or Plus models) computer, software and the training apparatus that looks like a hemithorax mounted on a suitcase with lights and a control panel. It retails for $6249, not including the cost for the Macintosh computer.

Four years ago, Dr. Saliterman founded Dynacath Corporation, the company that markets the Dynacath Trainer™.

Here's how the simulator works: the student or physician is presented with a case history on the computer display. But the cases aren't supplied by Dynacath. Instead, the doctors who purchased the system author their own cases based on actual patients. Entering a case history requires no programming skill. Actual EKG and hemodynamic pressure tracings that appear on the display add to the sense of realism.

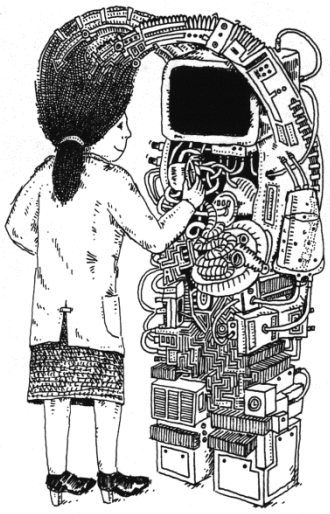
After reviewing the history and physical examination, the user orders appropriate laboratory studies and procedures such as blood tests and X-rays, then selects a treatment plan. As with most patient simulators, the Dynacath Trainer™ is an interactive program. The user gets to see the consequences of his clinical decisions. In addition, the computer keeps track of performance, evaluating the appropriateness of laboratory studies. Dr. Saliterman has also built in a system for rapid determination of indices used in critical care such as hemodynamic monitoring and ventilatory support.

Several features make the Dynacath Trainer™ unique. For one thing, Dr. Saliterman has chosen the Macintosh as the computer to support his software, a gutsy move at a time when the lion's share of medical software is written for IBM-compatible computers. It's a decision that makes some potential buyers nervous, but Dr. Saliterman shrugs off the criticism. He prefers the Macintosh because it has superior graphic displays, and because it's easier than an IBM to learn how to use.

"I have to look at the manual every time I use one of my programs on the IBM," he argues. "Whereas the people who use my program—as complicated as it is—[on a Macintosh,] rarely even look at the manual.

"At one of my test sites, I asked what they thought of my manual, and they said that they never even looked at it."

The Dynacath Trainer™ has the feel of a Macintosh program. The displays are divided into convenient windows;



Evan Pelenghi

key options are displayed continually. Although the software is sophisticated, it can be fully operated with a mouse; you can unplug the keyboard and forget about it.

Dynacath also differs from the competition in that it incorporates testing of manual skills into the simulation. To see a pulmonary wedge pressure tracing on the computer display, you have to insert a real catheter into a central vein located on the artifical torso, following all of the correct procedures along the way. Miss one step, and you don't reach your objective. On the display, a simulated pressure tracing changes in real time as the catheter is either advanced or withdrawn.

"The simulation follows the algorithm exactly," says Dr. Saliterman. "A lot of work went into that algorithm. You can miss your objective just as much as you would miss on a real patient. You can put the catheter across the chest, up the neck, and down the inferior vena cava."

The simulation is complex enough to permit several operations at the same time. For instance, while the catheter is still in place, the user can call up the therapeutic module and order up an inotropic drug. When the user returns to the pressure tracing, he finds that it has been altered by the treatment given.

"That's a true novelty," says Dr. Saliterman. "There's really no simulation in existence, other than Dynacath, that would allow you to do that."

Perhaps the biggest difference is that Dr. Saliterman has put all his effort into the software that drives the clinical cases, not the cases themselves. It's a radical departure from what the industry is currently producing; other publishers put their dollars into developing an up-to-date storehouse of knowledge. The problem with this strategy is that the database inevitably goes out of date in a few years; it's expensive to keep a database current. With Dynacath, the users keep the simulator up to date themselves by authoring new cases.

Dr. Saliterman says that one of his customers—the president of a Minneapolis hospital—liked the idea of being in control of the software.

"Her first thought was that she had no dependency on Dynacath Corporation," recalls Dr. Saliterman. "She liked that. She said: 'You might be gone tomorrow, but we've got your product. And that's all we need.' "

Although Dynacath's forte is critical care, it can handle virtually any kind of case, since the data is supplied by the clinician. The cases can run the gamut from azotemia to thyroid storm. "Remember, there's no database," says Dr. Saliterman. "You're the author. You've got the interesting patient."

Where is this kind of technology leading? Toward certification of internists, says Dr. Saliterman.

"People have come to me wanting to do studies," he says. "You have a requirement in the hospital that every physician be certified prior to doing a catheterization. How do you certify them? The tradition has been to 'see one, do one, teach one.' "

"I want to bring it [Dynacath] into that whole tradition. Let [the certification process] be supplemented by this nonpatient, a device on the table. Let them be certified on this first. You can throw at the student many more problems than they would get under the 'see one, do one, teach one' system. You can monitor what they're doing and how well they're doing it. Most important, you're not going to injure anybody in the process."

What do internists think of the Dynacath Trainer™? The jury is still out. Dr. Saliterman has shopped the simulator around to hospitals and universities across the United States. Interest is high, although early sales are sluggish. One of the hospitals expressing interest in the simulator is the Mayo Clinic.

"I liked playing with it," says Mark Callahan, MD, assistant professor of medicine at the Mayo Medical School. "There's the game nature of the program that makes it fun."

Dr. Callahan, a cardiologist at the Mayo Clinic, believes that the Dynacath Trainer™ could be useful in critical care settings. However, he stopped short of saying that it's of use to internists who work in catheterization laboratories.

"I think a lot of the clinicians would say, 'It's a nice toy, but we can do better with the real thing,' " he concludes.

Anecdotal evidence has convinced Dr. Saliterman that he's on the right track. "The cardiologists are fairly well-versed and can identify a number of problems, ranging from pericardial tamponade to pulmonary embolism," says Dr. Saliterman. "But the internists who are doing right heart catheterizations on critically ill patients tend to have the manual dexterity skills down, can identify that the wedge pressure is elevated, but can identify very little beyond that.

"Almost none of the people with whom I work were able to identify very simple valvular defects, pulmonary hypertension or pericardial tamponade."

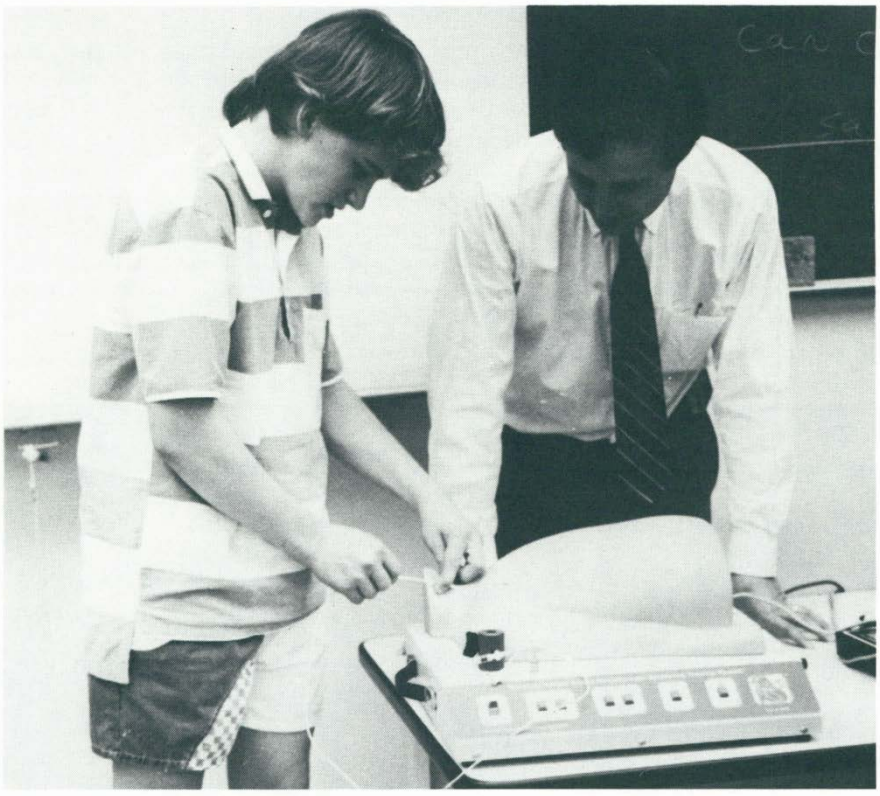
Dr. Saliterman is sanguine about the future for patient simulators: "If it isn't my device, it'll be someone else's." ■

St. Louis Park High
ECHO

Seniors' plans
— pages 4-5

INSIDE:
Sexual misconduct
— page 3
Indy's Last Crusade
— page 2

Vol. 60, No. 12 | St. Louis Park, Minnesota | Tuesday, June 6, 1989



STRAIGHT TO THE HEART
Doctor Steven Saliterman, a Park graduate, spoke to mechanical drafting classes on May 26 about his invention and development of a machine used to train medical students how to properly insert and operate a heart catheter. Here Saliterman explains to Freshman Greg Tronnes the proper method of inserting the catheter.
(photo by Rob Bellin)

computers & medicine

First International Periodical Devoted to Automation in the Health Field...Founded 1972 by the American Medical Association

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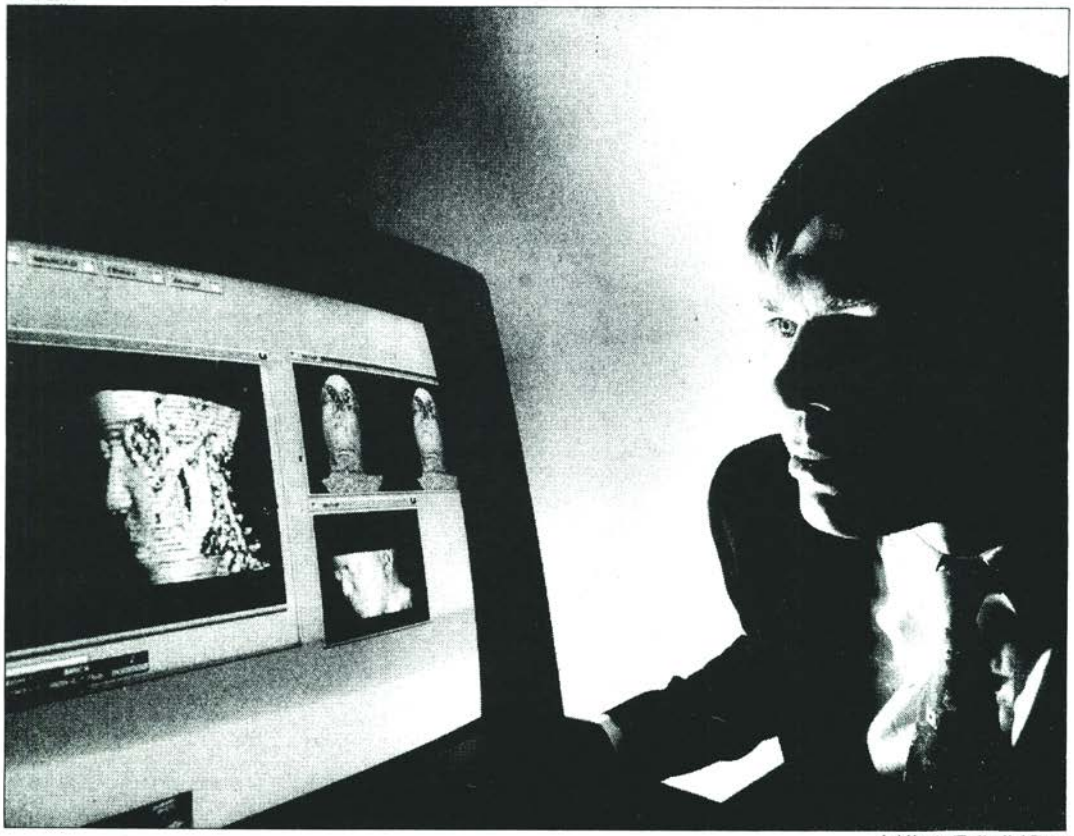


Jack Manning/The New York Times

Dr. Craig D. Hall, plastic surgeon at Montefiore Hospital, working with computer during rehearsal for skull reconstruction surgery

Spotlight on Simulation --

. . . Critical Care at Mayo Clinic

. . . Broader Use in Skull Surgery

. . . Easing Medical Student Anxiety

Current Insights About Healthcare Automation

Mayo's Simulator --

Preparing for Critical Care The Safe Way

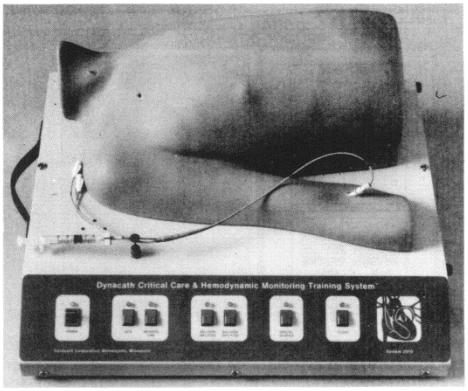
Make the wrong move at the wrong moment for the wrong reason in the urgency environs of a critical-care unit, as any medical specialist in this field will attest, and the procedure fades into a statistic.

Yet, how else but with a desperate life-grasping patient can the physician learn and retain his or her special skills? Now, after more than four years of development, there is a new technology for medical education that relies on computer-aided simulation to help ease the MD-trainee's transition to real-world professional action.

Costing less than $5,000 (plus computer), the portable Critical Care & Hemodynamic Monitoring Training System (CCHMTS) of the Mayo Clinic arrives at an opportune time. "The demand for proficiency among critical-care physicians and nurses has never been higher," says internist Steven S. Saliterman, MD, of Methodist Hospital in suburban Minneapolis. He adds:

"In recent years, this demand has been reflected in a dramatic increase in the number of publications focused in critical-care medicine. Board certification has also been instituted to ensure uniformity in training and development of high quality residency programs."

The CCHMTS is said to be the only available system that allows simulation of complete catheterization of the right side of the heart, with real-time simulation of cardiac rhythms and arterial and catheter pressures.



Photograph of Critical Care & Hemodynamic Monitoring Training System. In this replica of a human torso, a catheter may be placed by using standard insertion components and advanced through cardiac chambers into wedge position. System monitors insertion technique, including improper use of the balloon, prolonged time in wedge position, and "overwedging" of catheter. Anatomic landmarks—such as distance to tricuspid valve—are controlled by software.

Suitable medical coonditions for assessment include arrhythmias, cardiac tamponade, cardiomyopathies, congenital defects, constrictive pericarditis, fluid and electrolyte disturbances, myocardial infarctions and complications, postoperative conditions, pulmonary disorders, shock, and valvular defects.

No Inherent Data Base

The system consists of software that operates on a Macintosh microcomputer, a portable peripheral unit including a replica of a human torso, and various controls to display a real-time cardiac monitor on the computer screen. Trainees can develop manual dexterity skills in performing cardiac catheterization, and cognitive skills in interpreting cardiac rhythms and hemodynamic data.

In contrast to other simulators and computer-oriented instructional programs, the Mayo system contains no inherent data base. Instead, authors build a library of informative cases by using its hardware and software tools. Individual modules of authored clinical information are transparently linked as a student undertakes management of a patient.

"Although this is a technological achievement," says Dr. Saliterman, "determination of its usefulness as an instructional tool or certification aid must come from broader use and controlled studies."

"Although an airline pilot or an astronaut would not be expected to assimilate all skills necessary for their jobs by experiencing many potential disasters, critical care providers depend on actual patient contact"

Material & Methods

The simulated adult torso is made of rigid polyethylene, with access ports for right-heart catheterization. An internal guideway leads the catheter to precision-aligned rollers that rotate an optical encoder which provides information to the computer about

catheter position and direction of motion.

A three-way adapter is connected between the catheter and a syringe for diverting air into a durable internal balloon. A power cable connects the torso apparatus to the computer's modem port.

Two levels of operation are available: a case input and development function for instructors (or "authors") and a simulation function for students (or "trainees"). A computer keyboard is unnecessary during simlations; selections are made by using the apparatus switches or by pointing the computer to suitable screen buttons and controls.

The author creates a case by dividing the total management problem into individual operation or "modules." Each is a group of data consisting of a history and physical examination (or subsequent progress note or consultation), hemodynamic data, study options and results, four potential treatment plans, and appropriate discussion.

Data are entered for the patient's initial condition and for the consequence of each treatment plan. Histories, physical exams, progress notes, and consultations are entered via standard word processing.

Trainee Operation/Evaluation

The trainee begins a simulation by selecting a case from the library (shown as a menu item) and reviewing information provided on the initial history and physical exam. (See flow chart at right.)

As in a real-life situation, the trainee may order studies, select a treatment plan, seek consultation, or connect the patient to a cardiac monitor. Study alternatives are programmed by the author. Once a treatment plan has been chosen, all data change to conform with the intervention.

Trainee performance is monitored for both cognitive skills is patient management and procedural skills at catheterization. The former is achieved by assignment of a numerical score for the care provided, determination of unnecessary or inappropriate studies or treatment, and cost analysis of the care.

For example, if the trainee orders a lumbar puncture, the following authored response could appear: "Patient refuses. Performing a lumbar puncture would be unsafe in light of the head computed tomographic findings.(-10) $125."

In such a situation, the system recognizes the word "unsafe" and increase the "inappropriate" score by one. In addition, selecting this test

(Continued next page)

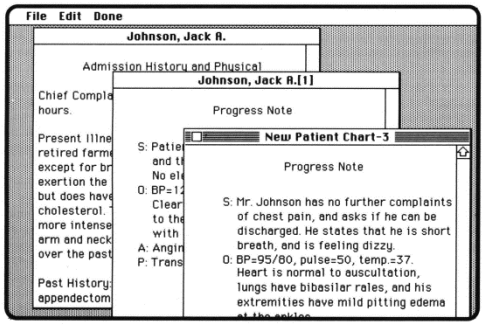
Mayo's Simulator --

Limitations

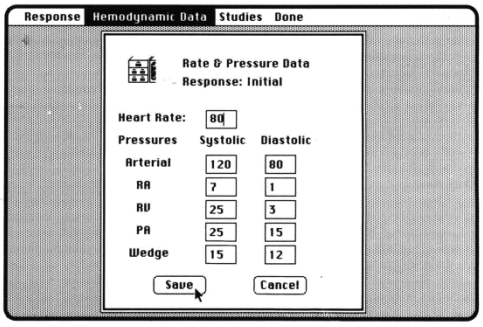
Although preliminary results are promising, there are limits to current effectiveness of the Mayo Clinic's critical-care simulator (see main story).

One is its inability to simulate ventilator management. Also, the component torso apparatus is not designed for placement of airways, chest tubes, or intra-aortic balloons or for performance of thoracentesis or pericardiocentesis.

A more worrisome potential drawback of the system is the prospect of a poorly authored case becoming widely used, thereby generating unacceptable procedures or methods. This risk can be reduced, suggests Dr. Saliterman, by peer review of authored cases, similar to the peer-review process for scientific manuscripts.



Example of computer screen appearance when history and physical examination are entered. Multiple documents may be open at one time, including the initial history and physical examination, progress notes, and consultations. Editing features include "cutting and pasting" of text within or between documents. Because each document is saved by a patient pseudonym, memory is also reserved for storage of module-specific data. *BP* = blood pressure; *S* = subjective; *O* = objective; *A* = assessment; *P* = plan.



Entry of module-specific data is by means of dialog boxes, such as example shown here for heart rate and hemodynamic values. Similar dialog boxes are used for entry of study options and results, treatment plans, and discussions. Computer cursor is moved to appropriate entry point above, and values are typed on computer keyboard. Default values (previously stored data) are shown when dialog box first appears. New data are incorporated into module by selecting "Save." *PA* = pulmonary artery; *RA* = right atrial; *RV* = right ventricular.

Mayo's Simulator --

Preparing for Critical Care The Safe Way

(Continued from page 7.)

decreases the trainee's "performance" score by 10 and increases the "cost of care" by $125. Because no standard of care is purported by the system, authors must give the same attention to detail and accuracy as they would a lecture or publication.

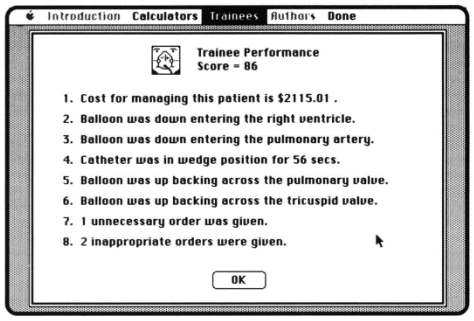
"The initial impression of specific users [of the system] have been favorable," Dr. Saliterman writes in *Mayo Clinic Proceedings.* "In particular, ease of use by the true computer novice and the quick ability to program cases and monitor tracings into the equipment are considered important features..

"This system is not intended to replace actual patient contact but rather to prepare the trainee before encountering certain management problems. The trainee may be a medical student learning basic skills or an experienced cardiologist desiring to study problems rarely encountered.

"In addition, the system may be used to demonstrate models of unusual cardiovascular function, such as an artificial heart. Finally, this computerized simulator offers an alternative to animal-oriented workshops in catheter use and thus may lessen the need for experimental animals for this purpose."

For additional information contact: Steven S. Saliterman, MD, Meadowbrook Medical Bldg., 6490 Excelsior Blvd., W-110, Minneapolis MN 55426. ■

"In contrast to other simulators and computer-oriented instructional programs, this system contains no inherent data base. Instead, authors build a library of informative cases from its hardware and software"



Performance is assessed for both cognitive and manual dexterity skills. The system automatically processes authored information to identify unnecessary or inappropriate actions taken by the trainee.

Mayo's Simulator --

Learning to Fly

One might well wonder why medicine has lagged so long behind aviation and space flight -- even behind automobile -- instruction in developing simulators as a vital learning source in the comparably death-dealing field of critical care.

Wonder no more, with Mayo Clinic's computerized simulator (see main story). As internist Steven S. Saliterman, MD, explains, "Although an airline pilot or an astronaut would not be expected to assimilate all the skills necessary for their jobs by actually experiencing the many potential disasters that await them, critical-care providers have traditionally depended on actual patient contact for much of their training.

"The complexity of treatment modalities and the sophisticated technologies available to providers have strained our traditional educational programs. Although perceived as an important adjunct, advanced simulators in medical training have been introduced slowly. In the future, simulators may play a crucial role in continuing education and the granting of privileges for performance of certain procedures."

True, Dr. Saliterman concedes, patient-management simulators have traditionally integrated varied manikin components with computer display of important physiologic events: "Some devices are impressive in their ability to duplicate bedside evaluation or administration of anesthesia, providing life-like responses for the student."

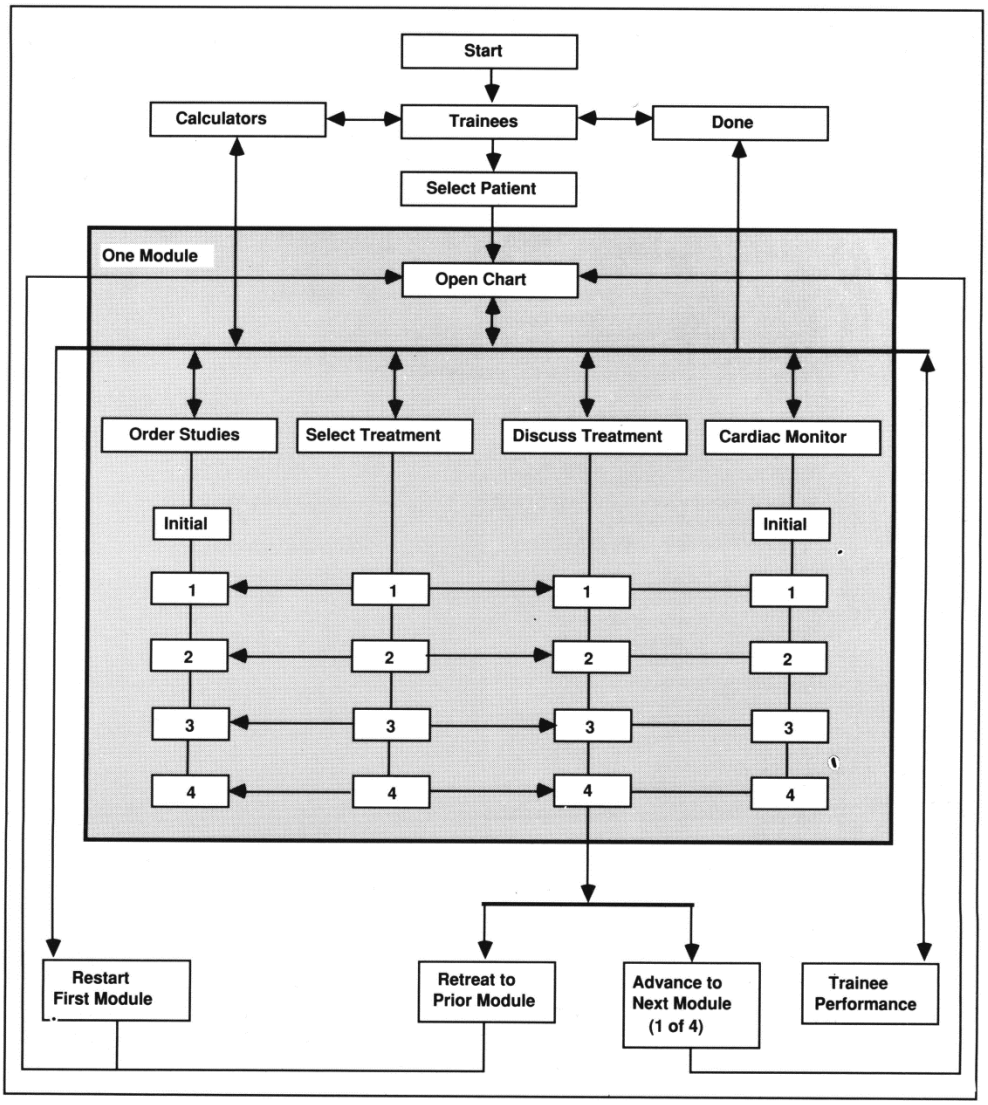
But not until the advent of Mayo's system has there been such a degree of automation for critical-care trainees. Its patent No. 4,642,055, awarded in 1987, has only recently been implemented for broad use. ■

In Quotes

Hospital Robots

Each year, 15,000 patients die from diseases contracted in hospitals. But the hospital patient of the next century will be admitted to a room that has been meticulously cleaned by housekeeping robots continuously active in decontamination and infectious waste management so as to minimize hospital-contracted disease.

All courier activities will be carried out by robots. They will deliver late meals, pharmaceuticals, medical records, surgical supplies, blood samples.
-- Joseph F. Engelberger in Feb. 11 HealthWeek



Flowchart of program operation for trainee level. Once a patient has been selected and the history and physical examination have been reviewed, the trainee may elect to order studies, select a treatment plan, review discussion material, or connect the patient to the cardiac monitor. "Initial" data are presented if no treatment has been selected. After one of four treatment plans has been selected, ordering further studies or review of the cardiac monitor will reveal the consequences to the patient (numbered boxes). If appropriate, the trainee may—by selecting "Advance to Next Module"—review the chart again for progress notes or consultations and thereby continue management of the patient.


Spinoff
1992
Environment
Recreation
Technology
Spinoff
Safety
NASA

Introduction

Competitiveness in the global marketplace is one of the most critical issues facing American industry today. Technology is the key to successful competition: the nation that boasts the most advanced technology—and the ability to effectively and efficiently apply it to new products—will inevitably be the leader. With this leadership comes a robust economy and an elevated standard of living for the leader-nation's people.

This is why the great storehouse of technology NASA has built over the past three decades of aerospace research is more important than ever. This technology is not perishable; it can be used over and over—and it can be applied in areas far different from those for which it was originally developed.

NASA-developed technology, therefore, represents an immensely valuable bank of know-how on which American companies may draw to bring new products and processes to the world market—at more competitive prices because the technology has already been developed.

Thousands of companies have taken advantage of this national technology resource. Many of them have generated secondary applications. Hundreds of spinoffs have resulted from the application of space-derived technology. In fact, considering the difficulty of tracing the technology source embedded in many of our new products, the actual number may be several times this estimate.

Whatever the number, spinoff products and processes have collectively made an enormous contribution to the U.S. economy, job creation, industrial productivity, and the nation's lifestyle. They represent a substantial dividend on the national investment in aerospace research.

Through its Technology Transfer Program, NASA seeks to broaden and accelerate the spinoff process to expand the economic and social benefits to the nation, and to facilitate the secondary application of NASA technology by those who can make productive use of it. This publication is designed to heighten awareness of the technology available for reapplication and its potential for public benefit.

Spinoff 1992 is organized in three sections:

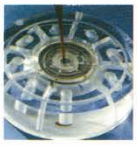
Section 1 summarizes NASA's mainline programs. These programs have objectives which require development of new technology and, therefore, expand the bank of technology available for transfer in future years.

Section 2, the focal point of this volume, contains a representative sampling of new spinoffs that have resulted from secondary application of technology originally developed to meet the goals of the mainline programs.

Section 3 describes the various mechanisms NASA employs to stimulate technology transfer. It lists, in an appendix, contact sources for further information about the Technology Transfer Program.

John G. Mannix
Assistant Administrator for Commercial Programs
National Aeronautics and Space Administration

Medical Training Aid

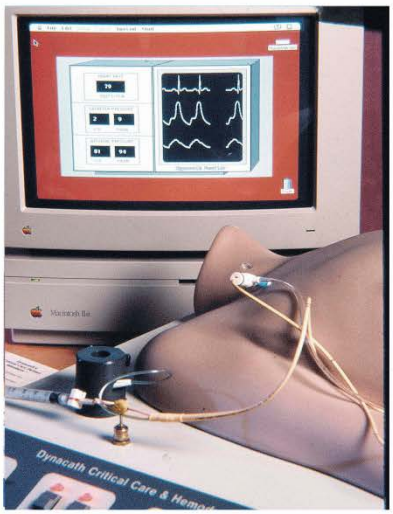


Below, Dr. Steven S. Saliterman (seated) of Minneapolis, Minnesota is explaining use of the Dynacath Critical Care Patient Simulator™ to a medical resident. Incorporating NASA simulation technology, Dr. Saliterman developed the system as a means of training physicians, students and nurses in critical care management and hemodynamic monitoring (monitoring the pressures associated with heart catheterization procedures). He founded Dynacath Corporation, also of Minneapolis, to market the system.

Linked to an Apple Macintosh computer, the main components of the Dynacath simulator are a computer program, a display unit (shown in closeup **at right**) and a lifelike replica of a human torso.

Hemodynamic monitoring is typically performed by a physician in a hospital's intensive care unit. Its purpose is to measure accurately the pressures within the heart and the pulmonary artery to determine the type and extent of cardiopulmonary disease, to monitor heart function and to evaluate treatment options. Where training in this procedure was formerly conducted at the bedside of a live patient, the Dynacath system allows training to develop both patient care and procedural skills through repetitive simulation.

The system's display unit shows patient histories, progress notes, consultations, treatment options and results. Patients' responses change based on the treatments selected. The torso and its internal sensors permit repetitive practice of catheterization, with realtime simulation



of heart rhythms and pressures displayed on the screen. In addition to its value as a training aid, the system is useful as an aid to physician certification or as a tool for evaluating the quality of care delivery.

Since its introduction in 1990, many hospitals and research universities have adopted the system and a number of heart catheter-producing companies have purchased units.

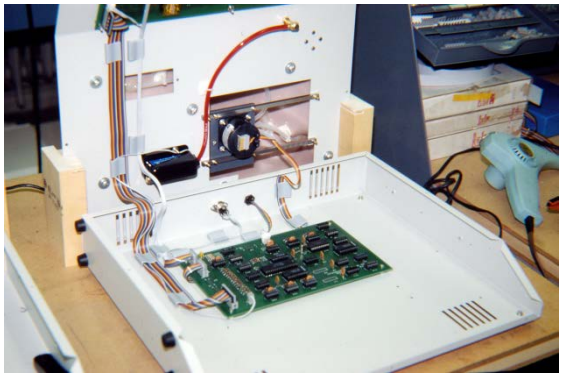
The Dynacath system is based on Dr. Saliterman's own extensive medical and engineering background and on NASA simulation and instrumentation technology acquired during his employment at two NASA centers. He attended Mayo Medical School and Mayo Graduate School, Rochester, Minnesota from 1973 until 1980. During that time, he also served as a summer intern at Johnson Space Center (1973-74) and as a life sciences research fellow at Ames Research Center (1976). Dr. Saliterman is currently a practicing physician at a Minneapolis clinic; a consultant at Methodist Hospital in Minneapolis; an instructor in advanced cardiac life support for the American Heart Association; and senior aviation medical examiner for the Federal Aviation Administration. ●

™Critical Care Patient Simulator is a trademark of Dynacath Corporation.

Ford Centre Lab & Production Facility

Ford Centre Desk

Manikin Shell Preparation

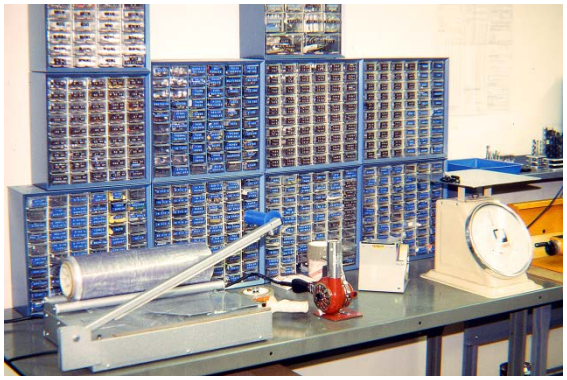


Assembly

Ford Centre Assembly Line

Assembly Line

Wet Lab



Parts & Shipping

Arbor Press

Drafting Table and Flat Drawers

Prototyping Area

Part Storage

Chemical Storage

Design

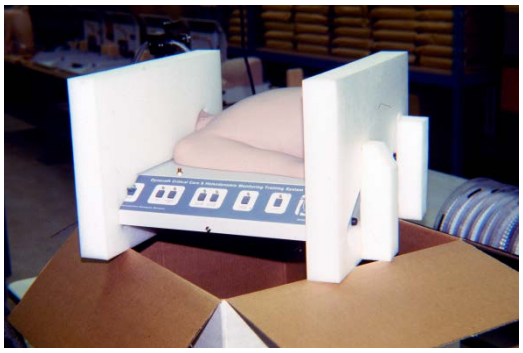
Data Processing

Lathe, Mill and Drill Press

Part Storage

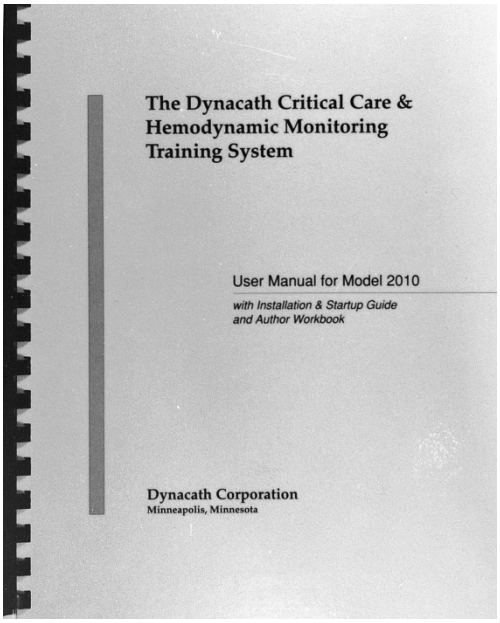
Case Authoring

Manikin Shell Preparation

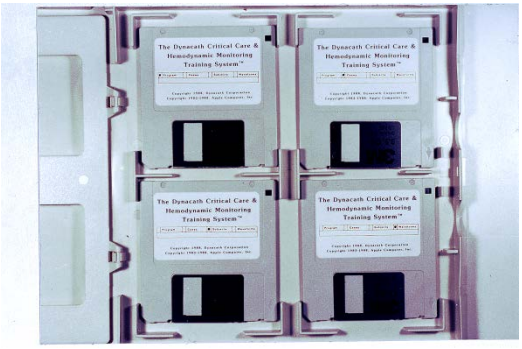


Shipping Box

Shipped Accessories



User Manual

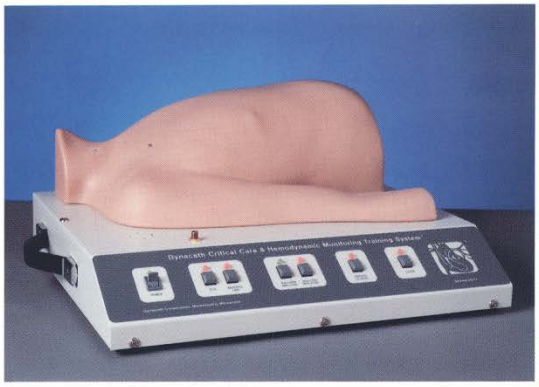


Software Case

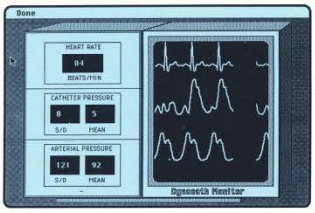
Power Supply

Brochures

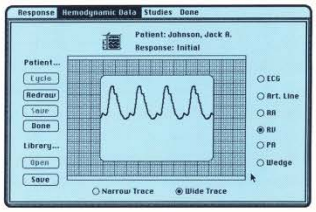
Tomorrow's Training Technology Today.



Interactive displays allow for review of histories, ordering studies and selecting treatment plans.



The cardiac monitor displays rhythms, and arterial and catheter pressures in real-time during catheterization



A waveform editor allows direct entry of existing waveforms into instructional cases.

Dynacath's Critical Care Patient Simulator

The **Dynacath Critical Care & Hemodynamic Monitoring Training System** is designed for training and certification in the management of critical care patients.

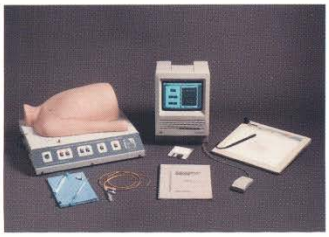
The Macintosh® computer displays patient histories, progress notes, consultations, study options and results, and a cardiac monitor. Patient responses change based on the treatments selected. The torso apparatus is used to practice right-heart catheterization, with real-time simulation of rhythms, and arterial and catheter pressures.

Instructors may create their own library of informative cases, or make use of the many demonstration cases provided. The comprehensive authoring system includes a word processor, interactive displays for data entry, and an ability to enter actual patient monitor strips by tracing on a digitizing tablet.

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

Potential users include medical and graduate students, residents, subspecialty trainees, hospital medical staff, nursing staff, and technicians. The system is portable, and is easily carried to conferences and workshops.

To find out more about this exciting new technology please call or write:



Typical work station includes the torso apparatus, Macintosh® computer, Kurta digitizing tablet, software, operating manual, and standard catheter components.

Dynacath Corporation

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Minneapolis, MN 55401 • (612) 333-4298

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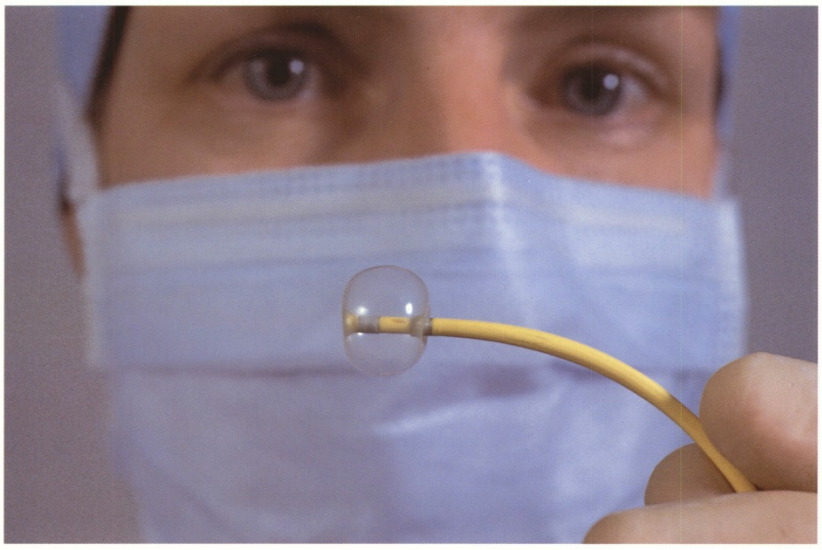
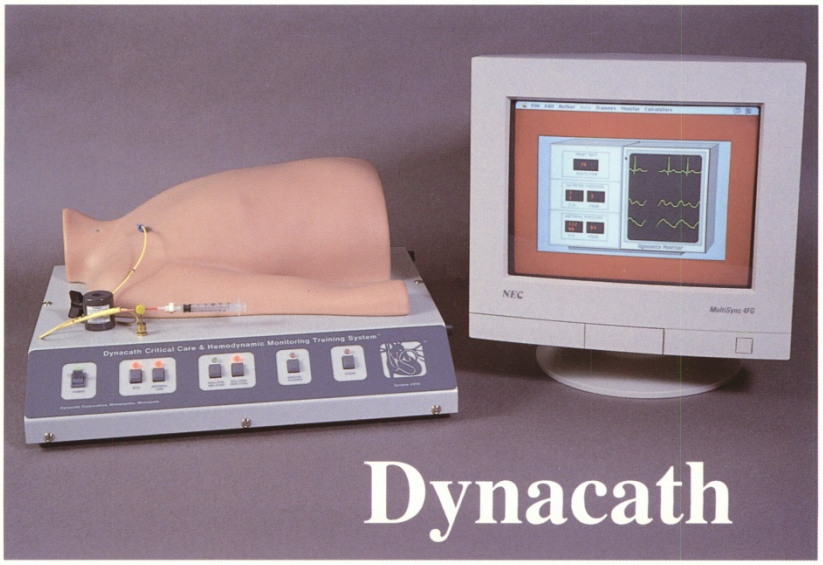
If you are passing these,



can you pass on this?



Dynacath's **Critical Care Patient Simulator** is designed for training and certification in the placement of pulmonary artery catheters, and management of associated medical conditions. It is especially useful for anesthesiologists, cardiologists, intensivists, pulmonologists, and surgeons involved in teaching.

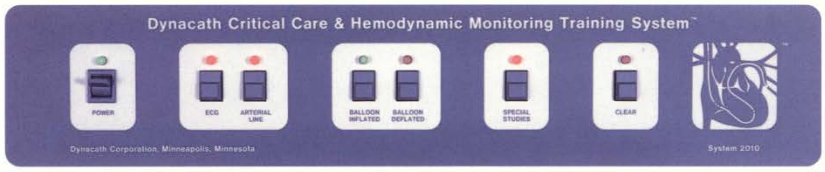
An Apple Macintosh® computer displays patient histories, progress notes, consultations, study options and results, and a cardiac monitor. The torso apparatus is used to practice right-heart catheterization, with real-time simulation of rhythms, and arterial and catheter pressures.

The comprehensive authoring system includes a word processor, interactive displays for data entry, and the ability to enter actual patient monitor strips by tracing on a digitizing tablet. Cases are entered by instructors at a given institution rather than being distributed by Dynacath. This encourages cases that are timely and tailored to the specific audience. The simulator is in use throughout the country, and cases may be shared with other users by exchanging standard computer diskettes.

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

Potential users include medical and graduate students, residents, subspecialty trainees, hospital medical staff, nursing staff, and technicians. The system is portable, and is easily carried to conferences and workshops.

Simplicity



Menu-driven displays on the Macintosh computer are easily learned even by the computer-novice.

After cases have been entered into the system, the student begins a case by opening a file containing a presenting history & physical, and is then prompted to order studies, show the cardiac monitor, perform catheterization, or select a management plan.

The course of action is left up to the student, and the system monitors unnecessary or inappropriate studies and treatments, cost of care, and procedural skills in proper catheter placement. An overall performance score is then determined for the student.

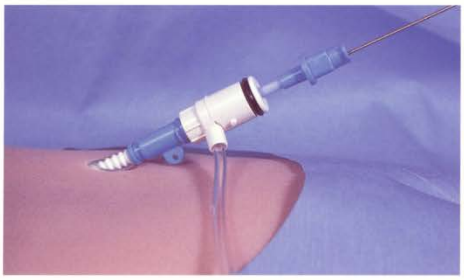
Advanced features include simulation of a three channel cardiac monitor, and ability to run a strip of the display for closer analysis. In addition there is a cardiac indices calculator that is dynamically linked to the monitor.

Customary pulmonary artery catheters and introducer kits may be used with the manikin apparatus. Electrocardiogram, arterial pressure tracing, cardiac output and oxygen saturation data may be selected from the front control panel. Air from the syringe is diverted into a durable internal balloon. Alternatively, switches on the control panel may be used in place of the syringe.

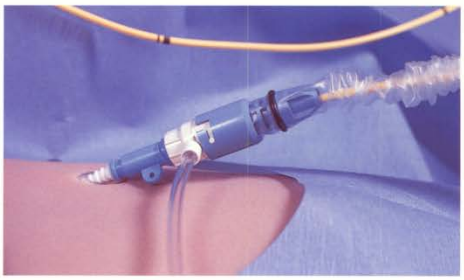
The system determines location of the catheter and whether the balloon was inflated or deflated when passing through a valve. It reports time in wedge position, and demonstrates a pressure change from wedge to pulmonary artery if the balloon is deflated in proper position. Moreover, overly advancing the catheter causes incorrect pressure readings.

The probability of missing the heart as the catheter is advanced, and distances to anatomical landmarks (tricuspid and pulmonary valves, wedge position) are instructor specified.

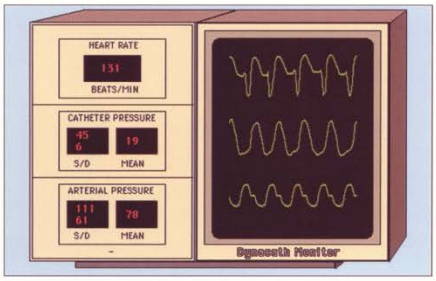
Realism



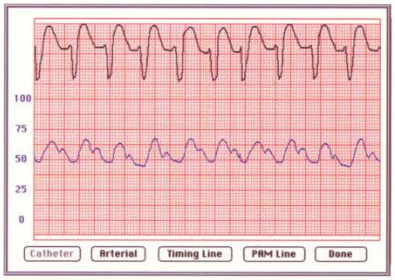
A pulmonary artery catheter may be placed from the right basilic, subclavian or internal jugular veins via fixed access ports. Customary insertion components and techniques may be used.



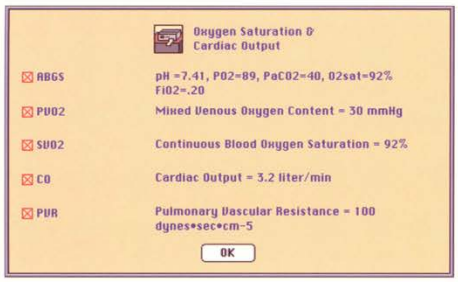
Internal sensors detect catheter motion and position. Air from the syringe is diverted into a permanent internal balloon, allowing an old catheter to be used, regardless of its balloon condition.



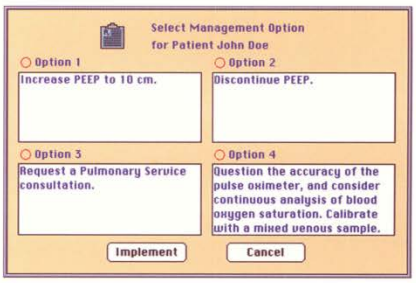
The cardiac monitor displays pressure data as the catheter is advanced through the heart into capillary wedge position.



Strips may be run of any monitor display allowing detailed analysis of timing and the a, c, v, x descent and y descent waveform components.

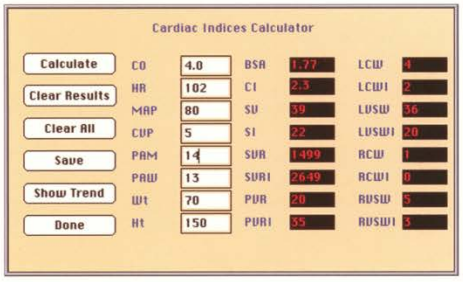


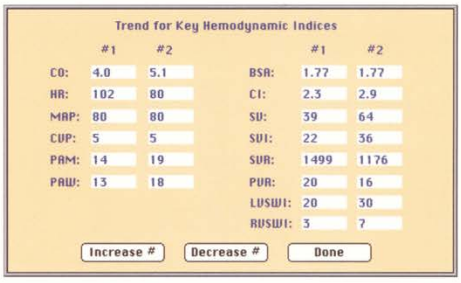
Interactive displays allow for ordering of laboratory, imaging and respiratory studies. Study options and results change depending on the management plan selected by the student.



Management plans may be selected at any time, and options change as a case advances. Immediate discussion text follows each selection.

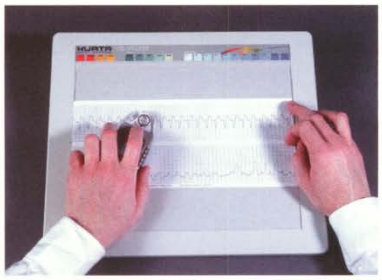
Calculators

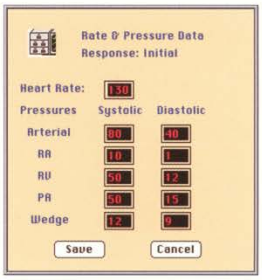




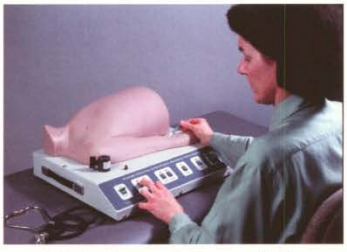
The Cardiac Indices Calculator is one of four calculators available. Others are for respiratory, ventilatory and renal function indices. This calculator is dynamically linked to the strip recording, allowing a student to identify the correct mean pressure prior to its being automatically ported to the calculator. This calculator also allows saving up to five sets of results to a trend display (above) during a case study, allowing comparison over time.

Authoring Cases





Recordings taken from the ICU, operating room or cardiac lab are easily traced with a cordless cross-hair cursor, allowing capture of up to a three second "wave bite" directly into a case scenario. Waveforms are processed to conform with selected rate & pressure data above. Similar displays are used to enter studies, management options and discussions.



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The standard for pulmonary artery catheter training.
Review articles: Mayo Clinic Proceedings 65:968-978, 1990; Computers & Medicine 20:6-9, 1991; NASA Spinoff, 1992, pp 76.