APPARATUS FOR AND METHOD OF SIMULATING THE INJECTION AND VOLATILIZING OF A VOLATILE DRUG

CROSS-REFERENCE TO RELATED APPLICATION

This application is a divisional of Applicant's U.S. Ser. No. 08/188,383, filed Jan. 27, 1994, now U.S. Pat. No. 5,584,701, which, in turn, is a continuation-in-part of Applicant's U.S. Ser. No. 07/882,467, filed May 13, 1992, issued as U.S. Pat. No. 5,391,081, the contents of all which are hereby incorporated by this reference.

BACKGROUND

1. Field of the Invention:

This invention relates to an integrated patient simulator and methods of using the same. In particular, this invention discloses an improved patient simulator capable of realistically simulating nerve stimulation, lung movement, lung volume measurement and lung breathing noise, administration, detection, identification and quantification of medicaments and fluids introduced during simulated surgery, bronchial resistance, computer controllable compliances and also possessing an improved computational configuration, an electric cardiac synchronization pulse, audible heart and lung sounds, simulation of continuous blood gases, pulmonary artery (PA) catheter inflation detection, difficult airway, spontaneous breathing and other anesthesiological indications, and gas exchange via a mass-flow controller.

2. Background of the Invention:

Currently, a new resident in medicine will receive a very limited duration of didactic teaching about the principles of particular medical procedures, such as anesthesia, before delivering care to his/her first real patient. The resident is then faced with a new and unfamiliar environment while shouldering the tremendous responsibility of caring for an ill and sometimes anesthetized patient. Similarly, experienced physicians who require continuing medical education, refresher courses (e.g., handling of rare ailments and situations) or familiarization with newly introduced and/or technologically sophisticated equipment or procedures do not have the opportunity for hands-on practice in a realistic environment, without risk to a patient. Of course, these undesirable situations also apply to other disciplines such as allied health care and veterinary medicine, for instance.

The patient simulator disclosed in U.S. patent application Ser. No. 07/882,467 addresses the above-mentioned deficiencies in medical, allied health care and veterinary education. The improved self-regulating full-scale patient simulator technology described herein comprises further embodiments of a patient simulator.

The lung portion of the integrated patient simulator disclosed herein consumes and/or produces gases including oxygen, carbon dioxide, nitrogen, nitrous oxide and volatile anesthetics. Under the control of a mathematical model of human physiology implemented on a computer, uptake and delivery of the above mentioned gases is computed by the uptake and delivery module of the physiological model. The computed uptake and delivery is then physically created by gas substitution in the hardware module for simulating gas exchange in the lung simulator portion of the patient simulator. The lung will also simulate spontaneous inspiration with computer control of tidal volume (VT), respiratory rate (RR) and functional residual capacity (FRC) and will also allow the simulation of a cough. In addition, the lung will exhibit the desired lung mechanics and gas exchange when mechanically or manually ventilated.

The patient simulator system of this invention has several components including lung mechanics (software and hardware): gas exchange (software and hardware); a physiologic model (software); cardiovascular; uptake and distribution; neuromuscular system; pharmacokinetics/pharmacodynamics; physiologic control models; and a unique linking of the different subsystems of the patient simulator so that the patient responds realistically to inputs from the trainee/student.

A major improvement of the lung/patient simulator is that it allows realistic action/reaction interplay between the actions of the trainee, responses of the simulated patient, data shown on the monitors and subsequent actions by the trainee. Another significant improvement that distinguishes the lung/patient simulator from similar systems is that its software and hardware are self-regulating. The present hybrid (mechanical and mathematical) lung model regulates itself regardless of type of gas (air, anesthetics, hypoxic, etc.) inhaled, and, surprisingly, even the blunting of physiological control mechanisms (e.g., ventilatory response to carbon dioxide) is self-regulated.

The present patient simulator is an integrated, self-regulating system. For instance, in a non-self-regulating system, an awkward input situation would invariably lead to physiologically implausible behavior from the system or such stimuli would result in an inability of the system to handle the input at all. A self-regulating system is more robust in the accommodation and simulation of unplanned events because it will still provide an appropriate response. Thus, self-regulation is highly desirable, yet glaringly absent from the prior art.

For instance, if the trainee accidently ventilates the lung with a hypoxic (lacking oxygen) gas mixture (e.g., pure argon gas), a conventional system may not be able to react appropriately. However, the present invention provides an integration of relevant systems such that, trough self-regulation, appropriate simulated manifestations of hypoxia would be produced in the various output devices of the patient simulator, e.g. increased breathing rate and heart rate.

As another example, those skilled in the art are aware that increased CO_2 levels in the lung will cause hyperventilation. Hyperventilation results in lowering of CO_2 levels in the lungs due to washing away of the carbon dioxide. In a non-self-regulating patient simulator, increased lung CO_2 may or may not lead to increased ventilation. If no increase occurs, the reality of the simulation is decreased, thereby lessening the teaching value of the simulation.

Thus, it is clear that self-regulating systems hold clear advantages above non-self-regulating systems.

Furthermore, a means for adequately handling the injection of liquid anesthetic into the breathing circuit has been attempted by other researchers. The problems encountered in the prior art included (a) freezing of the location where the liquid anesthetic is introduced because of the heat of vaporization extracted from the surroundings as the liquid anesthetic evaporates, (b) pooling of the injected liquid through lack of heat to vaporize the liquid anesthetic and (c) uncontrolled evaporation of the anesthetic liquid from the syringe to the breathing circuit (i.e. the tubing or conduit assembly which physically connects the anesthesia machine or ventilator to the patient/manikin). The instant integrated patient simulator solves these problems by providing a means as usable not only in the simulation but in real life anesthesia applications.