A Web Application of Simulation System of Artificial Respirator

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Abstract--A Web application of a ventilator simulation system was developed for the students of clinical engineering and health care professionals. The system runs on Internet Explorer (5.5 or higher) and was developed using HTML, VBScript and Active X control (tklsim.ocx 70kB). The system was composed of a ventilator module and a respiratory model module. The ventilator module makes various waveforms of flow and/or pressure as inputs to the respiratory module. The respiratory module is consisted of four resistances of respiratory circuit (Rt), main airway (Ra), right and left lungs (Rr, Rl), two compliance (Cr, Cl), and spontaneous breathing pressure (Ps). The modules simulate dynamic state of the respiratory system during various artificial ventilations. The Web application is useful to understand about systems physiology of the ventilator-lung system and to experience the ventilator operation virtually.

URL http://info.ahs.kitasato-u.ac.jp/tkweb/tklsim2/indexE.html

II. SYSTEM DESIGN

The application was designed to demonstrate the principles of ventilation from the viewpoint of the physiology and potential hazards by the misuse. The system assumed to be used by students of medicine, nursing, clinical engineering and health care professionals as a self-training tool.

It simulates physiologically the dynamics of pressures and flows in normal breathing and various controlled ventilation. The user of this system can try and lean various ventilation modes and hazardous situations in a virtual world.

III. SYSTEM OVERVIEW

The system was composed of a respiratory module, a ventilator module, and control panels (Fig.1).

Fig. 1 Diagram illustrating the system structure

The respiratory system was modeled with physiological aspect by lumped parameter system with four resistances Rt (respiratory circuit), Ra (airway), Rr (right lung) and Rl (left lung), two capacitances that were added in series represented the alveolar compliance, Cr (right lung) and Cl (left lung), and the spontaneous breathing pressure (Ps) (Fig.2).

The spontaneous inspiration was simulated by an exponentially decaying curve with an adequate time constant. The expiration was assumed passive, utilizing the recoil nature of the chest expressed by two capacitances of the model.

The respiratory module simulates the dynamic aspect of the respiratory system. It is composed of four resistances, Rt, Ra, Rr, and Rl, and two capacitances, Cr and Cl, which represent the compliance of the respiratory system. The spontaneous breathing pressure, Ps, is also included in the respiratory module.

The ventilator module generates various waveforms of flow and/or pressure to be used as inputs to the respiratory module. The ventilator module is composed of four resistances, Rt, Ra, Rr, and Rl, and two capacitances, Cr and Cl. The spontaneous breathing pressure, Ps, is also included in the ventilator module.

The system was designed to demonstrate the principles of ventilation from the viewpoint of the physiology and potential hazards by the misuse. The system is composed of a respiratory module and a ventilator module. The respiratory module simulates the dynamic state of the respiratory system during various artificial ventilations. The ventilator module generates various waveforms of flow and/or pressure to be used as inputs to the respiratory module. The system is useful for understanding about systems physiology of the ventilator-lung system and for experiencing the ventilator operation virtually.

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Index Terms--ActiveX control, CAL, simulation, respiratory physiology, ventilator, Web application
characteristics of the respiratory system to input with various waveforms given by the ventilator module.

The ventilator module makes various wave patterns of flow or pressure as an input to the respiratory module in combination with the ventilation modes. The prepared modes are: CMV (controlled mechanical ventilation), CPAP (continuous positive airway pressure), SIMV (synchronized intermittent mandatory ventilation), PSV (pressure support ventilation), and SIMV+PSV. Some basic waveforms of pressure and flow generators are available: sine wave, increased/decreased ramp functions, and square functions.

In addition, the module continuously monitors the pressure (Pa) and flow (Fa) at the mouth for sensing the ventilator's "trigger."

The control panels are the user interface, and its function is to control the two modules and the simulation speed. The control panel of ventilator has no setting box for the fractional concentration of O\(_2\) in the inspiratory gas (FiO\(_2\)), because the dynamics for blood gas was not treated in this system.

The functions of the ventilator module were described in the HTML file with about 900 lines of VBScript codes (40kB). This module is a main part of the system with the functions of (1) controlling a simulation speed, i.e. interval of timer events, (2) making the input function of pressure or flow, (3) setting the wave pattern and the parameter values for the respiratory module in the control panel, (4) monitoring the new state of respiratory system, (5) making alarms when the pressure and/or flow reached the threshold values, (6) logging all of the users operation, etc.

![Fig. 2. Representation of respiratory tube, airway and lungs by means of an electric circuit. Pv: pressure function of ventilator, Fv: flow function of ventilator, Rt: resistance of circuit tube, R: resistance of airway and each lung, C: compliance of each lung, P: pressure of airway and each lung, V: volume of each lung, and Ps: pressure function of spontaneous breathing.](image)

### V. SAMPLE RUN

All parameters of respiratory and ventilator modules may be altered in the control panels; frequency, amplitude, resistances, and capacitances for lung module, ventilation modes, waveforms, frequency, tidal volume, flow speed, end-inspiratory plateau, peak inspiratory pressure, I:E ratio (inspirator-expiratory ratio), PEEP (positive end-expiratory pressure), etc. for ventilator module.

The peak inspiratory flow rate determines how fast each breath will be delivered to the patient and is therefore a determinant of inspiratory time. The sensitivity setting determines how easily a patient can initiate mechanical ventilation.

There are some input boxes for alarm level in the panel. When the airway pressure or flow became out of the preset range, the alarm will sound each time.

Fig.3 shows the changes in airway pressure and flow at the mouth and the both lungs during spontaneous breathings without mechanical ventilation. The pressure (Pr and Pl) in lungs is negative during inspiration, and is positive during expiration.

Fig. 4 depicts the waveforms under normal and pathophysiological conditions in a same spontaneous breathing without mandatory ventilation. The pressure, flow and volume waveforms at the right lung were obviously different from the left lung (Fig. 4(b)). An increasing of resistance of right lung caused a decrease in the volume of right lung during inspiration, and increased the residual volume during expiration. The peaks of all waveforms were decreased compared to normal condition under a decreased compliance in a same normal breathing (Fig. 4(c)).

Two demonstration patterns in Fig.5 show the sample responses to increasing and decreasing ramp function of ventilator waveforms during mandatory ventilation without spontaneous breathing. In contrast to normal breathing, the
pressure was always positive during the controlled ventilation.

Fig. 6 shows two wave pulses, controlled ventilation (the first waves) and assisted ventilation (the second waves) in SIMV+PSV mode. The first waves were due to mandatory ventilation without a spontaneous breathing. In the second waves, a slightly negative pressure at the beginning of inspiration initiated the ventilation. This caused the ventilation to 'trigger' and gave a full ventilator breath. This additional flow rapidly produced a positive airway pressure during inspiration.

Although the above-presented waveforms were a little different from the clinical data, the essential characteristics were fully reconstructed in each ventilation mode and were rather exaggerated for learning.

VI. DISCUSSION

Computer-aided learning would make a significant influence on the skill levels in the use and the maintenance of medical devices. Some manufacturers, such as Hewlett Packard, have produced computer-aided leaning packages for their products [3].

Although there have been many computer-aided learning packages on a variety of topics, the large majority are either presenting the information in a linear manner, or being
browsed the contents through hypertext. Rational and interactive simulator, such as BreathSim [5], is needed for understanding the physiological effects of various ventilation modes. It will show the physiological dynamics in the ventilator-respiratory system in more sophisticated manner than the operating manual.

The simulator required a model that described reality as exactly as necessary from the point of view of the specific purpose. It was assumed that the respiratory system could be modeled by the lumped parameters of resistance and compliance. The assumption is clinically used, and the simple parameters may be obtained from the flow curve during the passive expiration [6].

Strictly speaking, the simulated waveforms in our system were a little different from the clinical data. The differences might be due to the simplicity of the model, and were in a allowable range for understanding the pressure-flow-volume relationships in the respiratory system. Further work will be needed to extend this model to include non-linearity of parameters such as a dynamic compliance of relaxation pressure curve.

Our simulation system was not intended as primary instruction tools. The system was designed to provide students with thinking tools for examining their understanding of respiratory physiology and mechanical ventilation. It assumed some familiarity with the concepts of this areas.

There is probably no more confusing or intimidating subject to the students or health care professionals than mechanical ventilation [1, 2]. The simulator would make the students to have more time to learn for themselves. It could simulate some rare but significant clinical states without the fatal consequences associated with the real life. Making mistakes and learning from the virtual experiences would be a unique face of CAL. The student can use our system on his own to deepen his knowledge.

Patients vary widely in their ventilator requirements, and it is virtually impossible to predict settings. As an alternative to an empirical approach, one can use information from simulation studies with a suitable model of the respiration
system. This tool will gradually have greater relevance not only for clinical trials but also for training.

The real goal of mechanical ventilation is to maintain adequate $O_2$ delivery to and $CO_2$ removal from the tissue. However, the dynamics for gas exchanges was not included in this system at present, since a simulation for blood gas needed a complex physiological model such as VentPlan [7-10]. The goal was typically replaced by a maintaining adequate ventilation.

An ActiveX control was constructed to calculate quickly the dynamic state of the respiratory model. ActiveX controls have become the primary architecture for developing programmable software components ranging from software development tools to end-user productivity tools. With the introduction of VBScript and ActiveX controls, it is now possible to construct an interactive Web site [11].

Internet and WWW offer a large number of high-quality resources designed for medical education. Haag had reviewed the conventional CAI programs and “Web-based training (WBT) programs,” and expected a trend from conventional CAI towards WBT programs [12]. Our system would provide one of new features to the WBT program by including the interactive simulation.

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REFERENCES