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THE RESPIRATORY SYSTEM

COMPUTERIZED COLLECTION AND ANALYSIS OF POSTOPERATIVE OXYHEMOGLOBIN SATURATION DATA

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Summary. **Software to collect and analyze data from a Nellcor N-200E oximeter has been developed and proved reliable in extensive clinical testing. The derived summary measures of desaturation can be used to study the effect of postoperative hypoxemia on clinical outcome.**

Introduction. Postoperative hypoxemia is common and, in some cases, prolonged. Pulse oximeters allow for frequent measurement of saturation (SpO_2) but generate vast amounts of data, which create problems in storage and analysis. Large-scale outcome studies are needed to determine the effect of postoperative hypoxemia, and these require objective, graded summary measures of desaturation. We have developed software to fulfill this need.

Methods. A program was written in TurboPascal to capture the output from a Nellcor N-200E oximeter; the time-indexed SpO_2, heart rate, amplitude, and status are written on disk. Another program was written to analyze the data file. The program initially verifies that the data are valid; outputs both summary measures of the mean saturation, percent of time spent at SpO_2 of <94% and <85%, number of episodes during which SpO_2 fell below 85%, and frequency distributions of SpO_2; and prints a graph of SpO_2 vs time. It also provides a graded measure of variability in SpO_2 over time (stability) by producing a graph of the maximum mean and minimum mean SpO_2 over time intervals ranging from 1 minute to 24 hours. We call this a *trumpet curve* due to its shape, and from it we derive two indices: area A, a measure of time-related instability, and area B, a measure of both instability and overall desaturation.

Results. We have collected and analyzed data from more than 500 monitoring days involving 300 patients in four studies. Typical postoperative SpO_2 data from 1 patient are shown in the time trace in Figure 1 and trumpet curve in Figure 2. The programs have worked reliably in collecting and analyzing over 4 million strings of oximeter output.

Discussion. Commonly used measures such as mean SpO_2

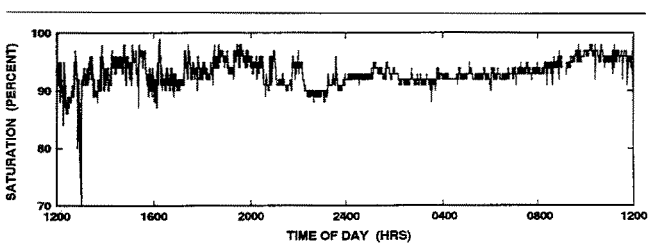

Fig 1. Typical postoperative SpO_2 data in a time trace.

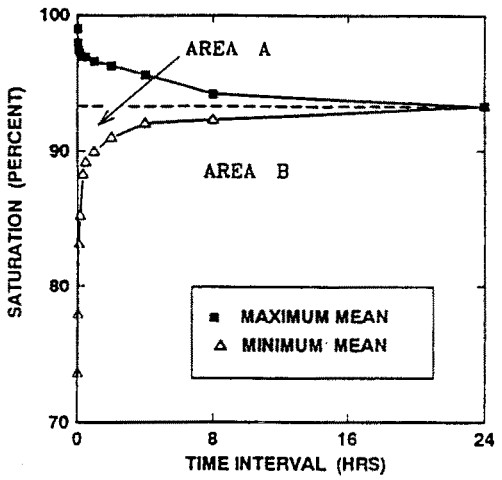

Fig 2. Typical postoperative SpO_2 data in a trumpet curve.

and percent of time with $SpO_2 < 85\%$ may not be relevant to adverse outcomes. Patterns of desaturation such as stability are thought to be important. Previously, profiles of desaturation have been subjectively placed in stability categories. Our method provides for a graded, objective measure.

VISUAL/AUDITORY RELAXATION AND SEDATION

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Summary. **We introduced and investigated the application of visual and auditory stimulation to induce relaxation and sedation and have found this technique to be effective in most subjects.**

Introduction. Visual/auditory relaxation and sedation (VARS) is a noninvasive and nonpharmacological means of inducing relaxation and/or a hypnogogic state. VARS employs the use of a programmable generator combined with audio headphones and light-emitting diode–fitted eyepieces. Synchronized visual and auditory stimulation (flashing lights and pulsating tone) at varying frequencies is delivered to the patient.

Theoretically, the patient's brain function is entrained by the stimulus, and then affected as the stimulus frequencies are varied in a controlled fashion. Entraining the patient's brainwave frequencies toward the theta and delta ranges should induce a relaxed state.

Methods. Subjects were seated in a comfortable chair with VARS eyepieces and headphones (InnerQuest IQ III model). Electroencephalographic (EEG) activity was recorded for 5 minutes prior to VARS stimulus, followed by a preset program from the VARS unit. EEG was also recorded 5 minutes post stimulus.

EEG waveforms of the left and right hemispheres were digitized, and analysis was performed on the data to determine frequency power spectrum. Power in the 4.5- the 5.5-Hz range (theta) was compared for all subjects at three times during stimulation: initial, relaxation, and final.

Results. Nine of 13 subjects exhibited EEG changes consistent with entrainment. Analysis of variance showed a significant increase ($p < 0.05$) in the target range power during the "relaxation" phase of the VARS program. Subjects reported psychological reactions to VARS, such as feeling relaxed or calm, or they described the experience as hallucinogenic.

Discussion. We are introducing the VARS concept as an adjunct to conventional anesthetic techniques for relaxation and sedation. The initial study suggests that brain electrical activity entrainment occurs. This technique may be an effective adjunct in anesthetic management.

INCIDENCE OF HYPOXEMIA DUE TO A HYPOXIC MIXTURE IN LOW FLOW ANESTHESIA WHEN USING NITROUS OXIDE

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Summary. **The incidence of hypoxemia with the use of N_2O and varying fresh gas flows (FGF) during general anesthetic maintenance was studied retrospectively using computerized patient records (CPR) from 1,064 patients. No hypoxemia occurred with FGF <3 L/min and the incidence of end-tidal O_2 (ETO_2) concentration <26% was significantly higher with FGF > 3 L/min ($p < 0.02$).**

Introduction. Despite the acknowledged benefits of using low FGF during general anesthesia (GA), higher FGF continue to be popular. A disadvantage of low FGF commonly cited is the risk of hypoxemia when N_2O is used. We compared FGF to study the incidence of hypoxemia with N_2O.

Methods. 1,064 GA cases involving N_2O use were retrospectively reviewed minute by minute using CPR that allowed no alteration of electronic captured ETO_2 and pulse oximetry (SpO_2) data. Three groups based on FGF were compared for incidence of hypoxemia, defined as SpO_2 <90% >60 seconds with a concurrent ETO_2 concentration <26% during anesthetic maintenance. Data analysis using the analysis of variance and chi square tests was done with the level of significance set at $p < 0.05$.

Results. One incident of hypoxemia was noted in the mid flow group. There was a significantly higher incidence of ETO_2 concentration <26% in the high flow group ($p < 0.02$).

Discussion. The use of the combined technologies of CPR and electronically captured SpO_2 and end-tidal gas values allows a unique and more robust retrospective review of case data than is possible with more traditional methodologies. The data showed that the incidence of hypoxemia using low FGF with N_2O is no greater than that with higher FGF. Also, the relative flows of N_2O and O_2 commonly used should be more of a concern in the potential development of hypoxemia, especially with higher FGF. The significant cost and environmental benefit that can be achieved from the use of low flow anesthesia should not be ignored without justification. The fictitious and heretofore unsubstantiated claim that low flow anesthesia increases the risk of hypoxemia is specifically refuted in this paper.

STABILITY OF PRESSURIZED CALIBRATION GASES

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***Summary.* We found that the anesthetic vapor concentration of calibration gases changed by less than 0.02 vol% over 15 months when stored in appropriate cylinders.**

Introduction. Calibration gases from pressurized cylinders are often used to calibrate anesthetic agent analyzers and vaporizers. When a single cylinder of calibration gas is used to verify the calibration of several different anesthetic agent monitors from different manufacturers, it is evident that the calibration standards used by the manufacturers are not consistent. To discover the reason for different factory calibrations, we suspected calibration gas tanks and therefore measured their stability over time.

Methods. Thirty 2-liter and eighteen 1-liter aluminum cylinders were purchased from Linde AG in equal lots containing approximately 1 vol% halothane, 1 vol% isoflurane, and 1 vol% enflurane, respectively. All cylinders were filled from the same batch of volumetrically and gravimetrically prepared gases. We used the IRINA, a precision infrared agent analyzer that we calibrated via refractometry, to measure the concentration in these tanks on receipt (1 month after preparation), 5 and 15 months after receipt for the 2-liter cylinders, and 12 months after receipt for the 1-liter cylinders.

Results. The concentration of the 1-liter cylinders decreased after 12 months by as much as 9%, 15%, and 3% of the reading for halothane, enflurane, and isoflurane respectively.

The concentration of the volatile anesthetics in the 2-liter aluminum cylinders did not change significantly over 15 months. On receiving the cylinders, the concentrations were 1.00 ± 0.007 vol% (mean ± SD) for halothane, 1.026 ± 0.005 vol% for enflurane, and 0.994 ± 0.005 vol% for isoflurane. After 15 months, the concentrations were 1.02 ± 0.014 for halothane, 1.039 ± 0.004 for enflurane, and 1.0006 ± 0.007 vol% for isoflurane. The average change was less than 0.02 vol%. The maximum change was less than 0.04 vol%. These changes are all within the precision of the infrared analyzer.

The concentration in the 2-liter tanks, as certified by the manufacturer, did not agree with our measurements on receipt of the cylinders. The certified concentration averaged 1.089 ± 0.011 vol% for halothane, 1.076 ± 0.005 vol% for enflurane, and 1.026 ± 0.005 vol% for isoflurane. The manufacturer guarantees an error of less than ± 0.02 vol%. The difference between the value certified by Linde AG and the values we measured are not within the guaranteed tolerances.

Discussion. Our results indicate that these volumetrically and gravimetrically mixed gases available from Linde AG were stable for 15 months when stored in 2-liter aluminum cylinders. They were much less stable when stored in 1-liter cylinders, which could be due to differences in material and valve design.

The certified concentration, however, did not agree with the concentration we measured. This difference may result because Linde uses gas chromatography with a flame ionization detector to determine the certified concentration, and we used a refractometer, which is calibrated differently. The difference may also have resulted from the absorption or adsorption of agent molecules during the month between certification and our measurement.

A RESPIRATORY FLOWMETER BASED ON A MODIFIED MAINSTREAM CO_2 CUVETTE

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***Summary.* We developed a signal processing technique that allows us to measure flow accurately using the pressure drop across a mainstream CO_2 cuvette.**

Introduction. Respiratory flow is a valuable parameter for assessing ventilation, lung mechanics, and breathing circuit integrity. Differential pressure-type flowmeters operate by relating the pressure drop across an airway obstruction to flow through the obstruction. Because this relationship between pressure drop and flow is nonlinear, many flowmeters use specially designed obstructions to linearize the signal. These linearizing techniques include screens, capillary tubes, and variable-orifice, flap-type flow obstructions. We have developed a system that allows the differential pressure signal to be linearized in software so that a low resistance, fixed-orifice obstruction can be used as an airway flowmeter.

Methods. Because of baseline drift and limited analog-to-digital conversion resolution, linearization of the differential pressure signal for flow measurement is not possible without additional analog and digital signal conditioning. Our system periodically actuates valves across the differential pressure transducer to simulate a zero-flow condition. A digital-to-analog converter provides an analog "zero-flow" signal, which is subtracted from the differential pressure transducer output to compensate for baseline drift and to allow amplification of the differential pressure signal. The signal is then amplified in four stages with gains of 1, 10, 100, and 1,000. The outputs of these amplifiers are filtered and fed into separate channels of an analog-to-digital converter. Each channel corresponds to a different range of flows. The computer program selects the appropriate channel, linearizes the signal, and reports the measured flow. To test the flow signal processing system, a mainstream CO_2 cuvette (Novametrix, Wallingford, CT) was modified by adding small pressure-sensing ports on both the proximal and distal sides of the optical window of the cuvette. Small diameter tubes connect these ports to a differential pressure transducer (Microswitch Model 163PC01D36, Honeywell-Microswitch, Freeport, IL). The accuracy of the cuvette flowmeter was measured by comparing its output with an instrumented 13.5-liter spirometer.

Results. Regression analysis of 978 flow comparisons yielded a r^2 of 0.999, an X coefficient of 0.999, and a standard error of the estimate of 0.626 L/min over a range of 1 to 200 L/min. The average percentage of error ([Flowmeter − Spirometer]/Spirometer) was 0.08%, and the standard deviation of the percent error was 2.66%.

Discussion. Use of improved signal processing allows a very simple flowmeter to provide superior accuracy and dynamic range. The simplified flowmeter design is a low-cost method for measuring airway flow and lung mechanics.

STANDARDS FOR THE ANESTHESIA WORKSTATION

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The International Standards Organization (ISO), the American Society for Testing of Materials (ASTM), and the European Committee (CEN) have each completed preliminary standards for the Anesthesia Workstation and its monitoring modules. The CEN standard is the closest to gaining approval. Balloting by 18 countries of the European Federation of Trade (6 countries) and the European Community (12 countries) was completed before March 20, 1993. This preliminary standard is now contained in a 200-page document. This work covers the anesthesia gas and vapor delivery system, breathing system, ventilator scavenging system, and associated monitoring and alarm modules and protection devices (oxygen cut-off device). The preliminary standard applies to workstations in which all parts have been assembled by a single manufacturer. The standard also applies to workstations that have been assembled by the user who has taken parts made by multiple manufacturers.

The ISO began drafting a standard on September 12, 1989. ASTM began writing their standards for an integrated anesthesia workstation in February 1993. The ISO standard follows the same approach as the CEN standard, whereas the standard planned by the ASTM is only for integrated workstations in which all components are built by a single manufacturer.

There is obviously considerable overlap of effort by these three standards groups. This overlap is costly and time-consuming, and if the resulting standards are different for each group, they may create unnecessary trade barriers and restrict technology transfer between countries. We will discuss how STA can play a vital role in coordinating the efforts of these three groups. Because of its international membership, STA members can help in the development of a worldwide standard. Because STA members have both academic and research orientations, they can help these groups to see that the overall objective of standards is to specify safety objectives without imposing design restrictions so that standards do not hamper the use of new technologies.

REFRACTOMETRY AS A CALIBRATION STANDARD FOR GAS MONITORS AND VAPORIZERS

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Summary. **If the refractive indices of the volatile anesthetic vapors were well established and accepted, refractometry could be used worldwide to produce accurate calibration. We propose that the values presented here serve as a standard until they are modified by independent investigators.**

Introduction. Anesthetic gas monitors are typically calibrated using calibration gases in pressurized cylinders. These gases are stable only when stored properly; they are expensive and difficult to transport. Anesthetic vaporizers have, on the other hand, been calibrated with refractometry. Refractometry could be the preferred method of calibration for both monitors and vaporizers if a data base of refractive indices were available.

Methods. We used a helium neon (632 nm) laser refractometer (AMIRENA, Drägerwerk, Lübeck, Germany) to measure the refractive indices for five volatile anesthetic vapors. We prepared calibration gases following the ISO 6145 international standard, whereby a gravimetrically metered amount of liquid agent is mixed with a known gas flow. We introduced these gases in 5 to 15 vol% concentrations and counted the shift in the fringe pattern. Taking into account the real gas nature of the anesthetic vapors after the second virial coefficients had been measured, we calculated the refractive index for halothane, enflurane, isoflurane, sevoflurane, and desflurane. Measurements were repeated with a wavelength of 546.1 nm with a Zeiss-Jena laboratory interferometer.

Results. The refractive indices for the volatile anesthetic vapors (at 633 nm, 0°C, and 1013 mbar) were: halothane 1603.2, enflurane 1540.4, isoflurane 1563.3, sevoflurane 1538.3, and desflurane 1211.7. These values increased to 1609.8, 1547.7, and 1569.0 for halothane, enflurane, and isoflurane, respectively, when measured using a wavelength of 546.1 nm due to dispersion.

Discussion. The maximum theoretical error for these measurements is 0.56%. Our refractive indices differ by less than 0.4% from measurements we made over 10 years ago. If these values for the refractive indices were universally accepted, refractometry could be used to produce accurate calibration without the need for expensive calibration gas tanks. A manufacturer or researcher could use a simple anesthetic vaporizer to produce new calibration gases for each application, for which the vaporizer output was measured by refractometry. Refractometry might eliminate errors that now occur because calibration gases supplied by numerous companies differ by 5 to 8%. We suggest that the values reported here be accepted as a standard until they are confirmed or modified by independent investigators.

A UNIFIED PHARMACOKINETIC MODEL FOR INTRAVENOUS AND INHALANT DRUGS

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Summary. **We unified the pharmacokinetic models for intravenous (IV) and inhalant drugs by choosing chemical potential as the state variable. The new model provides better understanding and should foster better control of anesthesia administration in clinical practice.**

Introduction. Many investigators are disquieted by the pharmacokinetic differences between IV and inhalant drugs. Currently, both models are analyzed, built, and clinically examined differently. However, IV and inhalation agents are exposed to the same influences once they reach the bloodstream. Thus, a unified theory may be possible.

In conventional IV models, the plasma drug concentration is the only measure of anesthetic in the body at equilibrium. However, concentration cannot be assessed continuously during surgery; therefore, it is not a reliable tool for controlling anesthesia. In addition, IV models ignore the effect of cardiac

output and misuse the concept of volume of distribution of the drug.

The inhalant model, on the other hand, uses partial pressure (tension) as the driving force toward equalization at equilibrium. Unlike IV models, tension can be monitored continuously during operation using end-tidal gas monitors. Cardiac output (CO) and volume distribution are vigorously used in inhalant pharmacokinetic models.

Method. We sought a variable to provide comprehensive unification between the IV and the inhalant pharmacokinetic models. Additionally, we considered CO to describe the IV pharmacokinetic equation properly. Accordingly, volume of distribution was revised when the effect of CO was considered the initial determinant of plasma concentration, followed by the effect of fast tissues.

The programming graphic language LabView was used to build the unifying model. This technique enabled us to monitor and display graphically the concentration and the tension in each compartment. The new model was compared to conventional models using available data.

Result. A thermochemical term, free energy, provides equality between compartments at equilibrium. Equalization occurs when free energy is at a minimum. Then it is chemical potential in equilibrated compartments that is equal. Thus, chemical potential is the variable that unifies the IV and inhalant drug models.

The inclusion of CO explains the elevated drug concentration measured directly after an IV injection. Infused drug is diluted by the continuous flow (CO), so that the drug concentration is elevated by infusion, not by a central volume of distribution as is the case with traditional IV models.

Discussion. The unifying variable allows unification of IV and inhalant models. The new model provides the means both to explain model differences and foster better understanding of the two drug classes in clinical practice. By using the unified variable chemical potential, incorporating the effect of cardiac output, and redefining the volume of distribution, IV and inhalant pharmacokinetic models become derivatives of one another.

TRANSFER FUNCTION FROM INSPIRED TO EXPIRED AGENT TENSION

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Summary. **The transfer function from inspired agent tension (Ax_I) to expired agent tension (Ax_E) was obtained using the recursive least-squares (RLS) system identification from real-time patient data. The model is first order with a time constant less than one-tenth that from Ax_E to systolic blood pressure (SBP). The second order system from Ax_I to SBP approximates a first order system with a time constant equal to the sum of the component time constants ($Ax_I \rightarrow Ax_E$ and $Ax_E \rightarrow$ SBP), estimating SBP within 10%.**

Introduction. Models describing $Ax_E \rightarrow$ SBP [1] and $Ax_I \rightarrow$ SBP [2], using RLS system identification, were first order with 10% accuracy. The time constants of these two models differed significantly. Here we describe an RLS technique that can directly measure the system transfer function from inspired to expired anesthetic tension ($Ax_I \rightarrow Ax_E$).

Methods. Ax_I, Ax_E, and SBP data were obtained from 15 patients anesthetized with either sevoflurane-N_2O, desflurane, or isoflurane using the disk logging feature of the Ohmeda Modulus 2 Central Display Anesthesia Delivery System. Using LS estimation for the initial conditions, we reconstructed the Ax_E curve using the Ax_I data, revising the parameters with the RLS algorithm until each Ax_E data point was predicted with less than 10% error. Results are expressed as mean ± SD.

Results.

1. A linear first order constant-coefficient difference equation describes the $Ax_I \rightarrow Ax_E$ behavior:

$$Ax_I(k + 1) = -aAx_I(k) + bAx_E(k) \quad (1)$$

where k is discrete time, $a = -e^{-\Delta t/\tau_A}$, $b = K(1 - e^{-\Delta t/\tau_A})$, and Δt is sampling time. This corresponds to the following transfer function:

$$G_{I\rightarrow E}(s) = Ax_E(s)/Ax_I(s) = K/(\tau_A s + 1) \quad (2)$$

where τ_A = alveolar time constant, and K = gain.

2. Accuracy of Ax_E was better than 8% for all points.
3. Gains for the three drugs were different ($p < 0.05$): τ_A = 14.3 ± 0.61 seconds, $K_{Iso} = 0.58 \pm 0.06$, $K_{SevoN_2O} = 0.72 \pm 0.05$, $K_{Des} = 0.80 \pm 0.04$.

The transfer function $Ax_I \rightarrow$ SBP [1,2] can be written as:

$$\begin{aligned} G_{I\rightarrow P}(s) &= K_{IP}(\tau s + 1)/(\tau_A s + 1)(\tau_B s + 1) \\ &= K_{IP}(\tau s + 1)/(\tau_A\tau_B s^2 + [\tau_A + \tau_B]s + 1) \\ &= K_{IP}(\tau s + 1)/([\tau_A + \tau_B]s + 1) \\ &\quad (\text{where } 1/\tau_A < s < 1/\tau_B) \end{aligned} \quad (3)$$

where τ_B = time constant $Ax_E \rightarrow$ SBP, $\tau_A < \tau_B/10$, and s is complex frequency. Equation 3 shows that the transfer function $Ax_I \rightarrow$ SBP can be described approximately by a first order system with $\tau_{IP} = \tau_A + \tau_B$, estimating SBP within 10%.

REFERENCES

1. Ji XB, Calalang ID, Philip JH. Transfer function from end-tidal agent tension to blood pressure. J Clin Monit 1992; 8:164–165 (Abstract)
2. Philip JH, Ji XB, Calalang ID, et al. Sevoflurane controls blood pressure faster than isoflurane. Anesthesiology 1992;77:A384 (Abstract)

FT-IR SPECTRUM OF DESFLURANE

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Desflurane is a new anesthetic agent patented by the Anaquest Division of the BOC Group. The agent is currently in the final phase of acquiring FDA approval. It is considered an improved agent based on its lower blood solubility (recovery aspect) and activity/dosage requirements. We have undertaken detailed FT-IR studies of anesthetic agents to determine how the existing IR gas monitors must be modified to include

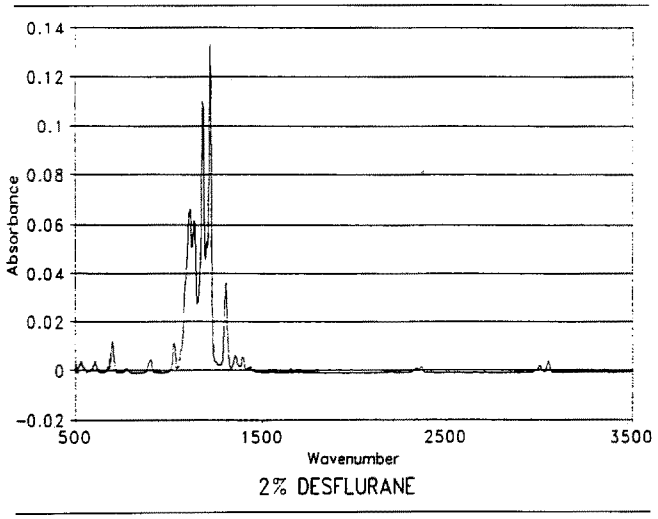

Fig. Diagnostic bands of desflurane.

desflurane. Our main objective was to determine the diagnostic bands of desflurane. The main IR bands are at 1355, 1304, 1219, 1180, 1136, 1112, and 1026 cm^{-1} in the mid-IR region. The bands at 1355 and 1112 cm^{-1} are best suited for use as diagnostic bands (Fig). The ones at 1304 and 1280 cm^{-1} are too close to the N_2O bands at 1299 and 1273 cm^{-1}; the 1219 cm^{-1} band overlaps with the isoflurane band at 1215 cm^{-1}; and the bands at 1180 and 1136 cm^{-1} are ruled out because of overlap with similar bands in halothane and sevoflurane. Details of these results are presented along with a discussion of the relative intensities of IR bands of other anesthetic agents such as isoflurane, enflurane, halothane, and sevoflurane.

TRANSCUTANEOUS CO_2 ($P_{tc}CO_2$) MONITORING IN ADULTS: COMPARISON BETWEEN 41 AND 44°C

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Summary. **$P_{tc}CO_2$ values were compared using 44 and 41°C temperatures employing a single probe (CO_2 only). The 44°C probe was removed after 8 hours whereas the 41°C probe was left for 24 hours with no complications. Compared to arterial pCO_2, r values of 0.89 (44°C) and 0.75 (41°C) were obtained.**

Introduction. $P_{tc}CO_2$ has been reported to have poor correlation at 41°C with $PaCO_2$ when a dual probe (CO_2 and O_2) is used [1]. If, however, $P_{tc}CO_2$ can be shown to function well at 41°C, it can be left in one place for more than 8 hours, which can be of paramount importance; hence we undertook this study to compare $P_{tc}CO_2$ at 41 and 44°C with $PaCO_2$ employing a single probe (CO_2 only).

Methods. Ten adult patients were studied in SICU with institutional review board approval. Arterial cannulas were in place in all of them for clinical reasons. Novametrix 840 transcutaneous monitors with single (CO_2) probes were used. Monitors were calibrated with 5% and 10% CO_2 gas and were configured to display the unadjusted $P_{tc}CO_2$ values. Two probes at 44 and 41°C were applied to the anterior chest of each patient. The probes were randomly selected. The probe at 44°C was removed after 8 hours, and the probe at 41°C was left in place for 24 hours. Simultaneous $P_{tc}CO_2$ and $PaCO_2$ values were obtained by blood gas analysis, uncorrected for patient temperature. The $P_{tc}CO_2$ values were adjusted by using the methods of Monaco (M) [2] and of Severinghaus (S) [3] so that the adjustment was independent of probe temperature. Regression analysis and bias and precision determination were performed.

Results. The comparisons of $PaCO_2$ vs $P_{tc}CO_2$ are shown in the Table below, and Figures 1 and 2 display bias and precision for 41°C and 44°C, respectively, using the Severinghaus-6 adjustment factor.

Discussion. Unlike the results previously reported [1], we found very good correlation between $P_{tc}CO_2$ at 41°C and $PaCO_2$ employing only a CO_2 probe. Furthermore, none of the patients developed burns or redness of the skin under the probe, and thus we conclude from this study that using a 41°C probe temperature appears to be a viable option for monitoring $P_{tc}CO_2$ in adult SICU.

Temp.	r	Reg. Slope	Bias ± SD (mm Hg)	N
41°C M[a]	0.75	1.03	−4.68 ± 4.27	83
44°C M[a]	0.89	1.10	−1.19 ± 3.64	44
41°C S-4[b]	0.75	1.32	1.31 ± 7.01	83
44°C S-4[c]	0.89	1.29	1.59 ± 4.62	44
41°C S-6[d]	0.75	1.32	−0.69 ± 7.01	83
44°C S-6[e]	0.89	1.29	−0.41 ± 4.67	44

[a] $P_{tc}CO_2/1.61$
[b] $P_{tc}CO_2 \cdot e^{[0.45(37-41)]} - 4$
[c] $P_{tc}CO_2 \cdot e^{[0.45(37-44)]} - 4$
[d] $P_{tc}CO_2 \cdot e^{[0.45(37-41)]} - 6$
[e] $P_{tc}CO_2 \cdot e^{[0.45(37-44)]} - 6$

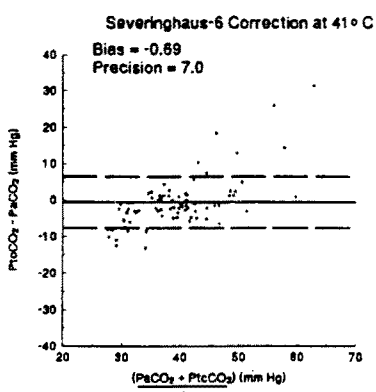

Fig 1. Comparison of $PaCO_2$ vs $P_{tc}CO_2$ using Severinghaus-6 adjustment factor at 41°C.

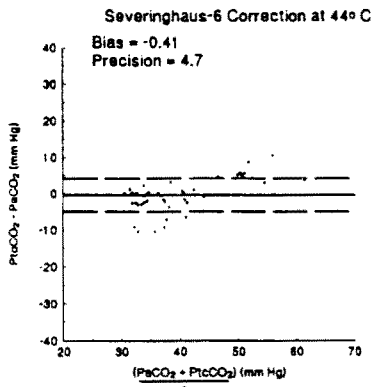

Fig 2. Comparison of $PaCO_2$ vs $P_{tc}CO_2$ using Severinghaus-6 adjustment factor at 44°C.

REFERENCES

1. Anesthesiology 1992;77(3A):A470
2. Am Rev Respir Dis 1983;127:322–324
3. Acta Anaesth Scand 1978;68:118–122

CLINICAL APPLICATION OF CONSTANT FLOW VENTILATION IN ANESTHETIZED PATIENTS

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Summary. **We investigated the efficacy of constant flow ventilation on gas exchange in anesthetized patients and found this technique efficient in satisfying exchange requirements.**

Introduction. Constant flow ventilation (CFV) has been reported by several investigators whereby the gas exchange in experimental animals can be maintained with a continuous flowing gas stream delivered into the main bronchi without an inspiratory or expiratory pause. The purpose of this study was to investigate the efficacy of CFV in anesthetized, paralyzed patients and to compare the resulting cardiopulmonary parameters with intermittent positive pressure ventilation (IPPV).

Methods. Induction of anesthesia in 9 patients (age 27–53 years) scheduled for upper abdominal and thoracic operations was carried out by intravenous administration of thiopental (6–8 mg/kg). The trachea was intubated following intravenous injection of succinylcholine (1.5–2 mg/kg). Anesthesia was maintained by a continuous infusion of 2% procaine, a standard technique in China. IPPV was initiated at a tidal volume of 10 ml/kg and an FiO_2 of 0.5, and the frequency was adjusted to yield an end-tidal CO_2 ($ETCO_2$) in the range of 4.6 to 4.6 KPa. Fifteen minutes after induction/intubation, during which time all patients were maintained on IPPV, ventilation was changed to CFV. Two catheters (50 cm long and 1.4 mm in internal diameter) were inserted through the endotracheal tube into the left and right main bronchi. Placement was confirmed by auscultation of breath sounds bilaterally. Catheter tips were positioned about 3 cm distant from the carina. For CFV, oxygen and compressed air were mixed to achieve an FiO_2 of 0.5. The gas stream passed through a flowmeter and the catheters and exited from a tube connected with a Y-adaptor at the end of the endotracheal tube. The end of the tube was in water of 5 cm in depth to maintain a low positive pressure in the airway. Arterial blood gas analysis was performed every 15 minutes during CFV. All data are expressed as mean ± SD. Analysis of variance and Q-tests were used to determine statistical significance.

Results. See Table.

Discussion. These results show that a constant flow of gas through the left and right bronchi at low Ppaw can satisfy gas exchange requirements in anesthetized patients. The depth of the catheter tip in the bronchus and 5 cm H_2O of positive airway pressure may be important factors in the success of this technique.

ELECTIVE USE OF PRESSURE-LIMITED OXYGEN INSUFFLATION

Thomas Scanlon, MD, *James York, MD, Scott Augustine, MD, Naval Hospital, San Diego, California; University of Minnesota, Minneapolis, Minnesota*

Introduction. Failure to oxygenate is a leading cause of anesthesia-related morbidity and mortality.

Methods. We report a case in which the use of elective pressure-limited oxygen insufflation maintained oxygen saturation during airway manipulation. A 127-kg male with a large tongue and limited neck and mandible mobility required panendoscopy for a large supraglottic mass. The surgeons' request for a small tube precluded the use of a fiberoptic laryngoscope. Blind awake intubation carried a risk of trauma with

Comparison of Ventilatory Efficacy of IPPV and CFV

			CFV	
	Preoperative	IPPV	15 min	30 min
pH	7.41 ± 0.02	7.40 ± 0.04	7.35 ± 0.03	7.32 ± 0.03*
$PaCO_2$ (KPa)	4.48 ± 0.42	4.85 ± 0.44	5.16 ± 0.39	5.40 ± 0.37
PaO_2 (KPa)	11.73 ± 0.93	27.71 ± 8.42	22.08 ± 5.69	23.02 ± 2.90
Ppaw (KPa)		1.94 ± 0.03	0.53 ± 0.01	0.53 ± 0.01*

*$p < 0.05$ (compared with IPPV).
Ppaw = peak airway pressure.

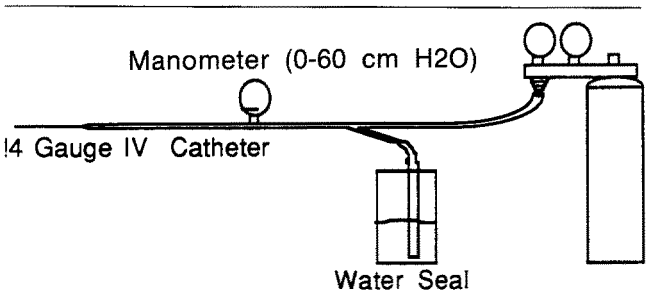

Fig. Equipment needed for pressure-limited oxygen insufflation.

seeding of the tumor. Jet ventilation is associated with a risk of barotrauma. The surgeons believed that a directly visualized intubation avoided the risk imposed by tracheotomy for tumor spread.

After preparations were made for possible emergent tracheotomy, a 14-gauge catheter was placed through the cricothyroid membrane, and pressure-limited oxygen insufflation was started (Fig). During inhalation induction, airway patency could not be maintained; the patient was relaxed and atraumatically intubated without difficulty. Arterial blood gas determination after intubation revealed the following measurements: pH 7.26, O_2 406, CO_2 91, BE +5, oxygen saturation 100%. The patient underwent panendoscopy with laser excision of the mass and was extubated while awake. Follow-up revealed no complications.

Discussion. Cases with anticipated airway difficulty are not uncommon. Unique conditions may preclude awake intubation techniques. Pressure-limited transtracheal oxygen insufflation allows time to manage the airway.

CAN THE PULSE OXIMETER DETECT PERIPHERAL VENOUS PULSATION?

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Summary. **Diastolic variability of the plethysmographic (pulse oximeter) waveform is still unexplained. The evidence presented demonstrates the impact of peripheral venous pulsation on the plethysmogram.**

Introduction. The pulse oximeter functions as an effective plethysmograph. The degree of light absorption is directly proportional to the blood volume in the finger. During routine use of a pulse oximeter in the operating room we noted that the plethysmographic waveform displayed waveform variability during diastole. Although arterial pulsation has been analyzed with photoelectric plethysmography, venous pulsation has not. We hypothesize that diastolic variability is the result of peripheral venous pulsation and that this pulsation is in turn a reflection of the central venous pressure.

Methods. Arterial, central venous, and peripheral tracings were obtained using the Hewlett-Packard (HP) Component Monitoring System during the course of 25 routine operating room procedures. The peripheral venous pressure was recorded from an IV catheter in the dorsum of the same hand as the one used for plethysmography. The 940-nm wavelength absorption band of the HP M1020A SaO_2/Pleth module (version B software) was used as the source of the plethysmographic signal. The analog output from the HP system was captured by a MacLab data recording system at 40 Hz.

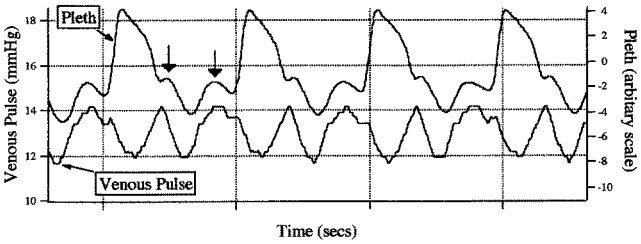

Fig. Diastolic variability of plethysmographic waveforms.

Results. Waveforms with diastolic variability were observed in 5 patients. The Figure shows the peripheral venous pressure (venous pulse) and plethysmographic (Pleth) waveforms from a patient undergoing removal of an ectopic pregnancy. It shows a close time correlation between the peripheral venous pulse and the diastolic peaks seen in the plethysmograph. Despite the fact that pressures in the venous system are low (<15 mm Hg) and venous pulse pressure is only 2 to 4 mm Hg, the effect on the plethysmograph is clear. It was observed in another patient that the venous pulse, as detected by the plethysmograph, vanished with significant surgical blood loss.

Discussion. The presence of the venous waveform on the plethysmograph is likely the product of a complex interaction between a number of factors including vascular tone, peripheral venous valves, right heart function, and relative blood volume. The detection of a venous pulse with a standard pulse oximeter opens up intriguing avenues of investigation. Changes in the amplitude of this venous pulsation may have important clinical significance. They may allow estimation of central venous pressure. Also, it should theoretically be possible to determine the peripheral venous oxygen saturation by using the plethysmographic information.

THE CARDIOVASCULAR SYSTEM

BASIC COMPUTER-AIDED INSTRUCTION FOR OBSTETRIC ANESTHESIA

David Seitman, MD, *Dan Nir, BA, Hahnemann University Hospital, Philadelphia, PA*

Summary. **We are developing a computer-aided instruction (CAI) environment with a pilot tutorial entitled OB Anesthesia and the Aortic Stenosis Patient.**

Introduction. Computers can play many roles in medicine. One expanding area of interest involves education, in which CAI can act as an adjunct to the conventional training received by medical students and physicians. Although the dynamic nature of computer education often appeals to students, we found that many already existing CAI programs have two problems: (1) they have nonmedical authors, and (2) they are inflexible. Most CAI programmers are not physicians, and consequently they often lack the insight into medical problems normally gained from clinical experience. Many CAI pro-

grams are built in a prepackaged, unchangeable format that makes it difficult for physicians to modify them to reflect changes in medical knowledge and their educational needs.

We are attempting to develop a CAI program that will deal with these problems. Our project is designed to be a flexible microcomputer-based environment that will facilitate rapid organization and development of specific computer-based tutorials by attending physicians or faculty members using the most up-to-date information from any source (e.g., recent medical journal articles, textbooks). In other words, we are developing a CAI tutorial generator. The pilot tutorial (which was presented at this meeting) is entitled Obstetrical Anesthesia and the Aortic Stenosis Patient in Labor.

Methods. We chose the Microsoft Visual Basic programming language, which is a component of the IBM PC-compatible Microsoft Windows Environment for our programming code. The Calera Wordscan Plus document scanning program is being used to accept specific data input. The pilot tutorial has three stages: (1) a modularized discussion of the diagnosis and treatment of the obstetric patient with aortic stenosis, (2) an accompanying quiz, presenting the user with questions and answers on the material, and (3) a patient management component that makes suggestions for individual patient care.

Discussion. The development of the pilot tutorial is the first step in the development of a larger project. We plan to use our CAI generator to produce a series of tutorials under the broad heading The Obstetric Anesthesia Patient with Cardiac Disease.

BEAT-TO-BEAT VARIABILITY CAN INDICATE SUBTLE DIFFERENCES IN CARDIOVASCULAR EFFECTS OF ANESTHESIA

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Summary. **Beat-to-beat heart rate variability was studied in 14 human subjects during sevoflurane and enflurane anesthesia. Spectral analysis of heart rate intervals showed a difference between sevoflurane and enflurane whereas standard hemodynamic parameters did not.**

Introduction. Since respiratory changes in heart rate are mediated by both the sympathetic and parasympathetic nervous systems, changes in heart rate variability (HRV) can indicate modulation of autonomic nervous system (ANS) activity. Analysis of HRV has been shown to be a useful clinical research tool in patients with diseases such as diabetes mellitus, in which impairment of the ANS exists [1]. Recent studies have indicated that HRV may also provide useful clinical information about anesthetic depth resulting from anesthetic mediation of the ANS [2]. In this study we compared the effect of sevoflurane and enflurane general anesthesia on HRV.

Methods. With the approval of the Human Subjects Committee, 14 healthy male volunteers were randomly selected to receive either sevoflurane or enflurane general anesthesia (7 each) at a minimum alveolar concentration of 1.0 to 1.2 for a duration of 2.5 to 3.0 hours as part of a study on renal concentrating ability. Besides normal physiologic monitoring, an additional set of electrocardiographic (ECG) electrodes was attached to each subject. A modified Hewlett-Packard 7830A ECG monitor triggered a digital input port of an analog-to-digital convertor within an IBM PC. At each R wave, R-R intervals of the heart rate were calculated and stored in the computer.

A moving window interpolation algorithm was employed to calculate R-R intervals at equal periods of 0.25 second, yielding data sets of 4096 points. Using a fast Fourier transform algorithm, the power spectrum for each set of heart rate values was determined. The heart rate spectra were divided into three frequency bands: low (0.02–0.06 Hz), mid (0.07–0.14 Hz), and high (0.15–0.40 Hz). Power in each band was calculated as a percentage of the total spectrum power.

Results. The mean percentage of power in the low frequency band of the sevoflurane subjects (27.8 ± 3.4 SD) was less than that of the enflurane subjects (41.7 ± 0.104 SD), using student's t tests with $p < 0.05$. Power percentages in both the mid and high frequency bands were not significantly different. Heart rate, mean blood pressure, and temperature showed no significant differences between the two anesthetics.

Discussion. The results of this study indicate that there is a difference in ANS mediation of heart rate between sevoflurane and enflurane as shown by the low frequency band of the HRV specrum. Since HRV activity below 0.10 Hz is generally considered an indicator of ANS activity, this may suggest dissimilar mechanisms of action in sevoflurane and enflurane. Further studies using HRV may prove it to be a useful research tool in understanding anesthetic actions and effects.

REFERENCES

1. Lishner M, Akselrod S, Mor Avi V, et al. Spectral analysis of heart rate fluctuations. A non-invasive, sensitive method for early diagnosis of autonomic neuropathy in diabetes mellitus. J Auton Nerv Syst, 1987;19:119–125
2. Kato M, Komatsu T, Kimura T, et al. Spectral analysis of heart rate variability during isoflurane anesthesia. Anesthesiology 1992;77:669–674

PATTERN CLASSIFICATION USING ARTIFICIAL NEURAL NETWORKS AND DISCRIMINANT ANALYSIS

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Summary. **A comparison of artificial neural network pattern classification and discriminant analysis was performed. It was found that for subtle differences between classes the ANN approach performed better than DA.**

Introduction. Artificial neural network (ANN) pattern classifiers have been widely used in anesthesia monitoring for tasks such as electrocardiographic (ECG) arrhythmia detection, electroencephalographic (EEG) analysis, and capnography. In most cases, however, it has not been clear whether better classification would have resulted if discriminant analysis (DA) or other classic methods had been used instead. Using simulated data with known statistical characteristics, we have made a detailed comparison of ANN classification with DA.

Methods. Twenty 64-point arrays of uniformly distributed random numbers were created to simulate the power spectrum of physiologic signals (such as EEG) with frequencies ranging from DC to 31.5 Hz. The arrays were divided into two classes, each initially having identical statistical character-

Table 1. Classification Accuracy of ANN vs DA

Modification Gain	% Power Change	% ANN Accuracy	% DA Accuracy
1	3.8	55	45
2	7.9	75	50
3	12.2	80	70
4	16.6	90	75
5	20.8	90	85
6	24.9	90	90

Table 2. Generalization Accuracy of ANN vs DA

Modification Gain	% ANN Properly Classified	% DA Properly Classified
1	60	60
2	75	60
3	85	65
4	85	65
5	90	70

istics. Incremental modifications were made to one class by increasing the power of activity at 5 Hz. This was achieved by multiplying every element in the array by one plus a normal distribution function with its center at 5 Hz, a standard deviation of 1 Hz, and incremental gains of 1 to 6.

ANN were trained, and the discriminant functions (DF) were derived to differentiate data belonging to each of the seven groups. ANN and DF trained with modification gain 6 were also tested on the other modified data sets to assess generalization performance.

Results. As shown in Table 1, the classification accuracy of ANN and DA reached 90% for modification gain 6, corresponding to a 24.8% change in power, although ANN had better classification accuracy at lower modification gains. Table 2 shows the results of testing ANN and DF trained with modification gain 6 on all other data sets. ANN performed better than DA at the four modification levels shown.

Discussion. The results presented here suggest that to distinguish subtle differences between classes, the ANN approach may be more accurate and may have greater generalization capabilities than DA. Although statistical methods are derived from a well-understood theoretical framework, more research is required to elucidate the function of ANN. ANN offers compelling properties (adaptation, generalization, and flexibility) but should be used in combination with classical statistical approaches.

ARTIFICIAL NEURAL NETWORKS USED TO ESTIMATE CARDIAC OUTPUT FROM PHONOCARDIOGRAMS

Kai Kück, Dipl-Ing, *Joseph A. Orr, PhD, Dwayne R. Westenskow, PhD, University of Utah, Department of Anesthesiology, Salt Lake City, Utah*

Summary. **Artificial neural network was trained to estimate cardiac output from animal phonocardiograms. Although the network correctly grouped similar recordings, the correlation with cardiac output was rather weak.**

Introduction. Use of esophageal stethoscopes during anesthesia is common and is sometimes even mandated by insurance companies instituting malpractice claims. Stethoscopes have the advantages of simplicity, robustness, and directness (no "layers" of electronics before signals reach the anesthetist). Evaluation and interpretation of the signal require a "good ear," a lot of experience, and intuition. However, the usefulness of the information obtainable with esophageal stethoscopes is subject to controversy. One of the unknowns is the relationship between heart sounds and cardiac output.

Artificial neural networks have been applied successfully to a number of medical tasks, such as interpretation of multivariable signals, artifact rejection, and decision support. Neural networks "learn" by example and apply the learned "knowledge" to cases not in the training set. We trained a network to estimate cardiac output from phonocardiograms.

Methods. A mongrel dog (22 kg) was anesthetized with halothane and mechanically ventilated. Cardiac output was decreased using halothane and esmolol and increased using isoproterenol. A microphone was connected to the end of the esophageal stethoscope, and the heart sounds were continuously recorded on a commercial tape recorder. Cardiac output was measured by thermodilution every 10 minutes (average of three measurements), for a total of 22 cardiac output determinations.

Blocks containing five segments of heart sounds of 8 seconds each were digitized (8 bit, 8 KHz) after every cardiac output determination, for a total of 110 segments. The digitized segments were then preprocessed to generate input features for the neural network. FFT frequency analyses (0–2,000 Hz) were made of the raw signal and of the envelope signal. From these signals, various features were extracted, such as location and amplitude of the peaks, mean power in frequency bands, etc. In addition, more general features were calculated, such as the mean and mean power of the whole signals.

A total of 61 features were extracted from each digitized segment. These were passed to a neural network (61 inputs, 10 hidden, 1 output, sigmoid activation function). Data from 75% of the digitized segments were used for training. The performance of the trained network was tested with the remaining 25% of the data. This procedure was repeated four times, so that all data were used once for testing. The cardiac output values, ranging from 1.34 L/min to 6.67 L/min, were divided into five groups (2, 3, 4, 5, and 6 L/min), and the network was trained to estimate the group of each input data set. The neural network estimates from the respective five segments belonging to a cardiac output determination were averaged.

Results. A preliminary training session showed that the neural network could easily recognize the block of data from which the data originated (linear regression showed a correlation of $r = 0.954$). The correlation between the average thermodilution cardiac output and the average value estimated by the neural network was $r = 0.645$.

Discussion. The network was able to recognize accurately to which block of five the individual segments belonged, showing that feature extraction and network training were appropriate for classifying phonocardiograms. However, even considering the variability of thermodilution measurements, the

correlation between cardiac output and neural network estimates from phonocardiograms was rather weak. Further steps needed to verify this result will include comparisons of our system with those of other experienced anesthesiologists and acquisition of a larger data base of phonocardiograms and corresponding cardiac output measurements.

A NEURAL NETWORK USED TO CALCULATE CARDIAC OUTPUT USING SMALL INJECTATE VOLUMES IN THE DOG

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***Summary.* We used a neural network to process thermodilution cardiac output signals in animals. The network produced accurate measurements with an injectate volume of only 2 ml.**

Introduction. Thermodilution cardiac output is usually measured using 10 ml of iced or room temperature injectate. These large volumes are needed to generate an adequate signal-to-noise ratio to ensure adequate signal strength for conventional cardiac output processing. Neural networks can be trained to process small signals in the presence of noise. We have trained a neural network to process cardiac output signals using injectate volumes of only 2 ml.

Methods. Anesthesia was induced and maintained in a 22-kg mongrel dog using halothane. An adult balloon-tipped thermodilution catheter (Viggo-Spectramed, Oxnard, CA) was introduced into the jugular vein and positioned so that the tip was placed in the pulmonary artery. Every 10 minutes we made three paired measurements of cardiac output using both 10 ml and 2 ml of iced 5% dextrose solution. Pulmonary artery blood temperature waveforms and information on average injectate temperature were stored digitally for each measurement. Cardiac output in the dog was raised and lowered pharmacologically.

Data were analyzed to compare the performance of a neural network measurement that used a 2-ml injectate with that of a conventional cardiac output computation using 10 ml of iced injectate. The average of the three conventional cardiac output measurements (using 10-ml injections) was assumed to be the actual cardiac output for training and testing purposes. Normalized samples (1 Hz) of the pulmonary artery blood temperature signal along with the average injectate temperature comprised the neural network inputs. The network consists of 28 inputs, 5 hidden layer nodes, and 1 output that corresponded to cardiac output.

Twenty percent of the data was held out for testing, and the remaining data were used to train the neural network. This process was repeated until all data had been used once for testing. Averages of the three 2-ml injectate measurements in each series were compared with the corresponding averages of conventional cardiac output measurements from each series.

Results. Regression analysis yielded a correlation of r = 0.947, an X coefficient of 0.956, and a standard error of the estimate of 0.497 L/min (n = 24). The average percent difference between the measurements was 2.54% with a standard deviation of 12.9%. The injectate temperatures for the 2-ml measurements ranged from 9.3 to 22.7°C with an average of 14.4°C. In 5 of the 24 measurements the conventional processing system was unable to calculate cardiac output when 2-ml injectate volumes were used.

Discussion. Neural network processing of thermodilution cardiac output waveforms allows the use of smaller injectate volumes. This reduction in fluid load should make possible more frequent measurements in patients. The ability to calculate cardiac output using a weaker signal may improve the accuracy of continuous cardiac output systems, in which less thermal input energy is available.

IMPROVING THE PERFORMANCE OF A NEURAL NETWORK–BASED ALARM SYSTEM

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***Summary.* We developed a neural network–based alarm system that identifies 23 specific faults in the anesthesia breathing circuit. After postprocessing of the neural network output, the system identified faults with 91.0% accuracy.**

Introduction. We have developed a neural network–based anesthesia alarm system. The alarm system identifies 23 specific faults in the anesthesia breathing circuit such as endotracheal tube leak or expiratory hose obstruction. The neural network is a data processing method based on mathematical models of physiologic reasoning systems The work described here is based on a much larger data set, which has more variability and more faults than our earlier work [1,2].

Methods. Features ranging from CO_2, flow, and pressure signals were extracted and stored to disk during ventilation of a lung simulator. The lung was ventilated at 48 different combinations of ventilator settings (tidal volume, respiratory rate, inspiratory flow), fresh gas flow, lung compliance, and airway resistance. At each setting, 23 faults were created in the breathing circuit. The system was allowed to return to an ambient state between each fault.

The features were normalized, preprocessed, and presented to the neural network for training and testing. The neural network had 55 input nodes (one for each feature), 30 hidden nodes, and 24 output nodes (one for each fault plus one for normal). The data were randomly divided into 12 sets, each set containing all 23 faults at four settings. Eleven sets were presented to the network for training, and the twelfth set was used to test the network. This was done for 12 training sessions, each time withholding a different set for testing. By training and testing in this manner, the network was always tested with data that it had not seen before.

The network was tested with and without an alarm filter. The alarm filter was a network postprocessor that made decisions on which alarm, if any, to report based on the previous six values (approximately two breaths) of each of the neural network output nodes. Decisions were based on the values of the output nodes and the degree of separation of these values.

Results. When the system was tested without the alarm filter (network only), the output alarm message was determined solely by the neural network output node with the highest value. The network by itself was able to identify correctly 76.6% of the *breaths* presented to it as one of 23 faults or normal. When tested with the alarm filter, performance increased to 91.0% correct identification of the *events* presented.

Discussion. The results suggest that postprocessing of the

neural network output improves the performance of the alarm system. To further improve results, more sophisticated post-processing methods and combinations of similar alarm messages are currently being considered. Although neural networks are useful for classification, performance is often improved when they are used in conjunction with other methods of analysis.

This work was supported by Ohmeda, Madison, Wisconsin.

REFERENCES

1. Orr JA, Kück K, Farrell RM, Westenskow DR. Neural network breathing circuit alarms in an anesthesia workstation. Anesthesiology 1991;75(3A):A1005
2. Farrell RM, Orr JA, Kück K, Westenskow DR. Differential features for a neural network based anesthesia alarm system. Biomed Sci Instru 1992;28:99–104

VENTRICULAR ASSESSMENT SOFTWARE ENVIRONMENT (VASE): A SYSTEM FOR THE ON-LINE DISPLAY AND ANALYSIS OF PRESSURE-AREA LOOPS

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Summary. **The objective was to design and implement a graphic user interface to display and analyze left ventricular pressure-area loops on-line to assess left ventricular function in patients undergoing cardiac surgery.**

Introduction. Left ventricular (LV) pressure-volume (P-V) loops have been used to achieve accurate assessment of both systolic and diastolic ventricular function. Unfortunately, LV volume data are difficult to obtain. LV cross-sectional area has been shown to be highly correlated with LV volume [1]. The substitution of LV area for LV volume in the construction of LV pressure-area (P-A) loops therefore closely approximates LV P-V loops. Transesophageal echocardiographic (TEE) automated border detection (ABD) can be used to provide instantaneous measurement of LV cavity area in the generation of LV P-A loops.

Methods. An analog LV area signal was generated by a Sonos 1500 TEE system (Hewlett Packard, Andover, MA) configured to perform ABD. LV pressure was recorded using a high-fidelity fiberoptic catheter (Camino Laboratories, San Diego, CA) placed through the right superior pulmonary vein. An Apollo DN3550 high-resolution graphics workstation (Hewlett-Packard, Chelmsford, MA) with signal acquisition hardware and software (Niagara Workstations, Inc, Buffalo, NY) was used to concurrently acquire, display, and store the LV area and pressure signals as well as other relevant hemodynamic signals (electrocardiographic data, arterial pressure, pulmonary artery pressure, and central venous pressure). P-A loops were concurrently displayed and analyzed on-line using specialized graphic and parameter extraction software (VASE, Department of Anesthesiology, University of Pittsburgh Medical Center, Pittsburgh, PA) written in the C programming language utilizing X Windows graphics library routines. Parameters such as stroke area, fractional area change, and stroke work area were calculated from each of the P-A loops during acquisition in addition to heart rate and various blood pressures. All of the extracted parameters were stored in a time-stamped, spreadsheet-style ASCII format data file for further off-line analysis.

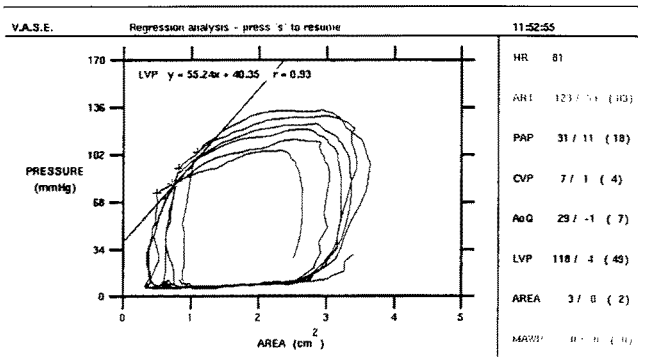

Fig. Cardiac cycles displayed on VASE interface.

Results. An example of the VASE interface is shown in the Figure, displaying several consecutive cardiac cycles from a patient undergoing an intraoperative inferior vena cava occlusion.

Discussion. P-A loops can be displayed and analyzed on-line using the LV ABD cavity area and LV pressure signals with the workstation-based VASE software. Its potential application to the understanding of P-V relationships and LV function is promising.

REFERENCE

1. Appleyard RF, Glantz SA. Two dimensions describe left ventricular volume change during hemodynamic transients. Am J Physiol 1990;258 (Heart Circ Physiol H277–H284)

COMPARISON OF CONTINUOUS NONINVASIVE BLOOD PRESSURE MEASUREMENTS BY PHOTOMETRY WITH SIMULTANEOUS INTRAARTERIAL PRESSURE MEASUREMENTS

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Summary. **The photometric pulse wave delay method of continuous noninvasive blood pressure measurement was compared with simultaneous invasive systemic arterial pressure measurements. This photometric method meets the AAMI/ANSI electronic standards for some pressure measurements.**

Introduction. Systemic blood pressure can be continuously and noninvasively (CNIBP) measured using a photometric pulse wave delay (PWD) technique that measures the PWD between two pulse oximeter probes, one on the ear and the other on the finger, and uses the PWD to estimate the diastolic blood pressure and pulse pressure. The purpose of this study was to compare CNIBP using the PWD technique with simultaneous systemic pressure measurements made by radial arterial catheterization (ART).

Mean Bias of Continuous Noninvasive Blood Pressure and Blood Pressure Made by Radial Artery Catheterization

Systolic Pressure (Mean ± SD)	Diastolic Pressure (Mean ± SD)	Mean Pressure (Mean ± SD)
0.98 ± 9.56	11.92 ± 6.29	10.38 ± 6.73

Methods. The study was approved by the institutional review board. Patients in the intensive care unit in whom radial artery catheters were already inserted for clinical reasons were studied. CNIBP was measured by PWD with an Artrac 7000 (Sentinel Monitoring, Indianapolis, IN). ART was measured with disposable transducers and a Hewlett-Packard Component Monitoring System. The arterial pressure signal was not filtered or electronically processed. The CNIBP device was used according to the manufacturer's recommendations; CNIBP was calibrated to an oscillometric noninvasive blood pressure (NIBP) cuff every 5 minutes. Systolic, diastolic, and mean CNIBP and ART pressures were recorded simultaneously every 5 minutes. Individual bias ± standard deviation (SD) statistics were calculated for each patient, whereby bias is the mean difference between paired CNIBP and ART measurements. Then all the individual bias ± SD measurements were averaged together to provide a grand mean bias ± SD.

Results. Nine patients were studied, and 21 ± 9.7 data pairs were collected for each patient. The grand mean bias ± SD for systolic, diastolic, and mean pressures are presented in the Table.

Discussion. The AAMI and ANSI standards for electronic/automated sphygmomanometers state that for systolic and diastolic pressures the bias between the test system and the reference system should be within ± 5 mm Hg with a SD ≤ 8 mm Hg. If we expect CNIBP devices to be as accurate as oscillometric NIBP devices, CNIBP devices should meet the same standards of accuracy as oscillometric NIBP devices. Compared with unfiltered ART measurements, CNIBP made by PWD met the AAMI/ANSI standards for SD of the bias for diastolic and mean but not for systolic blood pressure. Conversely, the PWD CNIBP met the AAMI/ANSI standards for systolic bias but not for diastolic or mean pressure bias. Because our ART measurements were unfiltered, excessive resonance or damping may have been present in our transducer system, and this may account for some of the differences in bias.

SYSTEMIC VASCULAR RESISTANCE APPEARS AS A NONLINEAR VALUE DURING EXTRACORPOREAL CIRCULATION

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Summary. **During extracorporeal circulation, systemic vascular resistance is not adequately described by the linear equation SVR = (MAP − CVP)/CO. A better description is provided by SVR = (MAP − Pa)/CO, where Pa appears to be the critical closing pressure.**

Introduction. Systemic vascular resistance (SVR) is calculated as the ratio of mean arterial pressure (MAP) less venous pressure (CVP) divided by cardiac output (CO). During extracorporeal circulation (EC) CVP is close to atmospheric; at that time, SVR = MAP/CO. This means that MAP is a linear function of CO where SVR is the slope and zero the intercept. We tested whether this was true in patients undergoing EC.

Methods. Four male patients undergoing elective coronary surgery were studied. Anesthesia was provided by fentanyl, pancuronium, and isoflurane. EC was performed at 25° with hemodilution and pump flow (CO) of 2.2 L/min/m^2. No vasoactive drugs were used. MAP was recorded from the radial artery with a calibrated transducer. Once stable EC was reached, baseline MAP was measured; then CO was lowered 12% during 30 seconds and MAP was recorded. CO was returned to baseline for 30 seconds and MAP recorded again; then CO was increased 12% for 30 seconds and MAP recorded a third time. The process was repeated by varying CO 25% above and below baseline. Measurements were repeated after rewarming and before termination of EC.

Results. MAP is shown in Figure 1 as a function of pump blood flow. Each point is an average of three readings. Each regression line corresponds to one set of CO step changes. There were no differences in hypothermia compared to normothermia. The slopes of each line, which are the graphic equivalents of SVR, are almost parallel despite differences in pressure. The intercept in all cases is not at the origin but at the Y axis at a nonzero pressure Pa, which is presumably equivalent to the "critical closing pressure." The function MAP-f(CO) is a straight line that may be described by the equation SVR = (MAP − Pa)/CO (Figs 1 and 2). Inasmuch

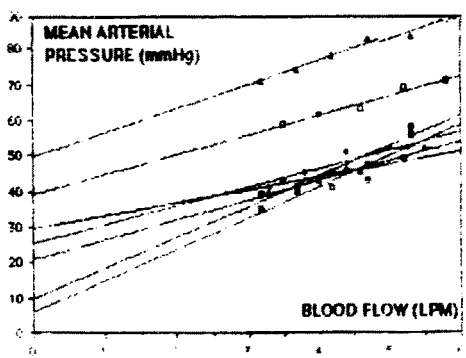

Fig 1. MAP as a function of pump blood flow.

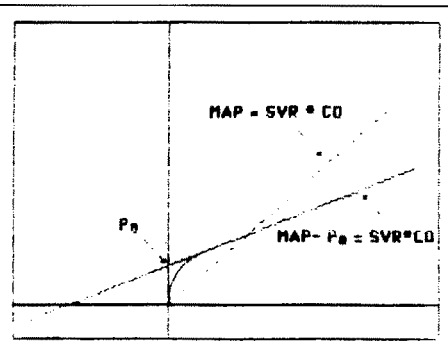

Fig 2. Nonlinearity of MAP near the Y axis.

as negative flows are not possible, the function must eventually approach zero, thus becoming nonlinear near the Y axis (Fig 2). Nonlinear behavior may be due to arterial wall elasticity (if transmural pressure decreases, diameter decreases, thus increasing resistance).

Discussion. During EC, SVR may be linearly described by the function SVR = (MAP − Pa)/CO, where Pa seems to be the critical closing pressure. Nonlinearity must exist near the Y axis. The normally used equation SVR = (MAP − CVP)/CO fails to predict the observed changes of MAP when step changes of CO are induced during EC.

Supported by FONDECYT 90-851.

THERMOREGULATORY VASOCONSTRICTION INCREASES THE DIFFERENCE BETWEEN RADIAL AND FEMORAL ARTERY PRESSURES IN HEALTHY VOLUNTEERS

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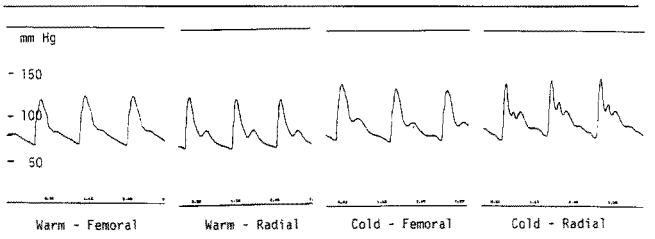
Summary. **Thermoregulatory vasoconstriction increases the difference between femoral artery pressure and radial artery pressure both in waveform and in peak systolic pressure.**

Introduction. Normally, radial artery pressure (RAP) differs from femoral artery pressure (FAP) in waveform and in systolic pressure (SP). Vascular resistance affects this difference; therefore, we attempted to determine whether thermoregulatory vasoconstriction increased the difference between RAP and FAP.

Methods. With institutional approval, 7 healthy male volunteers were subjected to cold and warm environments. RAP was measured from a 10-cm 20-gauge radial artery catheter and FAP from a 10-cm 20-gauge femoral artery catheter that was continuously flushed with saline and connected to calibrated MEDEX MX860 transducers by means of (1) a 10-cm, 2-mm MEDEX connector (minimal artifact system); (2) a 150-cm, 2-mm MEDEX MX564 connector; and (3) a 150-cm, 0.8 mm COMBIDYN 520-5689 connector. Vasoconstriction was estimated by the Vasomotor Index (VI), defined as (finger temperature − ambient temperature)/(core temperature − ambient temperature); it was considered maximal when VI < 0.1 and none when VI > 0.8. Core temperature was measured with tympanic membrane thermocouples. After baseline values were obtained, subjects were cooled by having cold air blown over them while lying on a cool circulating-water blanket. Rewarming was done by means of a Bair-Hugger and a warm circulating-water blanket. FAP and RAP were recorded when VI varied more than 0.1. The statistic method used was the paired *t* test; each subject served as his own control.

Results. Thermoregulatory vasoconstriction increased the differences between FAP and RAP. RAP showed large oscillations, which were more pronounced with the 150-cm connectors but were also present when a minimal artifact system was used (Fig). Radial SP exceeded FAP by 4.3 ± 5.6 mm Hg before cooling and by 17.3 ± 11.3 mm Hg during vasoconstriction; after rewarming, radial SP was 5 ± 7.6 mm Hg below FAP ($p = 0.0345$). Longer connectors further increased the gradient.



Oscillations in RAP during vasoconstriction.

Conclusion. Normal differences between RAP and FAP are increased during thermoregulatory vasoconstriction. These differences are exaggerated by pressure measurement artifact and may lead to erroneous patient management.

Supported by FONDECYT 90-851 and by Augustine Medical, Inc.

COMPARISON OF SYSTOLIC BLOOD PRESSURES MEASURED BY OCCLUSION PLETHYSMOGRAPHY VERSUS AUTOMATED OSCILLOMETRY

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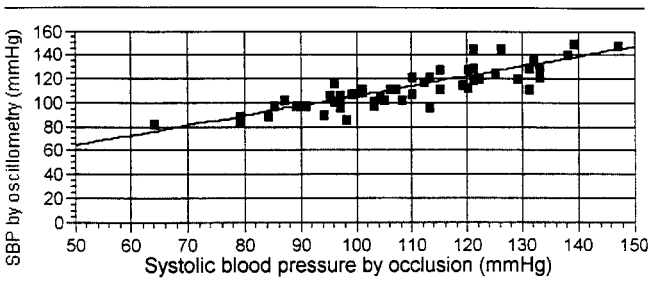
Summary. **Our study investigated the correlation between the systolic blood pressure measured by occlusive plethysmography and that measured by oscillometry using an automated noninvasive blood pressure device.**

Introduction. Frequently there may be a delay of up to several minutes while an automated noninvasive blood pressure monitor cycles, particularly when excessive patient movement or dysrhythmias are present. This delay may be of concern due to the effects of the prolonged compression as well as the delay in obtaining a blood pressure reading. By placing the pulse oximeter probe on the same limb as the blood pressure cuff, the systolic blood pressure can be determined by observing the return of the plethysmographic waveform with respect to the cycling cuff pressure. In this study, we correlated the systolic blood pressure obtained using occlusive plethysmography with that obtained by an automated blood pressure device using an oscillometric method.

Methods. Fifty-three ASA class I, II, and III surgical or critical care patients with normal sinus rhythm were studied. All readings were taken from an upper extremity without an arterial line. One set of data was collected from each patient. All readings were obtained using Marquette 7000 Series Input Modules. Values recorded included oxygen saturation (before occlusion and at the lowest point during occlusion), systolic blood pressure by occlusive plethysmography, systolic presure obtained by automated oscillometry, and time needed to obtain the two blood pressure measurements. Analysis of the pressure data was performed using standard linear regression techniques (least squares). Time data are presented as mean ± SD.

Results. The correlation coefficient between the occlusive and oscillometric methods was 0.87 (Fig). The time needed to obtain the occlusive systolic pressure was 19 ± 7 seconds



Systolic blood pressure obtained by occlusive plethysmography vs automated oscillometry (r = 0.87).

compared with 37 ± 15 seconds for the oscillometric pressure. The longest cycling time was 112 seconds, and the time required to obtain the blood pressure using the pulse oximeter in that case was 36 seconds.

Discussion. The close degree of correlation suggests that this technique may be useful in obtaining a systolic blood pressure quickly when a rapid indication of blood pressure is required. Examples of clinical situations in which this might be useful include situations in which patient movement or a significant cardiac dysrhythmia prolongs the time needed to obtain an automated reading.

NONINVASIVE VEGETATIVE SWITCH CONTROL OF HEART RHYTHM IN ANESTHESIA

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Introduction. It is well known that heart rate is under dual sympathetic and parasympathetic neural control. There are no noninvasive methods to characterize quantitatively the degree of sympathetic and parasympathetic control [1]. A noninvasive means of assessing parasympathetic control may be especially valuable, considering recent studies showing that parasympathetic cardiac control is reduced in patients with heart disease [2] and that vagal stimulation may provide a protective mechanism in acute myocardial infarction [3]. Rhythm beat-to-beat oscillations of one cardiovascular controlled variation might provide some criteria that could be used to interpret the complex interaction among the neural regulatory outflows. In this report we describe a new method of registering and calculating sympathetic and parasympathetic control in healthy persons and in patients before and after induction of anesthesia in the operating room.

Methods. We apply a new advanced monitor called Centavar [4] that registers and calculates vegetative switch by controlling 250 cardiointervals. Then we register graphically in print the curved line between the maximal and minimal range, which calculates automatically the absolute values of sympathetic-parasympathetic balance using the Baevsky R. M. formula:

$$RRi = AMo/2\,\partial \cdot Mo$$

where RRi is the index of cardiointervals, AMo is the amplitude mode in 250 cardiointervals in percent, Mo is the cardiointervals often seen in histograms in milliseconds, and ∂ is the variability of cardiointervals in all selections. The indicator of sympathetic-parasympathetic balance (S/PS) in units is calculated by modification of this formula. Thus it allows measured boundary limits with effects [4]. Eleven healthy persons and 10 surgical patients were studied. Patients were examined before and after induction of anesthesia and intratracheal intubation.

Results. In healthy patients at rest we obtained an absolute balance between sympathetic and parasympathetic evaluation expressed in percent (50%). All parasympathetic activity was 19.7 units. In patients before anesthesia, sympathetic activity seems to be more parasympathetic in 28.5%, whereas after anesthesia this occurred in 72%. All value of parasympathetic activity in patients was 40.5 before and 48.4 after anesthesia. In healthy persons vegetative switch was more rapid than in patients. Anesthesia contributed to more rapid vegetative switch.

Discussion. Controlling vegetative switch enables one to measure both sympathetic and parasympathetic activity and to choose an adequate pharmacologic approach and deep anesthesia.

REFERENCES

1. Katova P, Jih F. Respiratory sinus arrhythmia: noninvasive measure of parasympathetic cardiac control. J Appl Physiol 1975;39(5):801–805
2. Eckberg B, Drabinsky M, Braunwald E. Detection of cardiac parasympathetic control in patients with heart disease. N Engl J Med 1971;285:877–883
3. Goldstein R, Karsh R, Smith E, et al. The influence of atropine and vagally mediated bradycardia on the occurrence of ventricular arrhythmias following acute coronary occlusion in closed-chest dogs. Circulation 1973;47:1180–1190
4. Astakhov AA, Kiryanov IV. The field computerization of impedance cardiology. In: Computers in cardiology. Los Alamitos, CA: JEE Computer Society Press, 1991:569–572

HUMAN FACTORS

VIDEO ANALYSIS OF TWO EMERGENCY TRACHEAL INTUBATIONS IDENTIFIES ERRORS IN DECISION MAKING

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Summary. **Two videotapes of real emergency tracheal intubations show how a chain of errors can result from a single inappropriate decision. The tapes also identify errors precipitated by an inexperienced laryngoscopist and by lack of familiarity with alternative devices for emergency airway management. Last, the tapes demonstrate impaired vigilance due to distractors and the effects of stress on verbal communications between supervisor and trainee.**

Introduction. We studied videotapes of two emergency tracheal intubations in which a combination of unusual circumstances, erroneous information, inappropriate decision making, and

judgment errors occurred. Video analysis of the decision making of the anesthesia team during these stressful intubations was used to determine whether any changes were required in our algorithm or protocols for emergency management of the trauma patient's airway.

Methods. Videotapes were produced by a miniature camera suspended from the roof of two resuscitation areas at MIEMSS. The field of view included the anesthesiology team, and the audio channel captured team communications. The physiologic monitors were interfaced to a PC that included video overlay technology. Continuously updated physiologic data (heart rate, blood pressure, end-tidal CO_2 ($ETCO_2$), and O_2 saturation [SaO_2]) were overlaid onto the video image in real time during tracheal intubation when they were monitored. The videotapes were analyzed with OCS Tools, a commercial video analysis software package.

Results. The first patient (PT1) had tightly clenched jaws, an unrecordable blood pressure due to hemorrhage from an abdominal gunshot wound, and no intravenous (IV) access because he was a drug abuser. The second patient (PT2) had had an "arrest" in the field (or a head injury or drug effect?), a seizure, and was inadequately ventilated with an esophageal obturator airway (EOA).

The trauma team leader requested immediate tracheal intubation of PT1 after he was initially ventilated by face mask. Succinylcholine (SUX) was given into the tongue by the anesthesiologist, and nasal intubation was attempted by a nurse anesthetist. The patient gagged and vomited repeatedly when the tube was in the nasopharynx. SUX was given IV after cut-down gave access 3½ minutes later. SUX took 1½ minutes to circulate and produce relaxation adequate for tracheal intubation.

PT2 was unconscious and was hand ventilated through an EOA, which appeared clinically adequate. Ventilation was then delegated to an emergency medicine fellow (EMF) undergoing tracheal intubation training. SUX and 50 mg pentothal were given IV. The EMF had difficulty visualizing the cords but stated that "the EOA is in the trachea." The anesthesiologist told the EMF to "ventilate again and take it [the EOA] out and change to an ET tube." Cricoid pressure was applied, the EOA was removed, and the trachea was intubated by the EMF with some difficulty. The patient was ventilated by Ambu bag, and right endobronchial intubation was discovered and corrected. The ventilator was connected but had been accidentally switched to pressure support mode and therefore initially failed to ventilate the patient.

Discussion. PT1. Intramuscular SUX is a reasonable IV alternative that did not act in this case because of poor perfusion. There was a failure to use available $ETCO_2$ monitoring. The decision to abandon face mask ventilation was erroneous. That error was compounded by the attempt at nasotracheal intubation, which precipitated a dangerous regurgitation of stomach contents with no airway access. PT2. The anesthesiologists were not completely familiar with the EOA. In retrospect, blood gases show that the EMF incorrectly diagnosed the position of the EOA in the trachea. This error precipitated the risky maneuver of removing the EOA before the ET tube was in place. This decision could have caused aspiration of gastric contents. The anesthesiologist was anxious about the EMF's skill and could have personally checked placement of the EOA before deciding to remove it. Endobronchial intubation distracted him from determining the cause of the ventilator failure.

Conclusion. The algorithm for airway management was modified, when there is no IV access and clenched jaws occur with low perfusion, to provide mask ventilation and then cricothyroidotomy or mask ventilation until IV access is secured. These two cases illustrate that protocols for emergency intubation should include $ETCO_2$ monitoring. The two videotapes identify hazards to the patient including (1) inexperienced airway management, (2) information uncertainty leading to inappropriate decisions, (3) unfamiliarity with equipment (EOA), (4) judgment impaired by stress, and (5) failure to use available $ETCO_2$ monitors that could have prevented unwarranted actions that put the patients at risk.

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PERFORMANCE OF TRAUMA ANESTHESIOLOGISTS ASSESSED BY A SYNTHETIC WORK ENVIRONMENT

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Summary. **We investigated the effect of fatigue on performance in 5 trauma anesthesiologists using a multitasking synthetic work environment model (Synwork). We found no significant change in performance of Synwork in three assessments made during a 12-hour shift or during day vs night shifts. We conclude that day or night shiftwork and a 12-hour shift do not result in a decrement in performance of four simultaneous tasks that are similar to those carried out during administration of anesthesia.**

Introduction. Clinical anesthesia can involve prolonged periods of routine monitoring interspersed with intense and critical activity. With the increased use of complex equipment to monitor patient vital signs and the function of anesthetic machines, the anesthesiologist must be able to recognize, interpret, and respond to a wide variety of visual and auditory stimuli. Prolonged periods with minimal sleep or rest may be detrimental to patients if performance is adversely affected.

Synwork was used to assess the ability of anesthesiologists to carry out four simultaneous tasks over a 5-minute period. The tasks tested are similar to those performed in clinical anesthesia and include monitoring of visual and auditory signals, setting alarms, mental arithmetic, and short-term memory storage and retrieval. We used Synwork to determine whether there was a decrement in performance of these tasks over a 12-hour period and compared night with day shifts.

Methods. Each anesthesiologist achieved asymptotic performance on Synwork during ten practice sessions (Fig 1). Synwork was then performed at the start, middle (7–8 hours after start), and end of a 12-hour shift, both during the day (7 AM to 7 PM) and at night (7 PM to 7 AM). Testing was performed randomly over a 3-week on-call period for up to three day and night shifts per subject with a minimum of 12 hours rest between each shift. Results were compared by using paired t tests ($p < 0.05$ was significant).

Results. There were no differences between total scores on Synwork at the start, middle, or end of a 12-hour day or night

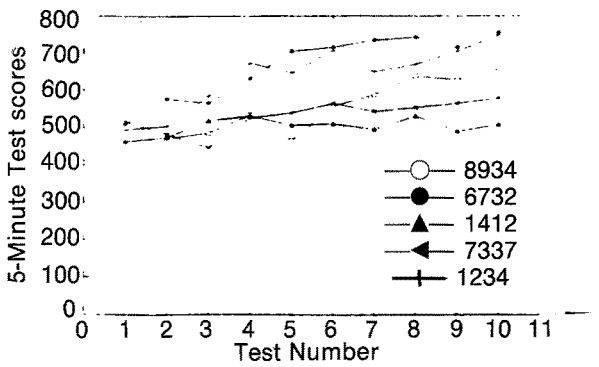

Fig 1. Practice scores of the five subjects studied showing asymptotic performance after six to eight attempts.

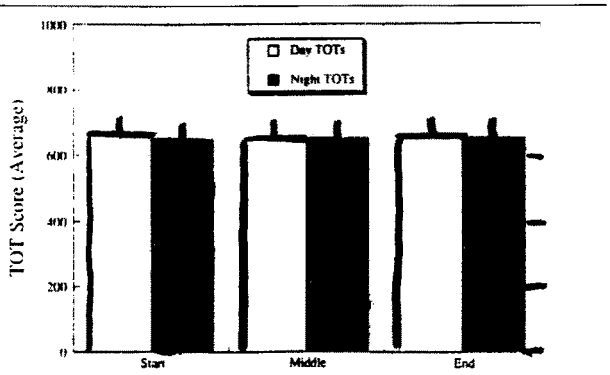

Fig 2. Mean and standard errors of total (TOT) Synwork scores for day and night.

shift (Fig 2). There was also no difference between night and day scores. In addition, we examined the four individual components of Synwork (memory, math, visual, auditory) and found no difference between night and day performance of the four components or in performance of these four tasks within the 12-hour shift.

Discussion. Synwork has been used to assess the performance of combat pilots and the effects of sleep deprivation [1]. The similarity of the multitasking software to the tasks of anesthesiologists makes it a potentially useful means of assessing clinical performance. During 12-hour shifts, we were unable to detect any decrements in performance of Synwork either in total scores or in any of the individual components.

REFERENCE

1. Elsmore TF. A synthetic work environment for PC-compatible microcomputers. Proc 1991 Med Def Biosc Rev 351–354

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EFFICIENCY AND PATIENT CARE: HOW SYSTEMS TRAINING CAN HELP

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Summary. **Efficiency and high-quality patient care are two widely acknowledged goals of the health care delivery system. Clinicians' options vary as to whether both goals can be accomplished simultaneously. Education's role in improving the efficiency of the health service delivery system is less well defined.**

Introduction. During the last 10 to 15 years, the health care system has witnessed an unprecedented increase in the number of medical devices used in the patient care environment. Moreover, recent studies have verified the value of computerized information systems, which are moving medical centers toward increased use of technology in the clinical environment.

Advances in medical technology systems are generally viewed as improvements in efficiency once the new users get past the initial introductory period. Some practitioners may view improvements in efficiency as barriers to patient care. However they are viewed, the introduction of new technology into the health care environment is rarely value-free. Resistance in some form and to some degree is the norm.

Methods. A phased systems approach to user orientation and education can ease the transition to the user's environment and increase the likelihood that the technology will improve both patient care and efficiency. The ARKIVE Patient Information Management System (Diatek Patient Management Systems, Inc, San Diego, CA) is an example of a technology that has significant potential to achieve both goals. Advanced product design, supported by a comprehensive education and training program to ease its introduction to hospital sites, is central to achieving these twin goals.

A series of post-sale orientation and planning strategies is implemented in advance of the actual on-site user training. These include assessment of site-specific training needs, design and implementation of a department-wide communication plan, selection and training of a "first wave" preceptor/facilitator team, strategically timed product installation, and the ongoing involvement of the user in product refinements and design evolution. User training—the 3- to 4-week time period during which most of the users are actually trained—is actually the fourth of five phases in the ARKIVE System implementation plan.

The training program developed by Diatek to introduce the ARKIVE System anticipates the operating room environment, in which clinicians are occupied with multiple tasks simultaneously, and have little time to learn and practice new technologies. Five training phases are used in the ARKIVE System training program:

1. *Preceptor training* consists of a team of users who are oriented and trained off-site.
2. *A communication plan* is tailored to each individual site.
3. *System installation is timed* to take advantage of the preceptors' return to their department after training and to avoid having equipment in place too far in advance of the full departmental training.
4. *User training* is supported with a program that meets the needs of each individual user.
5. *An ARKIVE Continuous Improvement Team* (ACIT) is selected and developed.

Discussion. A systems training approach requires that *inputs* from multiple sources be considered in advance of the training. *Outputs* from the ARKIVE System training system are planned, specified, and communicated as performance standards for personnel at all levels in the training process.

Overall outcomes for the ARKIVE System on-site training phase include standards that reflect high-quality criteria for accuracy, timeliness, and quantity. Similar standards have been developed for all five phases of the ARKIVE System implementation process. Standards are used because a systems approach to user education has little value unless the results can be measured. Although Diatek is still in the early stages of measurement design, the effort will produce major benefits in both the quality of patient care and the efficiency with which the hospital can use the new technologies.

A PATIENT SIMULATOR FOR THE TRAINING OF ANESTHESIOLOGISTS

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This paper discusses a patient simulator for use in anesthesiology training that is patterned after similar devices designed and utilized at several universities, primarily the one at Stanford University designed and built by Drs David M. Gaba and John Williams. The device described in this paper is now being readied for commercial introduction. We describe its benefits, its requirements, and some of the design issues faced by engineers in its development.

An anesthesiology patient simulator has a number of benefits. The most important advantage, of course, is that there is no risk to life during training, since a live patient is not involved. A resident can work on dozens of cases before he or she must face the first live patient. Practicing anesthesiologists can undergo training in extremely rare crises and in the team management aspects of anesthesiology, as in the Anesthesiology Crisis Resource Management course pioneered by Dr David M. Gaba. Training can be done at any convenient time, such as after hours and on weekends.

To serve as an adequate training aid, a patient simulator must fulfill a number of requirements. First, for complete training it is best to use a mannikin, of which the mouth, throat, and trachea must be anatomically correct, and into which the student can place an endotracheal tube. It should be able to breathe on its own but also should be capable of being ventilated mechanically. It must generate carbon dioxide in the amounts that the patient would produce. It is also desirable for the mannikin to exhibit certain other clinical signs, such as heart sounds, breath sounds, palpable pulses, and a number of other signs.

Among the operating room instruments that must be driven by the simulation are the capnograph, pulse oximeter, electrocardiograph and heart rate display, invasive and noninvasive blood pressure monitors, and body temperature monitors.

Behind the mannikin and the instruments must lie an array of mathematical models, which should include simulations of the heart (potentially including its electrophysiology), the lungs (including their ventilation), the circulation of the blood into various tissue compartments, the uptake and distribution of anesthetics and other drugs, the anesthetic and paralytic effects of various drugs on the central nervous system (such as nitrous oxide, halothane, isoflurane, enflurane, succinylcholine, and others), and the metabolism and elimination of these drugs.

Finally, the patient simulator must include the means to initiate various medical emergencies or events (often arranged in complete scenarios) to permit the anesthesiologist directing the simulation session to modify these events to reflect certain patient peculiarities, to record the actions of the student in dealing with the emergency, and to provide aids with which the student can be debriefed. Overall, this type of training allows the student to experience not only common anesthesia problems but also rare and infrequent emergencies and to learn the appropriate corrective action that may ultimately save lives otherwise at risk.

IMPROVING THE USER INTERFACE OF AN AUTOMATED ANESTHETIC RECORDKEEPER

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Summary. **Cognitive engineering principles and rapid prototyping were used to validate improvements to the user interface of an existing device.**

Introduction. How can a medical device such as an automated anesthetic recordkeeper (AARK) be improved to reduce the number of user errors? It was hypothesized that the application of cognitive engineering principles and techniques would result in an improved user interface, reducing learning time and error rates. Cognitive engineering is the application of human factors and knowledge of usability to the design of systems.

Methods. The research was conducted primarily by 4 undergraduate college students enrolled in a cognitive engineering course. The students had had no medical training prior to familiarizing themselves with the AARK and the operating room environment. The researchers produced hypothetical records and observed actual use of the device, documenting the difficulties that were encountered. Drawings of the AARK's touch screen display were used to develop rapid prototyping of the proposed changes. People with many levels of experience with the system were used to evaluate the prototypes. Clinicians' interactions with the prototypes were videotaped and carefully observed. After each test session the clinician was interviewed, and the responses were considered for the next prototype. Five repetitions of this rapid prototyping and testing process were performed.

Results. In 1 month of part-time work, several changes to the AARK's interface were prototyped and tested. During testing, changes were either validated or removed from the prototype. A common mistake made by several users was to press inactive areas of the touch screen while entering information. To solve this problem, the prototype did not display inactive areas of the screen. This change was validated through testing because users no longer made this mistake. Similarly, a button that was not commonly used was removed from a globally available panel and placed in other areas where it was appropriate. However, users showed a preference for having it available at all times in the same location, and therefore it was returned to its original location.

Subjects who interacted with the final prototype made fewer mistakes than those who interacted with the actual

AARK or with previous prototypes. Clinicians responded favorably to the proposed changes.

Discussion. This study demonstrates that application of the cognitive engineering technique of rapid prototyping for design validation and refinement can result in an improved user interface. This technique can produce valuable results in a very short period of time.

A SURVEY OF ANESTHESIOLOGISTS' ATTITUDES TOWARD PRODUCTION PRESSURES

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Summary. **A random survey of California anesthesiologists revealed that production pressure is felt strongly by many practitioners and that these pressures have resulted in suboptimal patient care in some instances.**

Introduction. "Production pressure" encompasses the economic and social pressures placed on workers to regard *production,* not safety, as their primary priority. Production pressure is thought to play a major role in many accidents in aviation, shipping, long-haul trucking, and the nuclear power industry. This survey was designed to reveal how anesthesiologists' practices are affected by production pressure. Production pressures may be internal (those put upon the anesthesiologist himself or herself) or external (those put upon the anesthesiologist by surgeons, colleagues, consultants, patients, families, or administrators).

Methods. After approval of the use of human subjects, 647 surveys were mailed to 20% of California anesthesiologists chosen at random from the 1992 American Society of Anesthesiologists membership list. Subjects received a packet containing an 8-page questionnaire, two consent forms, and two self-addressed stamped envelopes for return of the completed survey and a signed consent form. By providing separate envelopes for the survey and the consent form, the response to the survey remained anonymous.

Results. Of the 647 surveys that were mailed, 11 were returned as undeliverable, giving a final number of 636 deliverable surveys. We received 195 completed surveys plus an additional 19 from respondents who could not participate because they were retired from practice. This gives a final response rate of 33.6%. Seventy-nine percent of respondents were Board certified, and the average age of respondents was 45 ± 11 years. Respondents answered questions concerning sources of production pressure on a scale of 1 (no pressure) to 5 (intense pressure). *Internal pressures* were stronger than external pressures. Pressure was rated as 4 or 5 for these internal pressures; avoid litigation (48%); avoid delaying surgery (45%); "get along" with surgeons (36%); work when fatigued (21%); maximize cases done (17%); avoid appearing overly concerned about complicated cases (14%). *External pressures* rated as 4 or 5 included (1) surgeons' pressure to not cancel a case (32%), hasten anesthetic preparation or induction (14%), alter monitoring or anesthetic technique (11%); and (2) colleagues' pressure to not cancel a case (14%), hasten anesthetic preparation or induction (4%), alter monitoring or anesthetic technique (2%).

During the past 3 years, respondents had witnessed patients anesthetized for elective or nonemergent surgery in the following suboptimal conditions: insufficient medical or surgical evaluation (58%); significant contraindications to surgery/anesthesia (31%); inadequate monitoring or access (25%); another anesthetist called to do a case that had been refused by a colleague for safety reasons (31%). Production pressure occasionally resulted in intraoperative management problems, such as failure to call for help in a major crisis to avoid "looking bad" (16%); nonemergent cases not aborted after a catastrophe such as cardiac arrest (15%).

Subjects were also asked to rate the following suggested improvements in anesthesia patient safety on a scale of 1 (worsen safety) to 5 (major safety improvement). Some improvements were rated as 4 or 5 by a high proportion of respondents: More thorough understanding of anesthesiology by surgeons (71%), earlier anesthesia work-up of medically complex cases (68%); technicians available to assist in preparing for cases (66%); written guidelines between anesthesiologists, surgeons, and internists concerning appropriate work-up of patients with various medical conditions (63%); written guidelines for resolving disputes concerning the risks and benefits of the proposed surgery (38%).

Discussion. Although there is some risk of selection bias of the respondents to this survey, it is clear that many anesthesiologists feel that internal and external production pressures are a real part of their current practice. Although the degree to which these pressures affect patient outcome is uncertain, the experience of other industries suggests that it could be substantial. This study takes an important first step in confronting the production pressure problem by bringing it into the open. Identifying effective and economically feasible countermeasures will not be easy.

ELECTRONIC DATA ARCHIVING FOR CLINICAL RESEARCH IN THE OPERATING ROOM

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Summary. **Our laboratory is presently developing an electronic data logger as a useful tool in conducting clinical drug research studies. Data are automatically logged from multiple monitors into a computer data file as a means of alleviating the researcher's workload intraoperatively and facilitating data transcription to the study report forms. The first system version was not without failures, but future modifications and enhancements will result in a very powerful tool for the clinical environment.**

Introduction. Clinical drug testing for FDA approval can be a test of the organizational skills and patience of researchers. The traditional data collection method of handwriting vital signs, other physiologic variables, clinically relevant events, and associated times of occurrence may lead to inadvertent delays in data logging, oversights of clinical events, data filtering, and other researcher-influenced anomalies. Our laboratory is developing a Macintosh-based data acquisition system for use with clinical drug research in the operating room (OR). The system will automatically log data from multiple monitors at specified intervals, enter event markers by the user, and calculate clinical parameters of interest concurrently. It can also be enhanced to centralize and trend the display of the acquired data, alert the user to any collection-related

problems, and incorporate mouse/keyboard control of host-driven monitors. The objective of this work is to determine the efficacy of automated data collection and its compliance with existing processes of clinical drug studies.

Methods. National Instrument's LabView II was used to implement the acquisition system and user interface. LabView II is programmed, uniquely, with icons or virtual instruments. It also offers a designable end-user interface that can simulate any monitor or instrument front panel.

A Macintosh IIci computer with eight megabytes of RAM and a color monitor was used. A GreenSpring 1280 expansion board was installed to add four serial ports and increase the number of physiologic monitor connections. The acquisition of data occurs through serial communications with the monitors.

Data were collected in the OR for patients undergoing general anesthesia who agreed to the research protocol. A research nurse marked clinical events with a mouse, and the system time-stamped a corresponding event number into the data file. The description of the event was documented on a paper worksheet. The electronic data, consolidated with the event-worksheet information, was later transcribed to the drug study case report forms.

Results. Among the plethora of OR monitors, the system acquired data from three specific ones: the Critikon Dinamap 1846SX for blood pressure values; the Ohmeda 5250 RGM for ventilation values, oxygen saturation, and pulse rate; and the Datex 254 gas monitor for respiratory gas values. The drug company required data with a 1-minute resolution; the system, however, acquired data every 20 ± 10 seconds.

The front panel of the program was considered "user friendly" by the research nurse. It included a begin and halt acquisition button, displays of all acquired data and time of acquisition, an event button and number display, text entry to input patient information, and control buttons for the Dinamap monitor. These control buttons allowed the user to start or cancel a blood pressure assessment and to change the Dinamap monitor to Auto, Manual, or Stat mode through the computer screen.

Data for a total of 30 patients were collected over a 3-month period. Of the 30 cases, 3 patient files were corrupted, never logged, or never activated. The other 27 data files were used in the drug study case report forms.

Discussion. The 10% failure rate suggests a definite need for improvement but does not invalidate this system as a method of data collection in a clinical drug study. The failed cases were attributable to development software versions. Another problem included the superfluous volume of data that were not required by the drug company because data were collected in minute fractions. Nevertheless, the successfully collected data files create an interesting and useful database because of the number of variables, the frequency of data acquisition, the logging of clinical events, and the overall potential for analysis. The data and calculations from these files were readily transcribed to the drug study case forms.

The laboratory is continuing the system's development for future drug studies. It will be modified to:

1. Display variable trends, i.e., the anesthesiologist will know what the blood pressures were during the hectic intubation 5 minutes ago.
2. Generate alerts in response to either physiologic changes beyond protocol limits or monitor/signal faults, e.g., the absence of ventilation values over a certain period of time would trigger an alert.
3. Automatically control noninvasive blood pressure cycling intervals according to protocol or phase of anesthesia, e.g., the system will start a BP assessment in response to a change in inspired agent tension.
4. Estimate or calculate clinically relevant parameters in real time, e.g., MAC·hour, average minute volume, etc.
5. Include more monitor models.
6. Archive data on hard copy and automate recordkeeping specific to the drug study report forms.

FAILURE OF AN AUTOMATED NONINVASIVE BLOOD PRESSURE DEVICE: THE CONTRIBUTION OF HUMAN ERROR AND SOFTWARE DESIGN FLAW

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Summary. **The following case report describes how the software design flaw of an automated noninvasive blood pressure device and human user error combined to create a near catastrophe.**

Case Report. A 38-year-old male was undergoing a lumbar laminectomy in the prone position. He suffered from chronic low back pain but was otherwise healthy. History, physical examination, and laboratory examination were unremarkable. Anesthetic induction was accomplished with sodium thiopental 250 mg and meperidine 100 mg. Intubation was facilitated with 100 mg of succinylcholine. Maintenance of anesthesia consisted of nitrous oxide (65%) and isoflurane (0.3–1.2%).

Routine monitors were in place for this case, which proceeded uneventfully for the first hour. While dissecting into the epidural space, the surgeon commented on the large size of the epidural veins and requested that the anesthesiologist decrease the blood pressure in an attempt to minimize the blood loss. To monitor blood pressure more frequently, the resident anesthesiologist decreased the cycling interval on the noninvasive blood pressure (NIBP) device from 5 minutes to every 2.5 minutes but did not push the start button to reactivate the automatic cycling function. With this type of automatic blood pressure device the start function has to be activated after any change in cycling interval.

The resident and attending anesthesiologist then became involved in the task of mixing a nitroglycerine infusion to comply with the surgeon's request to lower the blood pressure intentionally. The anesthesia team had problems with the infusion device because the cartridge did not fit into place properly. Concurrently, the attending anesthesiologist noticed that the bellows on the anesthesia machine were not completely refilling despite fresh gas flows of 3 L/minute. A quick check of the anesthesia machine revealed no major leak of the circuit. An anesthesia technician was called to assist and changed the bellows, but the problem did not resolve. However, maintenance of fresh gas flow greater than 4 L/minute allowed adequate oxygenation and ventilation of the patient.

While the anesthesiologists were preoccupied with these tasks, the surgeon asked the circulating nurse to set up a second suction device because the bleeding was difficult to control and was causing the surgical site to fill with blood. This statement by the surgeon cued the attending anesthesiologist to check the blood pressure, which had last been measured 40 minutes before!

The attending anesthesiologist triggered a new cycle on the

blood pressure device, turned the anesthetic off, and administered 100% oxygen to the patient. The first blood pressure measured after being retriggered was 60/40. Help was called for to aid the anesthesia team administer fluids and vasopressors, place additional intravenous lines, and place an intra-arterial line for continuous blood pressure measurement. The patient's blood pressure responded quickly to these maneuvers, which allowed the surgeons to complete the planned procedure.

During resuscitation the patient received 4,000 ml of crystalloid, 500 ml of hetastarch, and 4 units of red blood cells. The estimated blood loss was 2,000 ml for the procedure. After the surgery was completed, the patient was turned to the supine position and extubated in the operating room. He was discharged 8 days later and made an uneventful recovery.

Discussion. This case illustrates many interesting problems that exist between human operators and the machines they use. There were three separate equipment problems during this case: the NIBP device, the mechanical infusion device, and the ventilator on the anesthesia machine. Although sophisticated in design and approved by the regulatory agencies, the software design of the NIBP device is faulty from a user standpoint because the machine stays in a "standby" mode until it is activated after the cycling interval is changed. If the user becomes preoccupied with other important tasks, the patient's blood pressure may not be monitored for extended periods of time. In the case presented, the other machine faults were also important and diverted the anesthesiologist's attention from the noncycling NIBP device. Once the problem was recognized, the anesthesia team called for help immediately. This allowed them to receive help in line placement, fluid and drug administration, and a second opinion about the care of the patient.

These NIBP devices have been taken out of service and replaced with monitors that do not have this problematic feature. The Food and Drug Administration was notified about the problem we had encountered with the machine under the Safe Devices Act. The company that manufactures this device has been contacted, and the problem was related to them. We suggested that the software of this device be altered, but at this time there is no plan to do so.

DESIGN OF A PEN-BASED ANESTHESIA RECORD

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Anesthesiologists working in today's modern operating rooms (ORs) are required to recognize, interpret, synthesize, and react to increasing amounts of complex, concurrent data. Data types include patient history and demographics, time-based physiologic measurements, drug and fluid administrations, and key clinical events. Data sources include preoperative medical records, automated physiologic signal processors, and physician observations. The anesthesia record (AR) is the primary resource for data capture, abstraction, and analysis. Ideally, anesthesiologists use the AR to aid in detection of clinically relevant trends. Unfortunately, the combination of data volume and inflexibility of the fixed-format AR results in a medical record that does not optimally link data collection and representation requirements with human pattern-recognition skills. In particular, the AR does not facilitate problem solving in an environment where the time scales of physiologic trends are unpredictable and are heavily context dependent and where the elucidation and solution of problems often involve a considerable amount of data manipulation.

In addition to its use intraoperatively by anesthesiologists, the AR is used postoperatively by other personnel, each with their own needs for specific AR data types and abstractions. Nurses and other physicians rely on the AR to provide a concise summary of relevant intraoperative events. Both academics and private practitioners review ARs retrospectively for teaching, clinical research, and self-monitoring. Scheduling, resource utilization, and billing operations are routinely based on data gathered from analytical review of ARs.

It is clear that both intraoperative and postoperative use of the AR could be enhanced by a more flexible and legible electronic AR. However, attempts to design an automated AR have been largely unsuccessful, primarily because such systems do not intuitively integrate automatic and human data collection and abstraction. For the past 6 months, we have been working on the design of a pen-based anesthesia record (PBAR) that would allow anesthesiologists to annotate, browse, and temporally abstract all available intraoperative data. Because the completed PBAR would be stored in electronic form, it would also provide the data summaries and abstractions required by other AR users.

In the course of our project, we encountered several development issues that are discussed in this paper. These issues include (1) selection of a pen-based development environment; (2) use of the pen (pointing, gesturing, or handwriting); (3) graphic display (data visualization) requirements; (4) various hardware issues including speed and battery life; (5) connectivity issues; (6) data base issues; (7) integration with existing HIS data; and (8) the need for and utility of voice recognition.

ISSUES IN DISPLAYING PATIENT-CONTROLLED ANALGESIA DEMAND DATA

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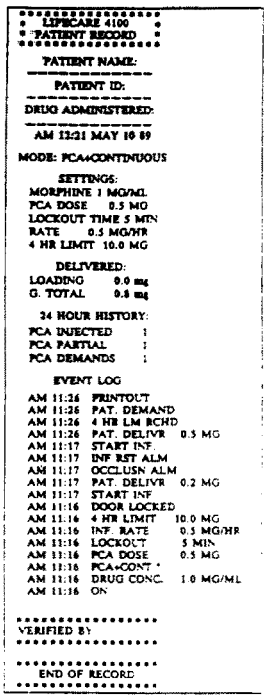
***Summary.* Following an analysis of the user interface of a patient-controlled analgesia machine, a project was carried out to exploit graphic means for improving the efficacy of displaying data about how patients demand and successfully receive pain relief from the machine.**

Introduction. Although patient-controlled analgesia (PCA) has since its introduction proved to be extremely effective in alleviating postoperative pain, it is our contention that the maximal effectiveness of this technology has not yet fully been realized. We recognize that much attention has been paid to maximizing the reliability and safety aspects of most machines; however, from an ergonomic perspective, significant improvements remain to be made from the point of view of both the patient and the medical personnel who must learn to program and operate the machines. In particular, current procedures typically do not exploit all available data about how patients actually use the machines, a source that encompasses potentially valuable information about the effectiveness of current treatment. For example, the suitability of a particular PCA regimen for a particular patient could conceivably be



LIFECARE 4100
PATIENT RECORD

PATIENT NAME:

PATIENT ID:

DRUG ADMINISTERED:

AM 12:21 MAY 10 89

MODE: PCA+CONTINUOUS

SETTINGS:
MORPHINE 1 MG/ML
PCA DOSE 0.5 MG
LOCKOUT TIME 5 MIN
RATE 0.5 MG/HR
4 HR LIMIT 10.0 MG

DELIVERED:
LOADING 0.0 mg
G. TOTAL 0.8 mg

24 HOUR HISTORY:
PCA INJECTED 1
PCA PARTIAL 1
PCA DEMANDS 1

EVENT LOG

AM 11:26	PRINTOUT	
AM 11:26	PAT. DEMAND	
AM 11:26	4 HR LM RCHD	
AM 11:26	PAT. DELIVR	0.5 MG
AM 11:17	START INF.	
AM 11:17	INF RST ALM	
AM 11:17	OCCLUSN ALM	
AM 11:17	PAT. DELIVR	0.2 MG
AM 11:17	START INF.	
AM 11:16	DOOR LOCKED	
AM 11:16	4 HR LIMIT	10.0 MG
AM 11:16	INF. RATE	0.5 MG/HR
AM 11:16	LOCKOUT	5 MIN
AM 11:16	PCA DOSE	0.5 MG
AM 11:16	PCA+CONT.	
AM 11:16	DRUG CONC.	1.0 MG/ML
AM 11:16	ON	

VERIFIED BY:

END OF RECORD

Fig 1. Sample PCA "ticker-tape" output.

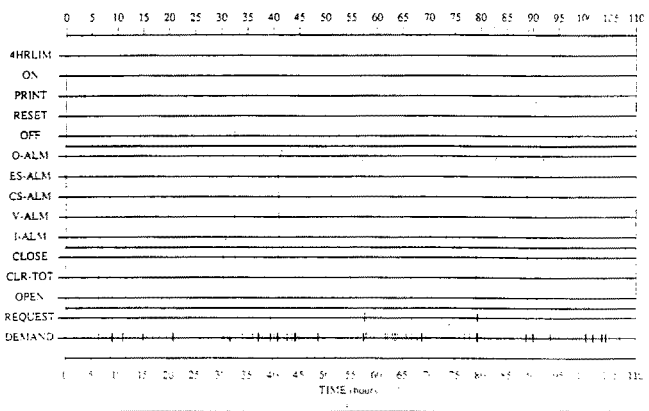


Fig 2. Sample event frequency diagram.

evaluated efficiently were data readily available about PCA programming parameters and the time of each delivered dose. Such data would enable the clinician to review and modify PCA parameters effectively if necessary. Typical current means of presenting such data are illustrated in the "ticker-tape" output shown in Figure 1.

Methods/Results. Printouts of PCA event timing data from a commercial PCA machine were obtained for 5 postoperative patients using PCA. These data were transformed for subsequent analysis on a graphics workstation. A variety of display options were evaluated, including analgesic demand histograms and event frequency diagrams. The latter, an example of which is given in Figure 2, were deemed to provide information about principal events of interest most effectively. In comparing this format to the event printouts shown in Figure 1, it is clear that the graphic display provides the clinician with a means of quickly integrating the data given and forming a global impression of the patient's behavior, that is, how frequently he or she has demanded pain relief, how often this was granted, how frequently demands have been refused, at what time of day principal events have occurred, and so on.

PROBLEM SOLVING IN ANESTHESIA: WHAT ARE THE REAL PROBLEMS BEING SOLVED?

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***Summary.* Apart from the obvious issue of how to respond to crisis situations, other kinds of problems are of equal importance to anesthesiologists. In a series of field studies we have explored two such categories of problems: noncritical but persisting problems, and problems associated with proactive strategies.**

Introduction. Without an understanding of the problems that anesthesiologists actually face while managing cases and how they solve those problems, one can hardly expect that equipment interfaces offering decision support can be designed properly. Traditional psychological laboratory studies do not typically shed much light on such issues; however, recent field studies in other complex domains (e.g., firefighting and air traffic control) have provided a good basis for understanding analogous problem-solving situations. For example, it has been recognized that, when time pressure is high in such domains, problem solving is rarely analytical but "*recognitional,*" whereby the current situation is matched to a prototypical situation, either trained for or personally experienced earlier. Despite progress in other domains, understanding problem solving in anesthesia nevertheless continues to elude us; we simply do not know enough about the range of problems that are regularly solved by anesthesiologists.

Method. Our study of problem solving in anesthesia has focused on an examination of performance demands, that is, the types of problems facing anesthesiologists. By collecting behavioral and protocol data from training rounds and actual cases, we have so far been able to identify a number of important features of the problems that anesthesiologists typically try to solve. Our findings are summarized here relative to two factors: *situation-related* factors and *strategy-related* factors. It is clear, however, that both the actual situations and the strategies adopted change the nature of the associated problems as well as the process of problem solving.

Situation-related factors—"going-sour" incidents. How an incident evolves obviously dictates the kinds of problem that face the anesthesiologist. Due to the complexity of anesthesia management, problem-solving situations can arise in different forms. Whereas some incidents start abruptly and immediately cause the patient's status to become critical, in the majority of cases the problems to be solved are noncritical. Some problems surface gradually, defy quick solution, and typically involve several underlying interrelated forces. These so-called *going-sour incidents* usually do not justify emergency procedures. Our findings on this class of incidents indicate that (1)

problem solving spans a long period of time; (2) multiple hypotheses have to be maintained continually; (3) multiple interventions are often required before a definite diagnosis can be made; (4) trouble spots have to be checked repeatedly; (5) integrated solutions are required; and (6) active recognition of induced problems is essential.

Strategy-related factors—proactive approach. Although it is important for anesthesiologists to know what to do in a crisis situation, extracting themselves from crises is not what most anesthesiologists want to experience. In an effort to avoid troublesome situations, anesthesiologists therefore typically were found to adopt a *proactive approach.* The problem of how to respond to troublesome situations then becomes one of how to anticipate and prepare, that is, how to (1) plan for contingencies and "bail-out" procedures, (2) rehearse relevant emergency protocols, (3) think through difficult maneuvers, (4) plot general strategies and target physiologic status, (5) prepare necessary materials and access needs, and (6) schedule tasks to balance the workload during busy times. In other words, problem solving in this domain is not strictly an event-driven process but involves much anticipation and preparation. Training in anesthesiology does in fact place great weight on anticipatory abilities. Failure to anticipate major untoward scenarios would certainly be considered a performance failure, although on the basis of overt behavior and ultimate performance, the importance of anticipatory processes may not always be apparent.

Discussion. With advances in computing technology, more and more cognitive aids relating to the practice of anesthesia will inevitably appear. Exploring the range of problems that must be solved will give us a better basis for the effective training and design of these technologies. From a task point of view, decision support should be provided in addition to aids for emergency responses to cover situations where multiple concerns are present. From a subjective point of view, on the other hand, the active role of the anesthesiologist in prevention and preparation should also be supported.

COMPUTER-AIDED PATIENT CARE SYSTEM

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***Summary.* We have developed a computer-aided patient (CAP) care system to aid in caring for post-open-heart surgery patients. It supports the monitoring and care of patients. This system is applicable to clinical care by physicians and nurses.**

Introduction. The regulation of water balance between total fluid infusion volume and urinary volume is an important factor in stabilizing the patient's condition after open heart surgery. Generally, a nurse manually adjusts fluid and diuretic infusion rates every hour as recommended by the physician. However, it is difficult to make a manual adjustment following a rapid increase in urine volume, for example, when a diuretic is injected.

The CAP care system supports patient care following open heart surgery in the intensive care unit (ICU). The purpose of the system is to develop the water balance control function for patients in the ICU according to the FUZZY reasoning approach.

Methods. The system consists of a bedside monitor, 10 infusion pumps, urine monitor, computer for water balance control, and bedside workstation. The system has the following characteristics:

1. The system gathers data from the bedside monitor, urine monitor, and infusion pumps continuously in real time.
2. Patient data are displayed in a form that allows the patient's condition to be easily evaluated on the CRT display of the bedside workstation.
3. Patient water balance is automatically maintained by injection of fluid and diuretic according to the physician's instructions.

The water balance controller has the following characteristics:

1. The fluid infusion rate is calculated minute by minute based on the patient's total water balance and urinary volume during the past 5 minutes in the fuzzy controller.
2. When urinary volume is too small, diuretic is injected automatically. The diuretic infusion rate is calculated minute by minute based on the patient's urinary volume for the past 60 and 10 minutes, respectively, in the fuzzy controller. These control rules, which imitate the regulation method used by physicians, are built into the fuzzy controller.
3. For a special fail-safe function, when the right atrial pressure is out of the physician's instruction range, diuretic injection is discontinued automatically and an alarm goes off.

Results and Discussion. The CAP care stystem with water balance control function was developed and applied in 13 open heart surgery patients. It was demonstrated that the system could maintain the patient water balance according to the physician's instruction. More effective care with less nursing labor is achieved.

AN APPLE MACINTOSH CLIENT FOR THE HEWLETT-PACKARD COMPONENT MONITORING SYSTEM

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***Summary.* Apple Macintosh client software provides access to the Hewlett-Packard Component Monitoring System to capture patient information for analysis and archival storage.**

Introduction. The Hewlett-Packard Component Monitoring System (CMS) is popular in operating suites and intensive care units. The CMS can manage all common types of patient sensors and reports measurements on a central display. The CMS supports sensor devices from several manufacturers. Hewlett-Packard recently added the capability for other computers to access CMS information. This access is achieved through the Hewlett-Packard Medical Computer Interface (MCIF) protocol.

Methods. The MCIF protocol is client-server based. The

CMS is an information server. A single CMS can support connections with several serial devices and several software clients on each serial device. The MCIF uses a variant of the RS-232 protocol with mandatory hardware handshaking. MCIF clients send messages to the server requesting patient information. The server responds with messages containing the requested information. A client may request CMS configuration information such as the number of sensors in use, parsed numbers such as heart rate, or sampled waveforms such as the electrocardiogram. Messages consist of binary data with a synchronization byte followed by a header (containing the message type, source, destination, and message length) and any message-specific data.

The Macintosh computer operating system includes a device driver to manage serial communications. This driver configures the Macintosh hardware and manages interrupts and buffers for the serial data. The Macintosh operating system interface is defined with Pascal data structures and procedure calls.

The Macintosh client software is a stand-alone application program written in Pascal with the THINK Pascal development system designed by Symantec Corporation. The program is organized in three layers. A low level layer makes device driver calls to send and receive messages. A middle layer composes outgoing messages, decodes incoming messages, checks for errors, and dispatches messages to the high level layer. The high level layer consists of procedures that record, analyze, and display the patient information.

Results. The Macintosh client software includes a high level procedure that can store CMS parsed numbers in a text file for archival storage. Other programs use this information for statistical analysis. Other high level procedures that store or display waveforms may be added. Additional high level procedures do not require modification of low or middle level layers. Many high level procedures may be used simultaneously.

Discussion. Patient monitoring information is valuable for a variety of projects including automated anesthesia records, statistics for research and quality assurance, real-time waveform analysis, alternative human interface elements, closed-loop drug administration, and improved alarms. Macintosh client software for the Hewlett-Packard CMS makes patient information available for these projects.

A TECHNOLOGY EDUCATION PROGRAM FOR ANESTHETISTS

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**Emory University School of Medicine, Atlanta, Georgia; †Brigham and Women's Hospital, Harvard University, Boston, Massachusetts; ‡Baylor University Medical Center, Dallas, Texas*

Since 1969, we have had a two-year program that awards a Master of Medical Science degree in anesthesiology and patient monitoring systems. The program is administered by the Anesthesiology Department, and the degree is awarded by the School of Medicine. The curriculum has placed strong emphasis on the technology of anesthesia delivery systems and monitoring systems (monitoring of both the delivery system and the patient). The course levels are based on premed admission requirements (i.e., college biology, math, chemistry through introductory organic chemistry, and physics through electricity and magnetism). Graduates function as anesthetists working under the direction of anesthesiologists and are certified at the state level as anesthesiologists' assistants (AAs, i.e., specialist physician assistants, analogous to surgeons' assistants and primary care PAs). The anesthesiology technology education curriculum is divided into three parts: (1) basic science (classroom and lab); (2) clinical support technology (working with and functioning as anesthesia technologists); and (3) applied clinical monitoring (which is done while the AA functions as an anesthetist's trainee).

The *basic science curriculum* consists of courses taught during the first year: (1) biophysics; (2) delivery system equipment; (3) blood gas analysis; (4) electronics; (5) ventilators; (6) patient monitoring techniques; (7) delivery system and patient monitors; (8) animal laboratory.

The *clinical support technology* sequence consists of rotations with Anesthesiology Technology Support Services (as students during the first and second years) and as part-time employees during the second year.

Applied clinical monitoring material is taught as an integral part of "bedside" anesthetist education.

We will present information on the evolution and current status of (1) course objectives and outlines; (2) texts and teaching aids; (3) examination methods; and (4) the role of education in technology in the contribution made by AAs to patient care, resident education, and research.

ERRATUM

In the article "Anesthesia systems. Part II: Operating principles of fundamental components" (J Clin Monit 1993;9:104–111), there were errors in the first paragraph of the second column on page 105. The first five lines in that paragraph should read: ". . . and moves upward. This action allows less fresh gas to travel through the bypass, thus increasing the amount of fresh gas that combines with the anesthetic agent. With more fresh gas available for the evaporation process, the final concentration continues to rise until . . ."