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TITLE: A SAFETY-ENGINEERED COMPUTERIZED ISOFLURANE DELIVERY AND VENTILATION CONTROL SYSTEM

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Introduction: A computer-controlled system was developed for the control of ventilation and delivery of Isoflurane utilizing a closed anesthesia circuit. Feasibility of feedback control of anesthesia has been previously demonstrated.(1) This was a totally new system, incorporating a digital computer for real-time data display and anesthesia recordkeeping, automated control of ventilation, and extensive safety circuitry. Under computer control, circuit volume, FiO2, PaCO2, and end-tidal anesthesia concentration were maintained at specified levels. Using a new coupled-control feedback algorithm, the system provided faster induction and more accurate maintenance than had previously been possible.

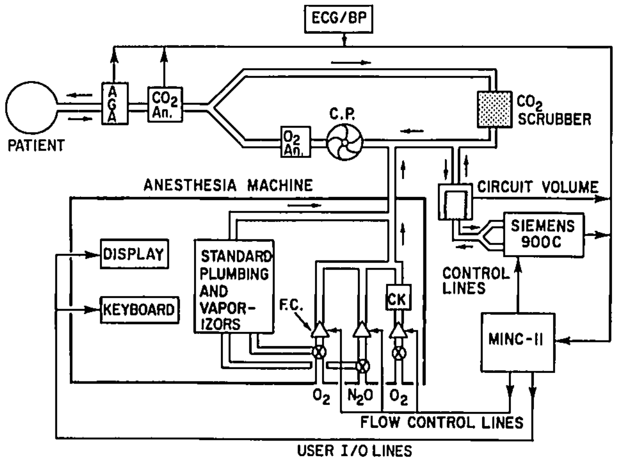
Methods: The system consisted of a microcomputer (DEC MINC-11/23) interfaced to a Siemens 900C ventilator and to three Tylan precision mass flow controllers for delivery of oxygen, nitrous oxide, and anesthetic. Gas concentrations were determined with a Siemens 930 CO2 analyzer, O2 analyzer, and a prototype Siemens 120 IR anesthetic gas analyzer. Circuit volume was determined by means of a Linear Variable Differential Transformer (LVDT) which measured the vertical displacement of the Ohio 7000 bellows. The entire system was designed around a standard anesthesia machine, with automated gas delivery lines placed in parallel with existing manual gas controls. A Revell circulating pump was used to minimize circuit equilibration time.

Ventilation and gas delivery were controlled through a series of non-linear coupled PID (Proportional, Integral, and Differential) feedback loops. The computer maintained PaCO2 by varying the respiration rate while keeping tidal volume constant. Arterial CO2 concentration was estimated using end-tidal CO2, corrected for physiologic dead space by the computer from periodic blood gases. FiO2 was controlled by the flow of O2 into the circuit, while circuit volume was maintained by varying the flow of both O2 and N2O. Finally, the end-tidal concentration of the anesthetic agent was established by controlling the flow of O2 through the vaporizer.

Tests of the system were conducted in the laboratory to determine the response time of the circuit. The system was then studied on five 20-25 kg dogs. In this study end-tidal anesthetic concentration was varied between 0 and 2%, with 15 minute equilibration times between steps. The system was then washed out to an end-tidal concentration of less than 0.1 percent and allowed to equilibrate for 1 hour. During this time the FiO2 was varied between 40 and 60 percent to test response of the system to step changes. Desired PaCO2 was also varied between 30 and 40 torr. Tests were also conducted to determine the system's response to external interference, such as Bovie noise and power failures.

Results: The response time of the anesthesia circuit for a step from 0 to 2% isoflourane was 1.5 minutes with less than 0.2% overshoot. In the dog the average response for a 2% anesthetic change was under 3 min. Once established, Isoflurane concentration was maintained within 0.1%. FiO2 was held within 1% while PaCO2 was maintained within 2 mm Hg. Response to a 10% step change in FiO2, from 40 to 50%, was accomplished in 4 min. Reducing the PaCO2 from 40 to 30 torr required less than 3.5 min. The new control algorithm also eliminated the oscillatory nature of gas delivery that had been prevalent in previous systems. The system remained stable and operational during Bovie application. Interruptions in gas supply or lack of Isoflurane in the vaporizer were recognized within 30 seconds. Breaks in the anesthesia circuit were reported within 1 breath. Computer malfunction, simulated by interrupting power, caused the system to safely revert to manual gas delivery.

Discussion: This total anesthesia delivery system provided accurate, rapid and safe anesthetic induction and maintenance, along with precise control of ventilation. Interaction with the anesthesiologist allowed easy adjustment of all controlled parameters. An immediate visual picture of the patient's anesthetic and ventilation state was provided through numeric and trend displays. Extensive redundancy in electrical and gas connections, as well as independent "watch-dog" circuitry, assured patient safety. All data, including anesthetic uptake, O2 consumption, and CO2 production were stored as a permanent record. This system is extremely flexible and could be used with a wide variety of inhalation anesthetics in both clinical and research applications.



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