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Anesthesia and Remote Monitoring for Intraoperative Radiation Therapy

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Intraoperative radiation therapy (IORT) is a relatively new form of cancer radiotherapy now being evaluated at several institutions in the United States and Japan.[1,2] Its advantages over conventional, external beam radiotherapy include: 1) more precise localization of the tumor in the radiation field; 2) reduction of radiation dose to critical normal tissues by displacing them away from the path of the beam; and 3) delivery of a higher radiation dose than can safely be applied externally. It may be particularly effective in treatment of locally unresectable, incompletely resected, or locally recurrent tumors in the pelvis and upper abdomen. Long-term cancer-free survival has been achieved in patients not curable by surgery alone.[3]

Patient management during IORT usually requires general anesthesia with tracheal intubation, muscle paralysis, and mechanical ventilation to: assure airway protection; allow retraction of the abdominal viscera; and produce immobility of the radiated field. Visual observation is possible only by closed-circuit television from the control room and is limited by multiple surgical drapes over the patient and the beam collimating apparatus. If difficulty is encountered, treatment can be interrupted and the concrete door opened within 20 s. The anesthesiologist can then reenter the room immediately, because no radiation persists once the beam is shut off.

Modern electronics should now enable patient monitoring from the control room with a degree of safety comparable to the best that can be achieved in the operating room. Although monitoring equipment designed for intensive care applications commonly has remote display of the ECG and blood pressure waveforms, respiration monitoring has been limited largely to simple, locally audible, airway pressure and expired volume alarms. Therefore, we designed our own monitoring system to allow remote access to the information from the electronic aids now routinely used in our operating rooms. Our objectives were to: 1) make the system as fail-safe[4] as possible in its ability to detect respiratory, circulatory, or gas delivery problems; 2) use instruments familiar to our personnel; 3) minimize additional cost; and 4) integrate the display of all information in one place.

METHODS

We use a physiologic monitor (Model 511, Spacelabs, Inc., Hillsboro, OR) as the basis of our system (see fig. 1). On its cathode ray tube (CRT), the monitor can display the ECG, three pressure waveforms, and associated numerical data including heart rate, systolic/diastolic/mean pressures, and two temperatures. A plug-in module (Spacelabs Remote Display Output Module, Option 19) allows the entire CRT display to be duplicated on an oscilloscope (Spacelabs Model DS2 display monitor) in the control room. We employ intraarterial pressure monitoring to assure continuous, reliable readings during patient transport and IORT.

For respiratory monitoring, we constructed electronic interfaces§ to allow the waveform output from an electronic spirometer (Model 8840, Boehringer Laboratories, Inc.) in the expiratory limb of the breathing circuit to be displayed on the "B" pressure channel of the CRT. This was calibrated to read the tidal volume in deciliters (see

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§ Interface design and fabrication required approximately 20 man-h and $50 worth of electronic components. Schematic diagrams of the interfaces are available from the authors.

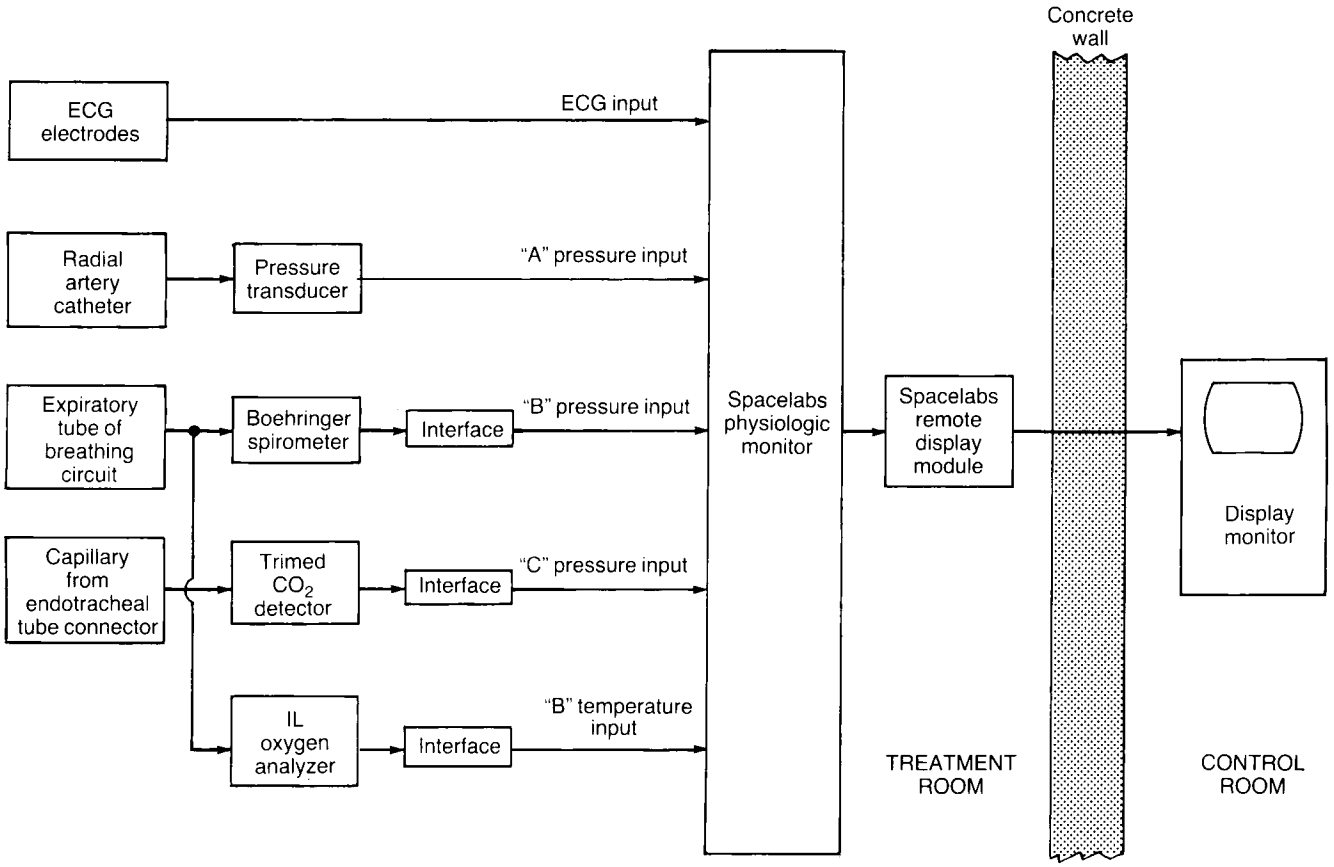

FIG. 1. Block diagram of monitoring system.

fig. 2). Because the spirometer can indicate tidal volume delivery (due to gas compression within the tubing of the circle–absorber circuit), even if disconnection occurs, we attached a qualitative carbon dioxide detector (Model 510 Respiration Monitor, Biochem/Trimed, Inc., Waukesha, WI) to show a square pulse on the "C" pressure channel after exhalation occurs. Alternatively, a quantitative capnograph could have been used. To assure oxygen delivery, we connected the oxygen analyzer (Model 402, Instrumentation Laboratory, Inc.) on the anesthesia machine to display digitally on one of the temperature channels of the physiologic monitor. With this combination of instruments we are able to detect total occlusion of the endotracheal tube or disconnections occurring anywhere in the gas delivery system. However, partial occlusion of the endotracheal tube may still go undetected.[5]

Although several institutions have combined operating room/radiation units, in ours the patient must be moved to and from the radiation unit through an elevator and some 100 meters of public corridor. The procedure begins in the operating room with an exploratory laparotomy, during which gross tumor may be resected and a decision made whether to proceed with IORT. After bleeding is controlled, the wound is temporarily closed and a bacterial barrier applied. To accompany the patient through the corridor, the surgical team members put on a second set of gown and gloves, which they can remove immediately in order to attend to the patient in the event of difficulty. In transit, the patient is ventilated with 100% oxygen, and anesthesia is maintained with intravenous agents to avoid additional complexity and a possible overdose hazard were an anesthetic vaporizer to become jostled enroute. In the radiation treatment room the surgical field is reexposed, and the patient is positioned under the linear accelerator with a sterile lucite cylinder in the wound to collimate the electron beam.

During radiotherapy, we use a volatile anesthetic carried in 100% oxygen to allow additional time before hypoxia ensues in the event of an equipment malfunction and because there is evidence that the radiosensitivity of tumor cells increases with increasing oxygen tension.[6] We also maintain skeletal muscle paralysis (monitored with a conventional nerve stimulator). In patients with upper abdominal tumors, we use ventilatory volumes less than 10 ml/kg to minimize the possibility of misdirection of the beam due to unexpected patient movement or respiration. Because any of our anesthesia personnel may be assigned to these procedures, we have a written protocol describing

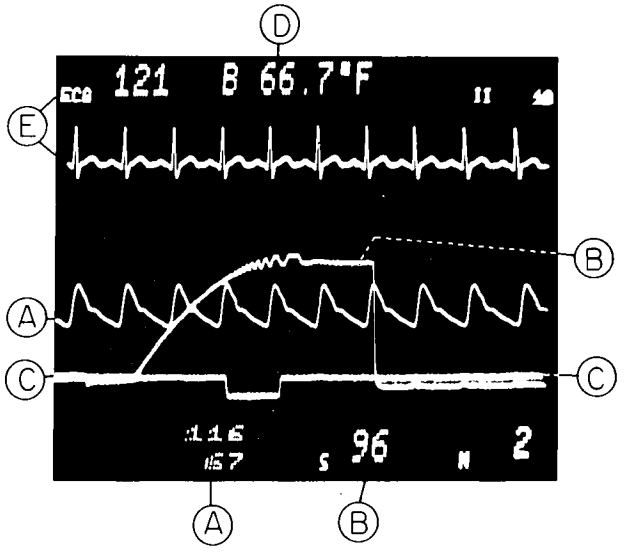

FIG. 2. Photograph of the CRT face. (*A*) Arterial blood pressure waveform and numerical display of systolic and diastolic pressure (116/67). (*B*) Expired tidal volume waveform and numerical display of a 960-ml breath. (*C*) Downgoing pulse showing presence of expired carbon dioxide (delayed by transport through the sampling capillary). (*D*) "Temperature" display showing the inspired oxygen concentration (66.7° F = 100%). (*E*) Electrocardiogram and pulse rate (121). Note: The characters "II" and "10" in the upper right corner refer to the use of electrocardiographic lead II with a scale of 10 mv/cm. The characters "M" and "2" in the lower right corner are extraneous.

use of the remote monitor and giving general guidelines for anesthetic management and transport.

RESULTS

Thirty-six patients have been explored surgically for IORT over a 16-month period. IORT was not performed in nine instances because of previously undiagnosed metastatic disease, disease too extensive to permit IORT or, in two patients, no cancer found at laparotomy. Typically, radiation treatment added approximately 90 min to the anesthesia time, of which 45 min were spent outside of the operating room. Radiation exposure lasted 20 min or less in all patients and 10 min or less in most patients.

Nine resident anesthesiologists and four nurse anesthetists have given anesthesia for IORT under supervision of 12 attending anesthesiologists. There have been no complications directly attributable to anesthesia, nor was it necessary to interrupt radiation in order to treat the patient. Four complications were potentially related to IORT or transport. One patient developed an intraabdominal abscess with *Staphylococcus epidermidis*, and another suffered a bile leak from a choledochojejunostomy (not within the radiated volume). A third patient died 2 days postoperatively of an acute myocardial infarction, and a fourth patient died 3 weeks postoperatively of adult respiratory distress syndrome unrelated to anesthesia.

DISCUSSION

In 1963, Cullen[7] first described anesthesia for IORT with a nuclear reactor. Respiration was monitored by having the patient breathe spontaneously through long tubes from an anesthesia machine located in the control room. Arterial blood pressure monitoring was by the Riva-Rocci method with long connecting hoses, and a remote ECG was employed. Electronic respiratory monitoring was reported by Abe *et al.*[3] using a CRT to display the waveform of the electrical resistance changes of a band placed around the patient's chest. Their technique does not quantify the tidal volume delivered, nor does it monitor proper operation of the gas delivery system. Similarly, Horton[8] used a thermistor or thermocouple mounted near the mouth and nose of nonintubated, sedated patients to detect temperature changes due to respiration during closed irradiation for carcinoma of the uterus.

Previous reports of anesthesia for radiodiagnostic[9] and closed radiotherapeutic[10–12] procedures have emphasized visual observation of the patient as the principal means of respiratory monitoring, either directly or by television, although Aidinis *et al.*[9] suggested that remote electronic monitors be developed. During IORT, electronic monitoring is particularly important, because respiratory chest excursion may be difficult to observe due to the multiple surgical drapes placed over the patient and radiation apparatus, and because low ventilatory volume may have to be employed to limit respiratory movement of an upper abdominal tumor.

Encouraging preliminary results with intraoperative radiotherapy will probably lead more centers to use this technique in the near future. For this application and for situations in which anesthesia with tracheal intubation is used for radiodiagnostic or closed radiotherapeutic procedures, we think that the monitoring apparatus described here will be nearly fail-safe in clinical practice.

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Anesthesia for Cesarean Section in Patients with Genital Herpes Infections: A Retrospective Study

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Patients with genital herpes simplex virus-2 (HSV-2) infection often require cesarean section to minimize the risk of neonatal HSV-2 infection and its high mortality rate.[1] The HSV-2 is a neurotropic virus that persists in sensory ganglia and postganglionic nerve fibers.[2] Regional anesthesia may be contraindicated in patients with HSV-2 infection because of possible dissemination of the infection. Relapses of herpes zoster lesions can occur following spinal anesthesia.[3] General anesthesia may also be hazardous in these patients because the anesthetics cause immunocompromise by: 1) affecting the function of bursa and thymus-dependent lymphocytes (B- and T-cells)[2,4–6]; decreasing cell motility and division, which results in decreased proliferation of lymphoid tissue in response to pathogens; and 3) by interfering with phagocyte mobilization.[6] Hormonal responses to the stress of surgery may also interfere with host defense mechanisms.[6] In addition, pregnancy itself may cause immunosuppression.[7] We describe our experience with lumbar epidural anesthesia and general anesthesia in patients with recurrent HSV-2 infection.

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METHODS

The study period extended from the years 1979 to 1984. All patients in the study were scheduled for cesarean section. Viral cultures were obtained from all genital lesions at least once during pregnancy. Culture studies were performed by the Smith-Kline Bioscience Laboratories (King of Prussia, PA). The laboratory uses the cell-culture technique for isolating the virus. The choice of anesthesia was at the discretion of the anesthesiologist. Some members of the anesthetic staff used general anesthesia in all patients with a history of HSV-2 infection regardless of the date of the positive culture because they felt that regional anesthesia was contraindicated in these patients. However, other members used regional anesthesia regardless of the date of the last positive culture report.

General anesthesia was induced by the iv injection of thiopental 3 mg/kg. The trachea was intubated under succinylcholine-induced muscle paralysis. Anesthesia was maintained with 70% N_2O in oxygen suppiemented by intermittent iv administration of fentanyl in 50 μg increments. Muscle paralysis was maintained with 6 mg incremental iv injections of *d*-tubocurarine. Muscle paralysis was reversed at the end of the procedure with a mixture of 1 mg atropine and 3 mg neostigmine iv. The tracheas were extubated uneventfully in the operating room.

Patients scheduled to receive lumbar epidural anesthesia were given an iv infusion of 1200 ml lactated Ringer's solution. Epidural anesthesia was induced to T6–T4 level by injecting 5 ml increments of lidocaine 1.5% with