pulsating arterial vascular bed between a light source and a detector. The optical transducer used in the Nellcor® instrument consists of two light-emitting diodes and a photocell mounted in adhesive tape. The pulsating vascular bed, by expanding and contracting, creates a change in the light path that modifies the amount of light detected. Nonpulsatile substances such as skin, bone, and venous blood are not detected. In order to determine the percentage of arterial hemoglobin saturated with oxygen, the oximeter measures the ratio of the pulse amplitude of a pulse of red light (660 nm) and compares it with the pulse amplitude of the same pulse in infrared light (940 nm). The ratio varies, depending upon the relative fraction of saturated to unsaturated hemoglobin in the arterial blood. This ratio is used to calculate the Sa_{O_2}.

Pulse oximetry is accurate for a wide range of hemodynamic conditions as long as a pulse is present beneath the sensor.[4] The oximeter we used accurately measures Sa_{O_2} to 70%.[4] Early recognition of hypoxemia (Sa_{O_2} <90%) by oximetry enabled us to institute steps to improve oxygenation, as illustrated in figure 3. Oxygenation can be optimized during OLV by a variety of means including CPAP to the nonventilated lung, PEEP to the ventilated lung, or discontinuation of OLV.[5]

We found no clinically significant differences between directly and transcutaneously measured Sa_{O_2}. With the pulse oximeter the information was available sooner, hence, there was no delay waiting for the results of blood gas analysis before beginning appropriate therapy. Although we still place an indwelling arterial line for blood pressure and arterial blood gas monitoring during thoracic operations, we now also monitor all our patients by pulse oximetry. We no longer are dependent on frequent arterial blood gas samples to follow arterial oxygenation during OLV.

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Epidural Block Using Large Volumes of Local Anesthetic Solution for Intercostal Nerve Block

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Repeated intercostal nerve blocks for analgesia have been used in postoperative patients, *e.g.*, cholecystectomy[1] and in certain trauma patients, *e.g.*, rib fractures.†† Adequate analgesia improves pulmonary compliance with coughing and deep breathing, thereby decreasing the risk of pulmonary atelectasis and ventilation/perfusion abnormalities.[2]

Continuous intercostal nerve blockade over five dermatomes has been achieved by inserting a catheter in one intercostal space.[3] Murphy has used this technique successfully in patients with rib fractures†† and following cholecystectomy.[4] How can a single injection of anesthetic into one intercostal space produce analgesia over several dermatomes? In cadaver studies, Nunn and Slavin[5] and Moore[6] identified the spread of an agent using small volumes of dye solutions. The use of radionuclides provides a method wherein the spread of an anesthetic

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†† Murphy DF: Intercostal nerve blockade for fractured ribs and postoperative analgesia. Regional Anesthesia 8:151–153, 1983.

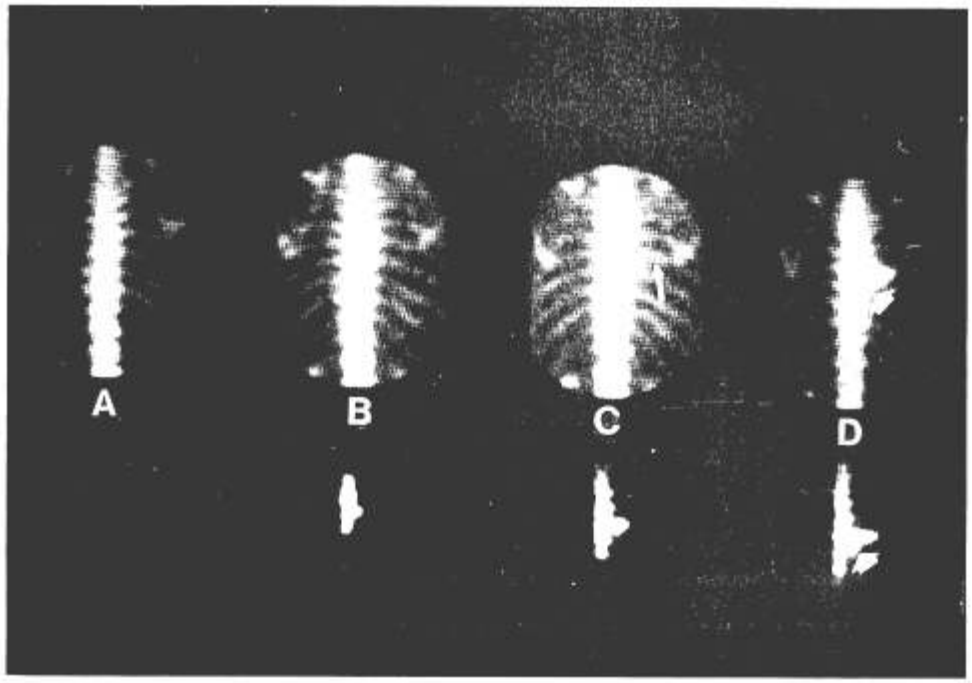

FIG. 1. Composite 1-min images of the posterior thoracic spine, ribs, and scapulae. Lower image in each case represents activity associated with anesthetic only, the bony elements having been subtracted. *A.* Preinjection. Upper image shows background bone scan activity. Lower (subtraction) image is blank, demonstrating the lack of anesthetic–radionuclide activity. *B.* Initial 3.0-ml bolus of anesthetic–radionuclide mixture. *C.* First 5.0-ml bolus. Arrow at right seventh rib. *D.* Third 5.0-ml bolus. Arrowheads indicate paravertebral spread.

can be followed while injecting *in vivo* with little or no risk to the patient.

REPORT OF A CASE

A 21-year-old man, involved in a motor cycle accident, was admitted with fractures of the right clavicle, and right third, fourth, fifth, and sixth ribs. The patient complained of significant right chest pain, despite iv narcotics, and splinting of the right chest wall was noted during respiration. Pa_{O_2} was progressively decreasing, with the most recent values at the time of the initial anesthesia consultation showing a pH_a 7.39, Pa_{CO_2} 40 mmHg, Pa_{O_2} 60 mmHg, with the patient breathing 4.0 l/min of oxygen via a nasal cannula. After informed consent, the patient was placed in the left lateral position, prepared, and draped aseptically. The seventh rib was identified by palpation and anesthetized 6 cm from the midline with 1.0 ml of 0.5% lidocaine with the use of a 22 gauge finder needle. A disposable Tuohy needle was advanced until contact was made with the rib. The needle then was walked caudally just off the rib edge and advanced an additional 3–4 mm. After a negative aspiration test, a standard epidural catheter was threaded 3–4 cm beyond the needle tip while the bevel was directed medially. The needle was withdrawn and the catheter secured. After a negative aspiration test, 20 ml of 0.5% bupivacaine with 1/200,000 epinephrine was injected in 3–5-ml increments at 4–5-min intervals. The patient reported complete pain relief after the block and was able to cough and deep breathe effectively for the first time since the accident. Immediately after placement of the block, with the patient still breathing 4.0 l/min of oxygen via nasal cannula, pH_a was 7.44, Pa_{CO_2} 38 mmHg, and the Pa_{O_2} 83 mmHg. During the injection period, arterial blood pressure decreased from 150/70 mmHg to 131/62 mmHg with no significant change in heart rate, ECG, or respiration. The patient did stop splinting with respiration.

To document the location and spread of the anesthetic, Nuclear Medicine was consulted and they recommended a flow study using technetium-99-m diethylene-triamminepenta-acetic acid (DTPA).

To better define the anatomy of the area to be injected, informed consent was obtained, and the patient was given an iv injection of 20 mCi of technetium-99-m in methylene diphosphonate 3 h before imaging. This is the standard agent and dose used for bone scanning at our institution, and in a patient with good renal function a high-quality bone scan may be obtained.

For the next injection the patient was brought to the Nuclear Medicine Clinic and positioned supine over a large field of view gamma camera fitted with an ultrafine collimator. The field of view included the posterior thoracic wall bilaterally and the catheter site. The camera was interfaced with a computer for rapid dynamic imaging. Images were obtained at the rate of three per minute over 30 min, into a 64 × 64 byte matrix. For identification of the route of anesthetic spread and ultimate destination, 500 μCi of DTPA were mixed with 0.5% bupivacaine to a total volume of 18 ml.

Seven hours after the initial anesthetic injection, following a negative aspiration test, the patient was reinjected incrementally with the radionuclide–anesthetic mixture. The initial dose of 3.0 ml was injected slowly, followed by 5.0 ml of the mixture every 3 min until a total of 18 ml had been injected. The patient was monitored continuously with ECG and the use of an arterial line during the procedure. His vital signs remained unchanged. The patient again reported more than 95% pain relief. When tested with pin-prick the patient had a T-1 to T-10 sensory block on the left and T-2 to L-1 on the right. There was no detectable motor block. The catheter remained in the patient for 28 h, during which time he received without difficulty two more injections of 0.5% bupivacaine with 1/200,000 epinephrine in the previously described manner. The third and fourth injections provided progressively less sensory block both in quality and duration, so the catheter was removed after the fourth injection. The patient recovered uneventfully. The investigative protocol was approved by the Clinical Research Committee.

Composite 1-min frames were created that provide optimal temporal and spatial resolution for the study. Representative images are reproduced (fig. 1). The first 5-ml bolus is shown at (C) and reveals further epidural spread of the anesthetic both cephalad and caudad to the injection site under the seventh rib. In addition, a small focus of activity is seen laterally. During the third 5-ml bolus, paravertebral

spread is now evident, as well as lateral extension of the anesthetic confined to the right seventh intercostal space and additional epidural spread both cephalad and caudad (fig. 1).

Discussion

Anatomic studies of the human intercostal space have revealed a triangular space bounded by the rib, the posterior intercostal membrane, and the intercostalis intima muscle.[5] The intercostal nerve, artery, and vein lie within this fat-filled space, which starts approximately 3–4 mm deeper than the caudal rib margin. The space is approximately 8 mm in depth, leaving a safety margin of 4–5 mm after introduction of a needle.

DTPA forms a water-soluble chelate when combined with technetium. It is promptly cleared from the body by glomerular filtration and is routinely administered iv in the assessment of renal function in doses six to thirty times that used here. In brain scanning, doses are 40 times the amount used here. There are no contraindications to the use of DTPA, although we do not routinely administer radioactive agents to pregnant or nursing mothers. No adverse reactions have been reported with its use. The estimated whole-body radiation exposure due to the bone scan is 0.13 rad. The additional exposure due to the DTPA would be a negligible fraction of the bone scan dose.

Prior studies of the spread of india ink in cadavers have been performed using small volumes.[5,6] Moore used 3.0-ml and 5.0-ml volumes and noted that spread of the ink was confined primarily to the costal groove of the rib.[7] Nunn and Slavin[5] found, however, using similar volumes, that the dye spread readily into the paravertebral space. The spread of anesthetic in the present report would explain the results of Murphy, whose two series of patients received excellent pain relief involving several dermatomes from a single large dose (18–20 ml) of local anesthetic administered in one intercostal space via a catheter. Our data support the contention that the intercostal space provides an alternative location to inject anesthetic solutions via a catheter that will result in the sensory block of several dermatomes above and below the site of injection. The continuous intercostal block may be safer and technically easier to perform than a thoracic epidural block, yet produces similar results in this patient. The risk of pneumothorax is a concern when performing an intercostal block. The use of a blunt-tipped Tuohy needle should minimize this risk, as should performing only one injection to cover a wide area and redosing through the catheter. Murphy has published[4] one series of 25 successive blocks with no evidence of pneumothorax. In another series[7] of 70 patients, there was one case of a massive chest wall hematoma related to an intercostal catheter placed after cardiopulmonary bypass. The patient recovered uneventfully.

Murphy has also reported a 15% incidence of tachyphylaxis, which is probably what occurred in this patient. The patient, however, stated he was extremely satisfied with the pain relief obtained from the procedure and was quite willing to have another catheter placed if needed.

The technique of continuous intercostal blockade warrants consideration as an alternative to multiple, repeated rib blocks and thoracic epidural blocks in patients with several rib fractures or who have had certain thoracic and abdominal procedures. The radionuclide study demonstrates the localization and spread of an anesthetic administered via this route *in vivo*. In addition, the radionuclide method described offers a new and safe technique for following the spread of a local anesthetic.

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