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Carbon Dioxide/Digital Subtraction Arteriography–Assisted Transluminal Angioplasty

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During a 62-month period, carbon dioxide was used to supplement or completely replace iodinated contrast agents in performing 27 transluminal angioplasties in 26 patients. The arterial segments addressed included the following: renal in two cases, iliac in five, femoral/popliteal in 15, infrapopliteal in two, and combined in three. Indications for intervention included lower extremity gangrene in 11 cases, ischemic ulceration in 10, rest pain in three, claudication in one, and ischemic nephropathy in two. Contraindications to iodinated contrast agents included renal insufficiency resulting from diabetes (n = 20) or ischemic nephropathy (n = 2) and congestive heart failure (n = 4). Eight procedures used carbon dioxide as the sole contrast agent, whereas 19 required supplementation of carbon dioxide with a mean of 39 ml of nonionic contrast medium. Technical success was achieved in 25 procedures with significant hemodynamic improvement in 20 patients. Complications included transient deterioration in renal function in two patients and myocardial infarctions in two. At 30 days 18 patients had demonstrated significant clinical improvement. Patients at high risk for iodinated contrast-related complications may undergo transluminal angioplasty using carbon dioxide/digital subtraction arteriography to reduce or eliminate the need for iodinated contrast agents. (Ann Vasc Surg 1995;9:448-452.)

Recent advances in vascular surgery have broadened the indications for endovascular intervention to include an elderly patient population that frequently has coexisting renal and cardiac disease or hypersensitivity to standard iodinated contrast agents. The morbidity of surgical and vascular interventional techniques has been dramatically reduced by innovations in minimally invasive technology and intensive care, thus allowing complex procedures to be safely performed in these medically compromised patients.

Transluminal angioplasty is an alternative to reconstructive surgery for occlusive lesions of the peripheral arterial tree. However, the nephrotoxicity, high osmolality, and allergic potential of currently available intravascular contrast agents remain significant hazards. For many patients the use of conventional contrast agents represents the greatest danger associated with an endovascular approach.

Carbon dioxide/digital subtraction arteriography (CO_2/DSA) uses carbon dioxide, a nontoxic injectable gas, combined with digital technology to provide images of the arterial anatomy. This approach represents a potential imaging alternative or supplement to standard contrast agents for patients who are candidates for an endovascular procedure but are at high risk for contrast-related complications.

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Presented at the Thirteenth Annual Meeting of the Southern California Vascular Surgical Society, San Diego, Calif., September 16-18, 1994.

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MATERIAL AND METHODS

Patients

During a 62-month period from December 1988 to March 1994, 26 patients with occlusive lesions of the peripheral arterial tree underwent 27 CO_2/DSA–assisted transluminal angioplasties.

There were 15 female and 11 male patients whose median age was 65 years (range 23 to 81 years). Medical illnesses included the following: diabetes in 23, chronic renal insufficiency in 22, hypertension in 16, symptomatic cardiac disease in 10, chronic obstructive pulmonary disease in four, and cerebrovascular disease in four. Contraindications to iodinated contrast agents included chronic renal insufficiency (serum creatinine > 1.3 mg/dl) secondary to diabetes in 20 or ischemic nephropathy in two patients, and severe congestive heart failure in four patients. Indications for intervention included gangrene in 11 cases, nonhealing ischemic ulcer in 10, rest pain in three, ischemic nephropathy in two, and claudication in one.

Technique

All procedures were performed through a femoral artery puncture using the Seldinger technique. Prior to the procedure, patients were intravenously hydrated overnight with a crystalloid solution and all received 12.5 gm of mannitol on call to the arteriography suite. Depending on the area of interest, an antegrade or retrograde femoral puncture was performed. Catheters, 4 to 6.[illegible], were used with angioplasty balloons appropriately sized for the vessel and lesion of interest. Sterile CO_2 was hand injected as a bolus using a 50 ml syringe over a 5- to 10-second interval. CO_2/DSA was used to provide diagnostic, roadmap, and completion images. One to 10 injections of 50 to 60 ml of CO_2 spaced at least 2 minutes apart were used in any one study. When images were suboptimal, nonionic iodinated contrast medium mixed 1:1 with normal saline solution was used to better define the arterial anatomy. The digital subtraction technique was the sole method of imaging.

For lower extremity procedures, elevation of the extremity often enhanced the quality of the study by taking advantage of the lower density of CO_2 as compared to blood. Renal artery imaging by CO_2/DSA was optimized by placing the patient in a prone, oblique, or lateral decubitus position such that the renal artery of interest was nondependent. Dilute nonionic contrast medium was used to inflate the angioplasty balloon. Resolution of the waist of the balloon was observed fluoroscopically.

Technical success was defined as fluoroscopic resolution of the balloon waist, equalization of intra-arterial pressures proximal and distal to the lesion, or completion arteriograms demonstrating a residual stenosis of < 50%. Hemodynamic success was defined as either postprocedure restoration of pedal pulses, an increase in the ankle/brachial index of > 0.15, or a combination of both. Postprocedure acute renal insufficiency was defined as an increase in the serum creatinine level of ≥ 25% from an immediate preprocedure value. At 30 days patients were assessed for symptomatic improvement in the primary clinical indication that had prompted the angioplasty.

RESULTS

Twenty-seven angioplasties were performed using CO_2/DSA. The following arterial segments were treated: renal in two cases, iliac in five, femoral/popliteal in 15, infrapopliteal in two, and a combination (two or more of the foregoing segments) in three (Table I). CO_2 was the only contrast agent used in eight procedures. Nineteen procedures required the addition of iodinated contrast medium (average 39 ml). In nine of 19 cases CO_2/DSA was employed as a diagnostic modality only, with iodinated contrast medium used exclusively for the endovascular procedure. The time required to perform the procedure ranged from 90 minutes to 6 hours and was dependent on the number and location of the stenoses dilated.

Technical success was achieved in 25 of 27 procedures with objective hemodynamic success in 20 patients. Two technical failures occurred as

Table I. Arterial segments treated by CO_2/DSA–assisted angioplasty

Arterial segment	CO_2 only	CO_2/contrast	Mean contrast (ml)
Renal	0	2	45
Iliac	3	2	20
Femoral/popliteal	5	10	39
Infrapopliteal	0	2	12
Combined*	0	3	77
	8	19	39

*Combined procedures include those in which angioplasty was used for lesions of more than one arterial segment.

a result of immediate thrombosis at the site of angioplasty. The cause of the thrombosis was arterial spasm in one and dissection in the other. One thrombosed femoral/popliteal lesion was successfully treated with intra-arterial urokinase and nitroglycerin. The other, an iliac artery thrombosis, failed to have patency restored with thrombolysis and required emergency femorofemoral bypass.

Myocardial infarction occurred following angioplasty in two patients, one of whom died 1 week following the procedure. Two patients who received 60 and 70 ml of nonionic contrast medium, respectively, sustained a deterioration in renal function. Both patient recovered with a return of serum creatinine values to baseline.

At 30 days clinical improvement was documented in 18 patients. This included healing of the digital amputation site in seven, healing of ischemic ulceration in seven, resolution of rest pain in two, and improvement in renal function in two.

DISCUSSION

CO_2 possesses several attractive properties as an intravascular contrast agent. It is nonallergenic, eliminating the possibility of fatal hypersensitivity reactions. It is rapidly diffused and has no effect on plasma osmolality. In addition, there is no evidence in either clinical experience or animal studies to suggest that CO_2 is nephrotoxic. These properties obviate the need for prearteriography hydration in patients in whom cardiac and renal dysfunction coexists. It can be used for sequential studies on consecutive days as is frequently required for completion of endovascular procedures. It is also very cost effective; one tank of CO_2 gas costs approximately $20, whereas the cost of nonionic contrast is $1/ml.[1]

In the past much concern has been expressed regarding insufflation of CO_2 into blood vessels for fear of gas embolism and chemical alterations in pH and Pco_2. Initial alarm about CO_2 embolization came from case reports in laparoscopic surgery of air embolism associated with CO_2 pneumoperitoneum. Albeit rare, this potentially fatal consequence has been reported in approximately 1 in 10,000 to 20,000 cases.[2-4] Multiple animal studies with intravascular injection of up to 13 ml/kg results in minimal physiologic consequences, although the presence of undissolved CO_2 has been demonstrated in the femoral vein of dogs after intra-arterial injection of CO_2.[5-7] Since the original report concerning CO_2/DSA in 1982, human trials have demonstrated both its utility and safety.[1,8-10]

The high solubility of CO_2 in blood, its passage through the pulmonary arterial system, and its rapid clearance by the lungs and blood buffers make the likelihood of gas embolism or deleterious physiologic effects extremely low. In our institution one patient undergoing diagnostic CO_2/DSA developed transient tachypnea and tachycardia, but it is unclear whether this event was related to the injection of CO_2.[1] To prevent the development of hypercarbia, we space CO_2 injections at least 2 minutes apart and possibly longer in those patients with known pulmonary disease. Significant CO_2 embolism has not occurred at our institution where more than 200 CO_2/DSA studies have been performed.

Physical properties of CO_2 must be considered during the performance of angioplasty to optimize this technique. Although the images obtained with CO_2/DSA may be less clearly defined than those obtained with standard contrast agents, they provided adequate visualization to successfully perform the angioplasty. As a gas, CO_2 has a lower density and layers anteriorly with the patient in the supine position. This property together with the spatial relationships of the various arterial segments must be considered in order to achieve adequate imaging of the arterial anatomy. Fig. 1 demonstrates the imaging possible using CO_2 as the sole contrast agent before and after angioplasty of the superficial femoral artery. Sequestration of CO_2 in nondependent segments of tortuous arterial segments can severely impair the ability to image the area of interest. The prone or decubitus position takes advantage of the posterior location and posterolateral aortic origin of the renal arteries in renal artery angioplasty. The supine position provides satisfactory imaging, thus allowing angioplasty to be carried out on lesions of the iliac/femoral segments. Elevation of the lower extremities increases flow of CO_2 into distal segments of the arterial tree. Altering patient position throughout the procedure to take advantage of the buoyancy of CO_2 is therefore an important albeit time-consuming element of successful CO_2/DSA–assisted angioplasty.

The 26 patients who have undergone CO_2/DSA–assisted angioplasty represent a fraction of the patients at our institution who have undergone endovascular therapy. In this select group, 19 of the 27 studies required the addition

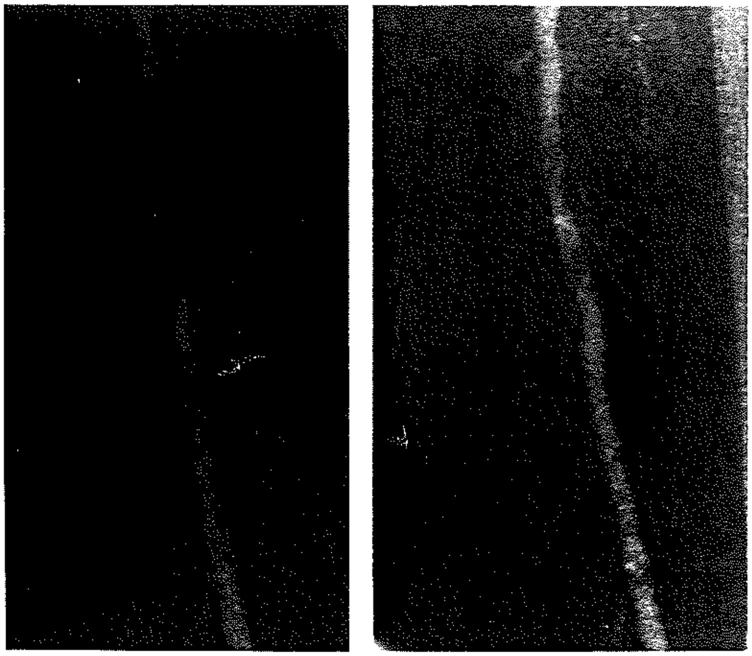

Fig. 1. Superficial femoral artery angioplasty using CO_2/DSA only.

of nonionic contrast medium (mean 39 ml per procedure) to satisfactorily visualize distal and collateral anatomy and provide completion studies. This volume of iodinated contrast medium is markedly reduced from the average 200 ml needed for a conventional diagnostic study and angioplasty.

A specific advantage of CO_2/DSA is illustrated by the two patients who had a transient deterioration in renal function after small amounts of nonionic contrast medium were used. One patient had diabetic nephropathy with a creatinine level of 2.5 mg/dl, which following angioplasty rose to 3.4 mg/dl. The other patient was diabetic and had an immediate preprocedure creatinine concentration of only 0.9 mg/dl, which rose to 1.5 mg/dl 24 hours later. These two patients illustrate the precarious condition of many patients with peripheral vascular disease and indicate that a much higher incidence of acute renal insufficiency may have been observed had CO_2/DSA not been used.

The successful technical result in 25 procedures after CO_2/DSA–assisted procedures attests to its ability to accurately image and guide angioplasty of critical arterial stenoses. Furthermore, the 7% rate of technical failure is comparable to that of previous reports concerning conventional angioplasty. The hemodynamic results and ultimate clinical benefit derived also compare favorably with short-term reports on endovascular interventions.[11-13]

CONCLUSION

Occlusive lesions of the iliac or femoral/popliteal arterial tree are the most amenable to the use of CO_2/DSA–assisted angioplasty. With diligence and patience, however, multiple and distal lesions can be treated by using predominantly CO_2/DSA. When necessary, dilute iodinated contrast medium can be used together with digital subtraction technology to minimize contrast volume.

This experience suggests that CO_2/DSA is not only an effective intra-arterial technique for diagnostic purposes, but it is potentially useful in therapeutic endovascular procedures to limit or eliminate the iodinated contrast load, thus minimizing the potential toxicity.

We thank Frances Harvey, RN, for her invaluable assistance in the preparation of this manuscript.

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Carbon Dioxide Embolism during Laparoscopy

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Laparoscopy is a frequently used technique for sterilization and differential diagnosis of pelvic pain and ectopic pregnancy. Anesthesiologists and surgeons are aware of the rare, but potentially lethal, complication of gas embolism.[1] The following is a report of a carbon dioxide embolism during abdominal insufflation for laparoscopy in which the patient survived.

REPORT OF A CASE

A 22-year-old, 60-kg, 160-cm woman, gravida 4 para 3, was scheduled for dilatation and curettage after spontaneous passage of a 20-week fetus and placenta. The possibility of an accompanying appendicitis necessitated laparoscopy. The medical history had no significant abnormalities, and she had been anesthetized uneventfully for a previous vaginal delivery. Physical examination revealed localized tenderness over the right lower quadrant and the uterus was tender and weeks in size. The remainder of the physical examination was normal. No heart murmur was noted. All laboratory results were normal, except for a white blood cell count of $19,500/mm^3$ and a urinalysis with 3+ ketonuria, 1–2 white blood cells, and 2+ bacteriuria.

No preoperative medication was given. Anesthesia was induced with thiopental, and endotracheal intubation was facilitated by succinylcholine. Anesthesia was maintained with nitrous oxide, halothane, and pancuronium. Ventilation was controlled with a tidal volume of 600 ml at a rate of 12 per min. Heart sounds were monitored with a precordial stethoscope. Electrocardiogram, temperature, and blood pressure also were monitored.

The patient was placed in the dorsal lithotomy position with a head down tilt. The curettage was uneventful. Then, a 1-cm incision was made at the umbilicus and a Verres needle was inserted into the peritoneal cavity without technical problems. Carbon dioxide, 3.5 l, was delivered through the needle at a rate of 1.0 l/min at an insufflating pressure of 10 to 20 mmHg.

Initial evaluation of the pelvic cavity through the laparoscope revealed the presence of purulent material. At this point, the laparoscopist noticed that the peritoneal gas had disappeared, which was thought to be due to leakage around the trocar. Insufflation was started again and another 500 ml of carbon dioxide were delivered during the next 30 s. Hypotension and a weak radial pulse immediately resulted. Within one minute, the blood pressure could not be obtained and auscultation of the precordium revealed a "mill-wheel" murmur. The patient's face was dusky.

Insufflation was stopped immediately and nitrous oxide was discontinued. The patient was placed on her left side with slight Trendelenburg.[2] Controlled ventilation was increased to 800 ml at a rate of 12 per min with a $F_{I_{O_2}}$ of 1.0, while an arterial catheter was inserted percutaneously into the left radial artery. The pH_a was 6.93, Pa_{CO_2} 103 mmHg, and Pa_{O_2} 44.3 mmHg. During the next 2 min, the blood pressure rose to 90/70 mmHg, and one minute later it was 110/80 mmHg. The right internal jugular vein was cannulated with a 16-gauge 30-cm long catheter. Twenty milliliters of foamy blood were aspirated from the central venous pressure catheter. Oscilloscopic display of the central venous pressure wave form tracked the position of the catheter tip from the pulmonary artery to the right ventricle to the right atrium during withdrawal. The central venous pressure was 14 mmHg. Most of the aspirated foam came from the right atrium.

The central venous pressure catheter was replaced by a flow-directed (Swan-Ganz) catheter. Pulmonary artery pressure was 40/20 mmHg, and pulmonary capillary wedge pressure was 18 mmHg. The patient's condition remained stable but a mill-wheel murmur still could be heard with a precordial doppler.

Anesthesia was maintained with fentanyl, halothane, and oxygen with controlled ventilation and PEEP of 10 cmH_2O. With the patient still in a slight left lateral tilt, the surgeons performed a laparotomy. A gangrenous appendix was found and removed. With a $F_{I_{O_2}}$ of 1.0, the pH_a was 7.07, Pa_{CO_2} 74 mmHg, and Pa_{O_2} 205 mmHg. With increased minute ventilation, the pH_a was 7.30, Pa_{CO_2} 57 mmHg, and Pa_{O_2} 400 mmHg. The patient was transferred to the intensive care unit where analysis of arterial blood gases was normal. PEEP and controlled ventilation were discontinued gradually. After 1 h of spontaneous ventilation, the trachea was extubated. The postoperative course was uneventful and the patient had no sequelae.

DISCUSSION

Venous gas embolism during laparoscopy is a rare complication. In 1974, Phillips reported 15 probable carbon dioxide embolisms in 113,253 laparoscopy cases in a 1-year period.[3] Six other cases of possible carbon dioxide embolism have been reported recently in the literature.[1,4–7]

Unfortunately, criteria for diagnosis of gas embolism vary considerably in the literature, and, therefore, accurate data on incidence are difficult to obtain. It seems that the only absolute criterion for diagnosis of gas em-

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Key words: Carbon dioxide: blood Levels; hypercarbia; embolus. Embolism: air. Surgery: laparoscopy.

bolism is confirmation of gas bubbles in the vascular system at the time of surgery or autopsy.

Cardiovascular collapse during laparoscopy has been reported previously. Many mechanisms have been implicated, including dysrhythmias from hypercarbia and halothane anesthesia,[8] perforation of a major vessel or viscera from direct injection of gas into the vascular system,[9] excessive compression of the vena cava from increased intra-abdominal pressure,[10] vasovagal reflex,[11] and unilateral or bilateral pneumothorax.[12] Hypercarbia results from hypoventilation or absorption of carbon dioxide from the peritoneal surface.[13]

Of the six cases reported above, evidence of vessel injury was noted in two of them.[5,7] In two other cases, direct injection of gas through the fundus of the uterus was noted and may have resulted in the injection of gas into a vessel in the uterine wall. McKenzie suggested that carbon dioxide might enter the circulatory system when a vein has been ruptured because of the increased intra-abdominal pressure.[14] Cardiovascular collapse was noted by Kleppinger, presumably secondary to carbon dioxide embolism through a bleeding mesosalpingeal vein.[15] In our case, the sudden hypotension immediately following carbon dioxide insufflation and aspiration of foamy blood from the right heart strongly suggested carbon dioxide embolism. Carbon dioxide may have been introduced by intravenous injection, although no vessel injury was noted. The possibility of increased carbon dioxide absorption through necrotic appendiceal tissue is possible.

If massive, carbon dioxide embolization can obstruct the pulmonary outflow tract, right ventricular failure may result. This can be controlled by placing the patient in a left lateral and head-down position to minimize the obstruction.[2] Carbon dioxide also has a direct effect on peripheral vascular resistance, producing the documented hypotension. When small carbon dioxide bubbles gain access to the pulmonary circulation, a transient increase in pulmonary artery, right ventricular, and right atrial pressures can be observed. This effect is diminished by the rapid solubility of carbon dioxide in blood and concomitant hyperventilation to promote carbon dioxide elimination. Since the diffusion capacity of nitrous oxide is lower than that of carbon dioxide, nitrous oxide will not increase the volume of the carbon dioxide embolism as it does with air. However, nitrous oxide must be discontinued to allow an $F_{I_{O_2}}$ of 1.0 to avoid hypoxemia from high alveolar carbon dioxide concentrations.

As carbon dioxide is highly soluble in blood, it is absorbed rapidly from the bloodstream. This accounts for the rapid reversal of the clinical signs of carbon dioxide embolism with treatment. These characteristics must be considered in the selection of an insufflation agent in laparoscopy. Nitrous oxide is slightly less soluble than carbon dioxide, and air is five times more lethal. In angiocardiography, carbon dioxide has been well tolerated in doses as high as 7.5 ml/kg, while injected doses of 0.25 ml/kg of air in cats have been lethal. In dogs, the dose equivalent of one liter of carbon dioxide in humans can be given before cardiac output is altered profoundly.[16]

Carbon dioxide embolism is an extremely rare complication of laparoscopy.[3] However, it can be lethal.[1] For this reason, patients obviously should be monitored carefully during laparoscopy.[13] During insufflation with carbon dioxide, end-tidal carbon dioxide has been shown to increase slightly.[17] If carbon dioxide embolism occurred during laparoscopy, a further increase in the end-tidal carbon dioxide concentration would be expected. However, no such increase has been reported. End-tidal carbon dioxide monitoring obviously needs further investigation. A precordial doppler is a sensitive device, but the low incidence of gas embolization during laparoscopy may preclude its routine use.[18]

In conclusion, to minimize the chance of a carbon dioxide embolus during laparoscopy, we recommend restriction of carbon dioxide volume and pressure to three liters and 30 mmHg, respectively. Also, the blood pressure, electrocardiogram and heart sounds should be monitored carefully for early detection of carbon dioxide embolism.

The authors acknowledge the assistance of Laurie Ramsbacher in the preparation of this manuscript.

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Anesthesiology
57:535–538, 1982

New Methods for the Performance of Unilateral Lung Lavage

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Massive bronchopulmonary lavage using a double-lumen endotracheal tube has become an accepted modality for the treatment of pulmonary alveolar proteinosis.[1–5]

During single-lung ventilation, the non-ventilated lung is lavaged with tidal volumes of saline until return of sediment is minimal; the procedure is then terminated.

Massive bronchopulmonary lavage is not without haz-ı. During the initial lavage of a patient, complete gas exchange must be accomplished by a single severely compromised lung. Periods of tidal drainage are accompanied by reperfusion of the non-ventilated lung[6] and potentially dangerous levels of hypoxemia. Drowning is prevented only by proper positioning of the endotracheal tube and adequate cuff inflation.

Recognizing these hazards, we have modified the published techniques of massive bronchopulmonary lavage to: (1) ensure correct placement of the double-lumen tube, and (2) investigate maneuvers to maximize gas exchange during unilateral lavage. Experience was gained during eight lavages performed on three patients with biopsy-proven alveolar proteinosis.

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Key words: Lung: alveolar proteinosis; lavage.

METHODS

Patient evaluations included history, physical examination, arterial blood-gas analysis, and pulmonary function testing. In addition, preoperative ventilation-perfusion scanning was performed with the patient in the supine position ($F_{I_{O_2}}$ = 0.21 to 0.30) using standard techniques.[7]

With the patient in the supine position having received 5–10 min of preoxygenation, anesthesia was induced by the administration of 3–4 mg/kg sodium thiopental, iv, in divided doses, and inhalation of 0.5–2.0% halothane or 0.5–3.0% enflurane (patient 3) via mask. Following the onset of surgical anesthesia, the patients were paralyzed with pancuronium (0.15 mg/kg, iv).

For all lavages we used the National Catheter Corporation left lung, double-lumen tube. With one exception, we used the largest size tube that could be passed atraumatically through the glottis. The correct position of the double-lumen tube was confirmed by passing a fiberoptic bronchoscope (Machida FBS 4T bronchoscope) down both lumens of the tube. Via the left lumen, the subcarina separating the upper and lower lobes was clearly visible. The volume of air in the left endobronchial cuff was adjusted until the left endobronchial lumen just began to invaginate due to the external cuff pressure. Via the right lumen, a clear view of the carina was observed as well as the upper surface of the left endobronchial balloon.

The tracheal cuff was inflated until slight to moderate tension was palpated in the pilot balloon. We confirmed complete separation of the two lungs by clamping the tube connected to one lung proximal to the open suction port. A length of tubing was attached to the suction port, and the free end of this tube was submerged under water. When the ventilated lung was inflated statically to +50 cm H_2O, endobronchial cuff inflation was ad-