Technical Facets of Radioaerosol Delivery

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A new high-frequency ultrasonic nebulizer system for radioaerosol delivery is described. Since the successful use of this equipment is dependent upon technical proficiency, the technical facets of radioaerosol delivery have been listed in detail.

Knowledge of the imbalance between regional pulmonary ventilation and perfusion has proved to be of considerable clinical value *(1-3)*. With such information it is often possible to distinguish pulmonary vascular occlusion from the multiple other airway and parenchymal lung diseases which cause perfusion abnormalities.

Two different radionuclide techniques have been generally used to evaluate ventilation. The inhalation of ^{133}Xe gas simulates the usual conditions of ventilation, and it can provide quantitative measurements of regional ventilation. The inhalation of radioaerosols, on the other hand, can provide useful qualitative information on the distribution of ventilation.

The relative merits of these two techniques have been previously described *(4)*. Radioaerosols have the advantage of being relatively inexpensive and simple to produce. They can also be delivered at tidal volume respiration and breath-holding is not required. Therefore, acutely ill patients can be studied, and the resulting images represent the cumulative effect of several minutes of respiration, rather than a single breath. Once the radioaerosol is delivered it remains in the alveoli; thus multiple high-information-density images can be obtained.

There are many variables which determine the pulmonary distribution of aerosols, including aerosol particle size, aerosol concentration, air flow rate, and airway turbulence *(5)*. The technical difficulty of controlling all these variables has often resulted in suboptimal images and excessive extrapulmonary deposition of aerosol in the oropharynx and trachea; therefore, the radioaerosol technique has not been widely adopted.

We have recently described equipment which improves the delivery of radioaerosols *(6)*. The successful use of this equipment is dependent upon careful attention to technical details. The purpose of this report is to describe the important technical facets of radioaerosol delivery.

Materials and Methods

The equipment consists of a high-frequency ultrasonic nebulizer coupled with a nebulization chamber specifically designed for radioaerosols. The DeVilbiss model 900 ultrasonic nebulizer has a frequency of approximately 4 MHz, which is a higher frequency than most standard model ultrasonic nebulizers. Other ultrasonic nebulizers can also be successfully used with the special nebulization chamber described below.

The nebulization chamber (Fig. 1) has an *injection inlet* which permits gradual addition of the radiopharmaceutical during the delivery procedure. This is necessary because the injected solution lies on a cellophane or Cryovac membrane (which covers the *interface*). The ultrasonic beam is transmitted through the membrane and the solution lying on the membrane is nebulized. If the volume of the solution is too large, nebulization will be impaired.

The *impaction sphere* serves three purposes. (A) Larger aerosol particles are impacted and thus prevented from depositing in the oropharynx and trachea. The intent of this design is to create a higher proportion of particles in the 0.5- to 3.0-μ size range. It is primarily particles in this size range which are deposited in peripheral bronchioles and alveoli. (B) The sphere permits recovery of the larger particles for renebulization, thus improving delivery efficiency. Less of the radiopharmaceutical remains on the walls of the chamber and tubing. (C) The sphere also traps the generated aerosol in a small volume. When the patient inhales, a fairly compact aerosol "bolus" is released in the early portion of the tidal volume. Relatively little aerosol is distributed in the late portion of the tidal volume. Since the later portion of the tidal volume is filling dead space only, any aerosol in this volume is not available for alveolar deposition and is thus wasted. This feature, therefore, also serves to improve overall delivery efficiency.

Each patient is uniquely different, and therefore the delivery method must be individualized to fit the circumstances. The anxious patient will require reassurance

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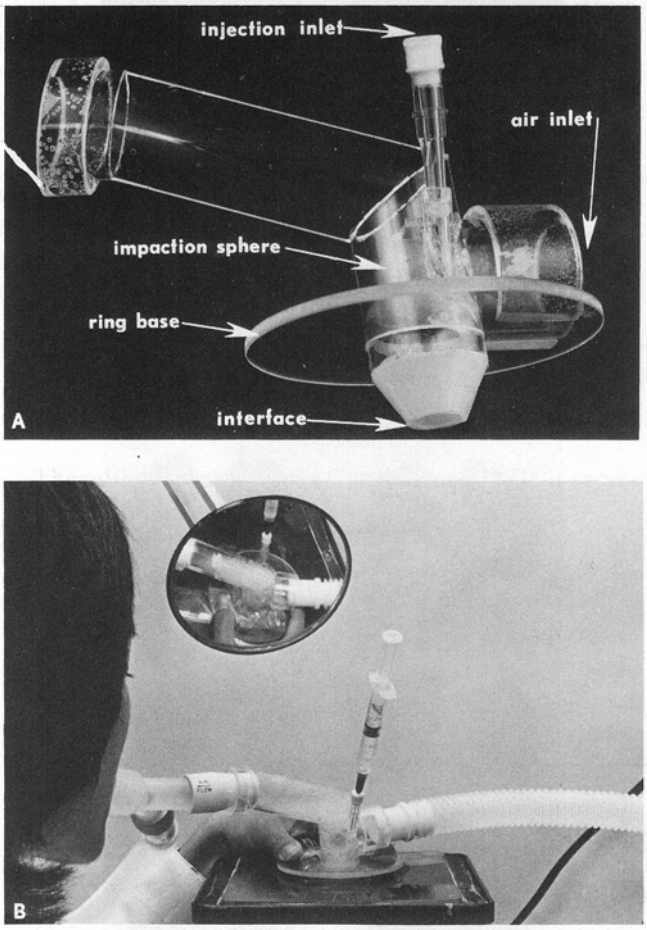

FIG. 1. (A) Side view of nebulization chamber. Ring base slides over tapered bottom of chamber, pulling membrane taut over interface. (B) Close-up view of chamber during nebulization. ^{99m}Tc-phytate is added incrementally through injection inlet.

and encouragement. Some patients do not understand how to mouth-breathe and require practice prior to radioaerosol delivery. If the technologist is not willing to spend the time and effort required, less than satisfactory delivery can be expected.

Referring to Figs. 1 and 2, the following steps should be followed.

The upper compartment of the ultrasonic nebulizer should be filled with water.

The tapered bottom of the chamber should be covered with a 3- by 3-in. sheet of very thin cellophane or Cryovac film (0.68 mil). Thicker membranes will not transmit the high frequency as effectively. The *ring base* slides over the membrane, pulling it taut over the *interface* and holding it in place. The membrane must be taut for effective nebulization.

The tapered bottom is inserted through the opening on the top of the nebulizer. The membrane should interface the water in the upper compartment. The chamber should be firmly anchored so that the reservoir lies *directly above* the ultrasonic crystal. An elastic shock cord, attached to the base of the nebulizer and running over the top of the *air inlet*, will provide a secure anchor for the chamber.

A mouthpiece is attached to a three-way Y tube. One-way valves are attached so that inhalation can occur only through the chamber and exhalation only through the exhaust tubing. The DeVilbiss input check valve No. 2-1019 has been found to be most suitable; it may also serve as an additional impactor for larger aerosol particles. The exhaust tube should be vented into an exhaust hood.

The DeVilbiss air supply module No. 3100 is attached to the air inlet. This assists movement of the aerosol bolus, but it does not appreciably increase air flow rate. Stronger blowers or positive pressure devices should be avoided because at high flow rates more particles are impacted in the pharynx and trachea. All connections should be airtight.

Check equipment performance before beginning patient inhalation. Inject 0.5 cm^3 of normal saline through *injection inlet*. Set the nebulization rate at 3 or 4

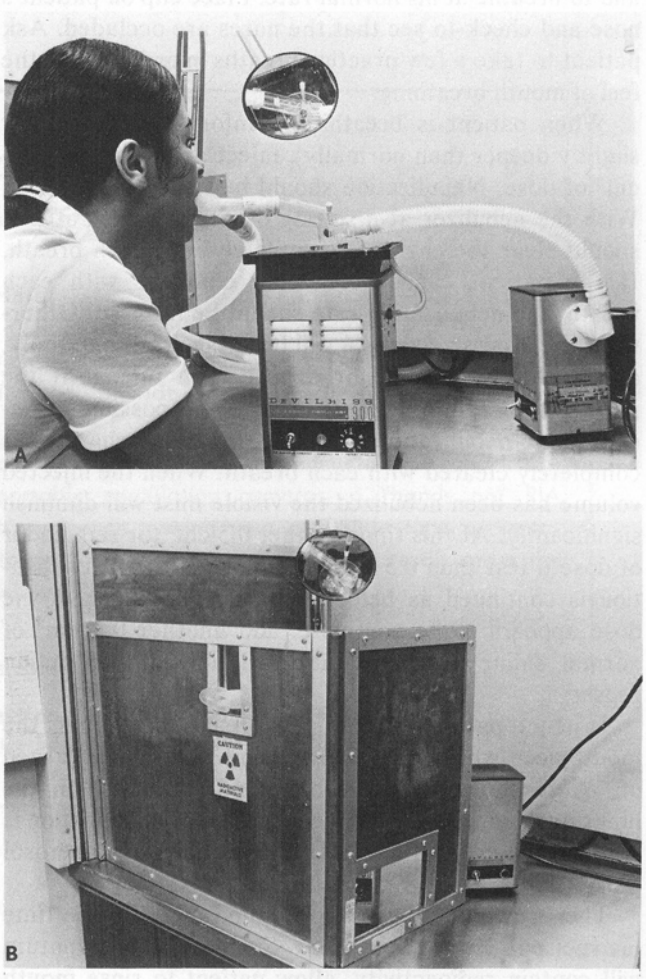

FIG. 2. (A) Complete system without shielding. Blower is not capable of opening one-way valves; therefore, system remains closed until patient inhales. Then blower assists movement of aerosol bolus. (B) Shielding effectively minimizes exposure to technologist. Mirror permits technologist to monitor nebulization, and nebulization rate can be adjusted through side opening of shield.

and turn nebulizer on. Within 30–45 s a fine mist should appear in the reservoir. Allow nebulization of saline to continue for at least 5 min.

Place needle and syringe containing radiopharmaceutical (20–30 mCi of ^{99m}Tc-phytate) into the injection inlet, but do not inject. Other ^{99m}Tc-labeled agents, including ^{99m}Tc-albumin and ^{99m}Tc-sulfur colloid, may also be used. Indium-113m-albumin has the advantage of permitting simultaneous inhalation studies following ^{99m}Tc-MAA perfusion studies. The advantages of ^{99m}Tc-phytate, and the percentage of the dose actually delivered to the patient, have been previously described *(6, 7)*.

The entire nebulizer, chamber, and tubing should be appropriately shielded [Fig. 2(B)]. Technologist exposure rate during the delivery is less than 0.3 mR/h.

The patient should be made as comfortable as possible in a sitting position. When absolutely necessary, the semirecumbent position can be used; longer tubing is then required. Carefully explain the procedure to the patient; instruct patient not to swallow during procedure and to breathe at his normal rate. Place clip on patient's nose and check to see that the nares are occluded. Ask patient to take a few practice breaths in order to get the feel of mouth breathing.

When patient is breathing comfortably (preferably slightly deeper than normally), inject approximately 0.5 cm^3 of dose. Nebulization should be visible within 30 s. With the nebulizer at a setting of 3 or 4 most patients should clear the chamber completely with each breath. If the patient cannot clear the chamber with each breath, the nebulization rate should be lowered. Otherwise, the excessive aerosol will be filling dead space only, and it will be exhaled or deposited in tubing. If the patient is breathing deeply, it may be possible to increase the nebulization rate, so long as the chamber is completely cleared with each breath. When the injected volume has been nebulized the visible mist will diminish significantly. At this time another 0.5 cm^3 (or remainder of dose if less than 0.5 cm^3) should be added. Nebulization is continued as before. When nebulization of the dose appears to be complete, add another 0.3 cm^3 of normal saline and continue until aerosol production ceases.

Instruct patient to continue breathing through the mouthpiece while the nebulizer and blower are turned off. Aerosol particles which are not deposited in the lungs are immediately exhaled; thus after nebulization is stopped the exhaled air no longer contains radioaerosol particles.

Then remove the mouthpiece and at the same time instruct patient not to swallow. Since saliva and sputum will contain radioactivity, allow patient to rinse mouth thoroughly with water before moving to the imaging room. This will help to reduce the amount of swallowed activity in the stomach. Appropriate precautions should be employed when handling saliva or sputum.

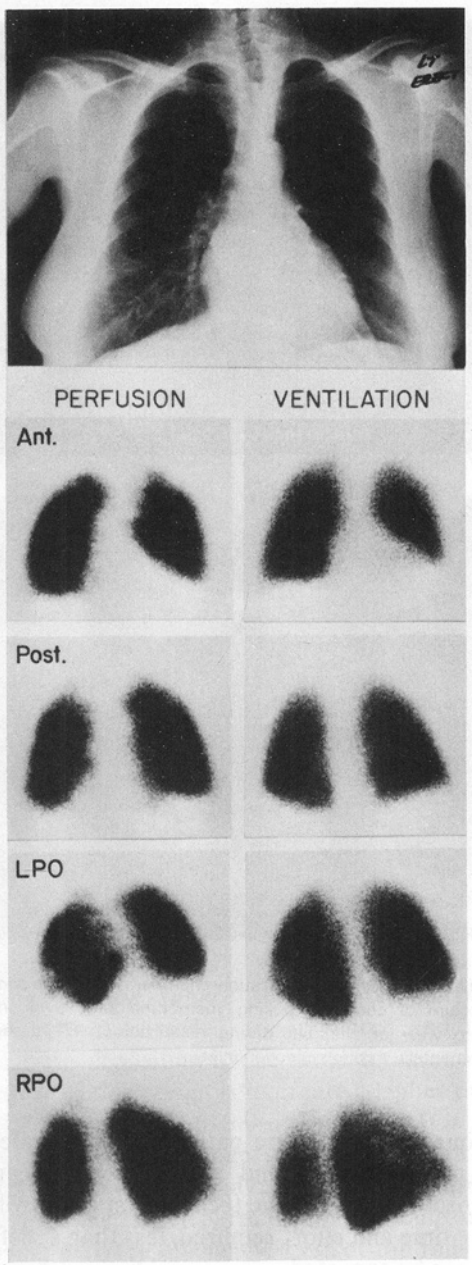

FIG. 3. Typical V/Q mismatch in patient with pulmonary embolism. Since perfusion deficit to posterior basilar segment of left lower lobe is best visualized on LPO view, it is quite advantageous to be able to image ventilation in same projection. Note absence of gastric or tracheal activity.

Results and Discussion

As previously described, rapid and efficient delivery can be achieved, even in critically ill patients *(6)*. Another major advantage of this system has been the minimal extrapulmonary deposition of aerosol. A typical patient study (Fig. 3) illustrates the importance of imaging ventilation in the posterior oblique position, since the perfusion defect was apparent only in this position.

Relatively few problems have been experienced with the delivery system. Occasionally aerosol production ap-

pears too slow; this usually results when an excessive volume of radiopharmaceutical covers the interface membrane, impairing the ultrasonic vibration of the membrane. It may also result from improper alignment of the nebulization chamber with the ultrasonic beam.

There are many variables that affect delivery results, but the most significant variable is the diligence and proficiency of the technologist. Therefore, careful adherence to the technical factors listed above is essential for the successful use of this delivery system.

Acknowledgment

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