Scintiphotography of Lungs with Dry Aerosol—Generation and Delivery System: Concise Communication

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A compressed-air nebulizer with low holdup and high output was used to nebulize [^{99m}Tc] pertechnetate presented in normal saline. Generated droplets were dried in line and led to an inhalation chamber from which the dry aerosol was inhaled using a nose or mouth inhalation unit. The mass median diameter of the particles was 0.8 microns, with an associated geometric standard deviation of 2.0. The deep lung delivery efficiency—defined as the ratio of the activity deposited in the lung area to the activity nebulized—was found to be reproducible and consistent (15–22%) in all the subjects studied. A 3–5 min inhalation of aerosol, nebulized from 20 mCi, was sufficient to provide a lung image of good information density. No noticeable deposit was seen in the trachea or major brochi. The system is inexpensive, stable in performance, adaptable to other solutions or colloids, and is promising for routine use.

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The technique of using aerosol inhalation for gamma imaging of the lungs is of recent origin. The first step in this procedure is to generate and administer the aerosol by inhalation. The customary procedure uses an ultrasonic nebulizer to generate a small-droplet aerosol suitable for inhalation. Several workers have modified the ultrasonic nebulizers to improve the efficiency and the predictability of the aerosol delivery into the deep lung area (1–4). Even though dry aerosol is considered desirable, since it provides scintiphotos of better quality (*1*), the systems based on ultrasonic nebulizers cannot be used to produce such aerosols. This is because of their relatively large holdup volumes and nebulization rates, which require an unacceptably large volume of air to dry the output. The wetness of the aerosol has been one of the reasons for not getting higher, and more predictable, aerosol delivery during inhalation.

A new system has been developed in our research center to generate and administer dry aerosol with high efficiency and reproducibility. The system is based on a specially developed low-holdup, high-output, compressed-air nebulizer (*5*).

INSTRUMENTATION

The aerosol generator, the aerosol chamber, and the inhalation system are shown in Figs. 1 and 2.

The fabrication and performance of the nebulizer used in the present work has been described elsewhere (*5*). A small needle baffle (J, Fig. 1) is fixed at about 1 mm from the jet (H), and the solution-intake needle (I) dips into a tapered-bottom test tube. The tapering permits nebulization of small volumes. Filtered compressed air from a small pump is branched into three lines. One leads to the nebulizer section (I,H), and the others provide drying air through two No. 21 hypodermic needles, 1 in. long (G). When compressed air enters at 25 lb/in.^{2} air flow through each section is about 3.5 l/min.

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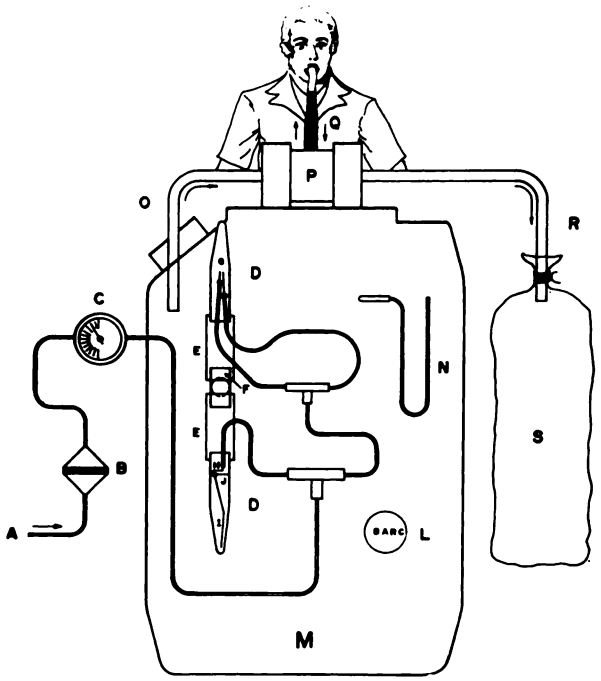

FIG. 1. Diagram of system (mouth-breathing mode). A = Compressed-air line; B = Membrane filter; C = Pressure gauge; D = Two tapered test tubes; E = Two polyethylene adapters; F = Metal T-tube; G = Two jets for drying air; H = Nebulizer; I = Solution-intake needle; J = Baffle needle; L = Vacuum-relief valve; M = Aerosol chamber (20-l polyethylene carboy); N = Water manometer; O = Duct for dry aerosol; P = T-junction, with inhalation and exhalation valves; Q = Short duct to patient; R = Exhalation line; S = Plastic bag for expired air.

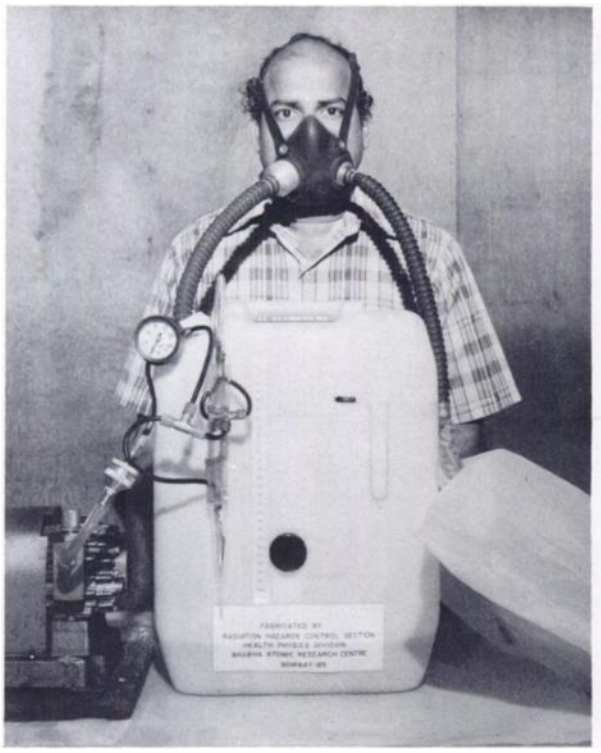

FIG. 2. Apparatus in nose-breathing mode.

One ml of [^{99m}Tc] pertechnetate in normal saline (0.85% NaCl) is placed in the nebulizer tube. The droplets generated by the nebulizer evaporate in the accompanying air (G), leaving a dry aerosol of NaCl containing pertechnetate.

The aerosol and its accompanying air enter the aerosol chamber, a 20 l polyethylene carboy. The chamber is fitted with a manometer, a vacuum relief valve, and a duct leading to a three-way inhalation/exhalation unit. One outlet leads to the patient through a face mask or mouthpiece, and a second is the intake line (O) from the aerosol chamber (M) through a valve that prevents backflow into the chamber. The third (R) leads to a 75 l plastic bag through a valve that permits flow only into the bag. Care is taken to see that the bag is leakproof; it expands easily as exhalation continues. Pressure in the carboy is monitored by a water manometer (N), and undesirable negative pressure is prevented by a relief valve that admits room air if the pressure falls below −5 mm of water. The 20 l volume of the carboy minimizes pressure fluctuations during the respiratory cycle; pressure remains between −2 and −5 mm water, thus discouraging leakage of aerosol into the room.

RESULTS

Table 1 shows the results. One milliliter of solution was used for nebulization. The subject started inhaling as soon as the compressed-air input to the nebulizer was turned on. After an inhalation period of about 5 min, the subject was immediately taken to the scintillation camera for lung imaging. A posterior view is used, totalling 300,000 counts. Exposure time was between 10 and 15 sec. Figure 3 shows a typical image. An estimate of pulmonary radioactivity was made by comparing these count rates with those obtained from routine perfusion pictures after an intravenous injection of Tc-99m albumin microaggregate. In each case, the radioactivity left unnebulized was measured. Table 1 gives the details of the experiments.

In an auxiliary experiment, an eight-stage Anderson cascade impactor (*6*) was used for the measurement of the particle-size distribution. A sample was taken from the aerosol chamber during the entire period (5 min) of aerosal generation. Radioactivity collected on each of the eight stages was estimated. The data were processed to obtain particle-size distribution curves (*6*). The calibration data for the cascade impactor were corrected for NaCl aerosols. Figure 4 gives the results, and also gives the aerosol sizes when NaCl concentration in the carrier solution was varied.

TABLE 1. LUNG DELIVERY EFFICIENCIES OF THE SYSTEM

Subject No.*	Volume taken for nebulization (ml)†	mCi placed in nebulizer (%)	Duration of generation/ inhalation (min)	mCi nebulized (%)	Nebulizer's mCi delivered: mCi put in (%)	mCi in lung region	mCi in lung: mCi nebulized (%)	mCi in lung: mCi placed in nebulizer (%)
1	1.0	19.0	5.0	12.0	63.2	2.22	18.5	11.7
2	1.0	23.0	5.0	13.0	56.5	2.86	22.0	12.4
3	1.0	32.0	5.0	21.0	65.6	4.00	19.1	12.5
4	1.0	35.0	4.0	28.0	80.0	4.30	15.4	12.3
5	1.0	15.0	4.0	9.5	63.3	1.74	18.3	11.6
6	0.9	23.0	5.0	15.0	65.2	3.33	22.2	14.5
6	0.9	17.0	3.5	11.0	64.7	2.22	20.2	13.1
7	1.0	21.0	5.0	13.3	63.3	2.70	20.3	12.8

* Subjects 1–6 breathed by mouth; 6 and 7 by nose.

† Pertechnetate entered in saline solution (0.85% NaCl). The nebulizer was operated at 25 lb/in^2. The mass median diameter of the dry aerosol was 0.8 μm, with an associated geometric standard deviation of 2.0.

DISCUSSION

Only 60–70% of the solution placed in the nebulizer becomes nebulized, since 0.3–0.4 ml of the solution clings to the walls of the nebulizer during the operation and therefore becomes unavailable. The estimated lung uptake is seen to be fairly constant, ranging between 15 and 22%, with an average of about 20%.

The aerosol used in the study had a mass median diameter of 0.8 μm with an associated geometric standard deviation of 2.0 (Fig. 4). This means that 50% of the radioactivity is carried in particles smaller than 0.8 μm, 75% below 1.3 μm and 90% below 2.0 μm. For such a particle-size distribution, the lung model (7) predicts a deep-lung deposition of 26%, somewhat higher than the value of 20% obtained in the present work. This may be due to adherence on the walls of the inhalation chamber and the inhalation tubes. It is possible to increase the delivery efficiency by decreasing particle size. From the results in Fig. 4, the expected increase (7) calculates to be only marginal (from 20 to 21%) when the concentration of NaCl is decreased from 0.85 to 0.1%. It is important to remember the role of NaCl in providing carrier aerosol, especially because of the carrier-free nature of the pertechnetate. If this carrier aerosol is absent, there will be practically no deposition in the lungs. Experiments carried out with Tc-99m phytate in carrier solutions of different NaCl concentrations gave particle-size distributions very similar to those obtained for pertechnetate, thus predicting similar lung-delivery efficiencies.

Scintiphotos of the normal subjects referred to in Table 1 showed negligible deposition in trachea and bronchi. The lung model (7) also indicates that the total deposition in the entire tracheobronchial region should be less than 4% of the inhaled amount.

Subject No. 6 also inhaled the aerosol through the nose on a different day. There was no significant change in the lung-delivery efficiency, as compared with mouth breathing, nor was there any change in the lung-deposition pattern. This was to be expected for the size ranges under consideration. For such aerosols, the expected nasal deposition (7) is 8%, and the activity available for lung deposition would be 92% of that available by mouth breathing. The expected decrease in deep-lung deposition efficiency is only marginal (from 20 to 18.5%). In the nose-breathing mode there may be external contamination of the face, and a good wash may be necessary to remove such contamination. Nose breathing, however, has some advantages. Being a natural mode,

FIG. 3. Lung image taken after 5 min of breathing on instrument. Posterior scintiphoto accumulated 300,000 counts in about 10 sec.

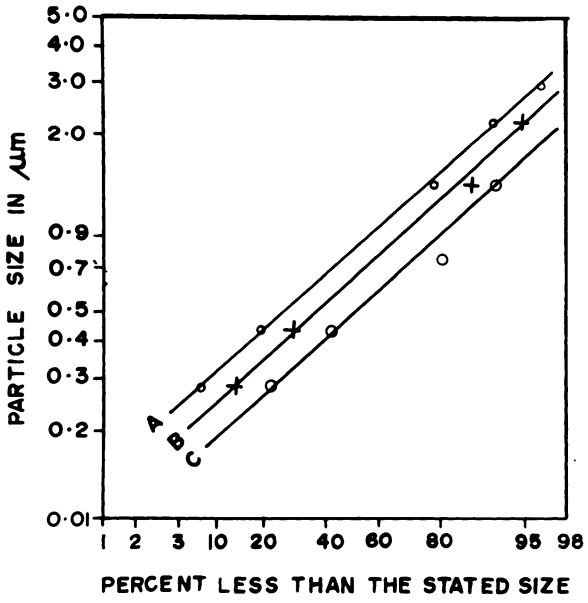

FIG. 4. Particle-size distribution of dry aerosol. Concentrations of carrier solution were 0.85, 0.43, and 0.1% NaCl for curves A, B, and C, respectively. Mass median diameters were 0.8, 0.6 and 0.5 μm, respectively, with an associated geometric s.d. of 2.0.

deposition is closer to the natural deposition. Patients find it more comfortable to breathe through the nose, and this may be important for patients in respiratory distress.

It may be of interest to review the lung-delivery efficiencies obtained by systems using an ultrasonic nebulizer. The Washnich (*4*) system is perhaps the best described so far. He has used a special arrangement and generated aerosol of sizes "0.5 to 3.0 μm in higher proportions." Delivery efficiencies (as defined in col. 9 of Table 1) had ranged from 3.1 to 23%, with an average of 10.7%. The radioactivity placed in the generator varied from 20 to 35 mCi. Lung retention ranged from 1 to 4 mCi during an inhalation period of 3–15 min. Other investigators (*1–3*) do not provide such information for comparison with our results, but ours are seen to be better than those of Washnich (*4*).

No major advantages can be claimed for the ultrasonic nebulizer. The high-frequency nebulizers are expensive, they need a skilled technician to operate and maintain them, and they are also subject to drift, with consequent change in droplet-size distribution. In contrast, the compressed-air nebulizers can be made at a throwaway price (less than five dollars) and their performance is reproducible, if one takes the following precautions: (a) maintain constant pressure, and (b) keep the nebulizer clean by running it with alcohol for 2–3 min after each inhalation procedure. The system can be coupled to the laboratory's compressed-air outlet and the air can be made sterile by using a membrane filter paper.

CONCLUSION

The described system in this paper is inexpensive and easy to fabricate. The performance is reproducible and predictable. It is possible to control particle size by controlling the concentration of the carrier solution. An inhalation period of less than 5 min is sufficient to provide a lung image of good information density. The aerosol particles, being small and dry, provide lung images of improved quality. The system is adaptable to other solutions—even suspensions and colloids—with no modifications. The system's slight negative pressure makes it leakproof, so it can be operated in an ordinary room.

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REFERENCES

1. TAPLIN GV, ELAM D, GRISWOLD ML, et al: Aerosol inhalation in lung imaging. *Radiology* 112: 431–433, 1974

2. LIN MS, HAYES TM, GOODWIN DA, et al: Distal penetration in radioaerosol inhalation with an ultrasonic nebuliser. *Radiology* 112: 443–446, 1974

3. ITOH H, ISHII Y, SUZUKI T, et al: Inhalation scintigraphy with radioaerosols in bronchegenic carcinoma. *Radiology* 119: 623–631, 1976

4. WASNICH RD: A high frequency ultrasonic nebulizer system for radioaerosol delivery. *J Nucl Med* 17: 707–710, 1976

5. KOTRAPPA P, MAYYA YS, RAGHUNATH B, et al: The performance of nebuliser and air ejector made from section of hypodermic needles. *Ann Occup Hyg* 19: 363–366, 1977

6. MERCER TT: *Aerosol Technology in Hazards Evaluation.* New York, Academic Press, 1973, p 237

7. Deposition and Retention for Internal Dosimetry of the Human Respiratory Tract. Task Group on Lung Dynamics. *Health Phys* 12: 173–207, 1966