TECHNICAL NOTE

A Quantitative Evaluation of Breathing Systems Used with Kr-81m Generators

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A quantitative evaluation of breathing systems currently in use with Rb-81 → Kr-81m generators is presented. Four systems were evaluated: a reservoir unit, a disposable oxygen face mask unit, and two types of nasal oxygen cannula units. These systems were used on 30 patients. It was found that the reservoir breathing system (a) delivered approximately 10% more Kr-81m gas to the lungs, and (b) reduced the image collection time by a factor of two or more, compared with the other three systems.

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Krypton-81m is an inert short-lived ($T_{1/2}$ = 13 sec) radioactive gas; it is the daughter of Rb-81 ($T_{1/2}$ = 4.58 h) and can be supplied continuously from a Rb-81 → Kr-81m generator. Because of the many suitable physical, chemical, and physiological properties of Kr-81m [gamma photon energy of 190 KeV with an emission rate of 64.5%, low radiation dose to patients (*1*,*2*), low tissue absorption, etc.], the demand for this generator for pulmonary ventilation studies continues to increase. This demand cannot be met readily due to cyclotron production limitations: limited beam current, tolerance of beam current by the target windows and material, etc. There is, however, room for improving the efficiency of the generators at the site of use.

The breathing systems used with these generators vary between hospitals. The efficiency with which the Kr-81m gas is delivered to the patients is not the same for all systems. Use of a more efficient system could lead to an increase in production of relatively low strength, but usable, generators. The quantitative evaluation of the breathing systems does not appear to have been published previously. We present here an evaluation of four breathing systems currently in use, and discuss their merits and demerits.

MATERIALS

Four breathing systems were used: (a) A reservoir system consisting of a pair of anesthetic elephant tubes (500 cc) attached to a two-way nonreturnable valve and hung on a drip stand (Fig. 1). Krypton-81m gas was supplied continuously to the tube on the inlet side of the valve. The patient breathes through an anesthetic face mask held firmly against the face and connected to the valve. The expired Kr-81m air mixture is vented by way of the second tube away from the camera's field of view. Use of a two-way valve ensures that the concentration of CO_2 does not increase in the Kr-81m inlet side. (b) An oxygen face mask. (c) A nasal oxygen cannula with a soft sponge at the ends*. (d) A nasal oxygen cannula without sponge†. The method of delivering the Kr-81m gas in the last three systems was by connecting the generator outlet catheter as close as possible to the mask or the nasal units in use each time. An inorganic $ZrPO_4$ type of Rb-81 → Kr-81m generator was used.

METHOD

Thirty patients were studied. After a normal ventilation/perfusion sequence, each patient was asked to volunteer for the investigation. The patient breathed Kr-81m gas at a flow rate of 1 l/min (~10 mCi/min) from the generator via each system in turn. A 100 K-count (total field of view) posterior image was collected for each system with a gamma camera, and was stored by a com-

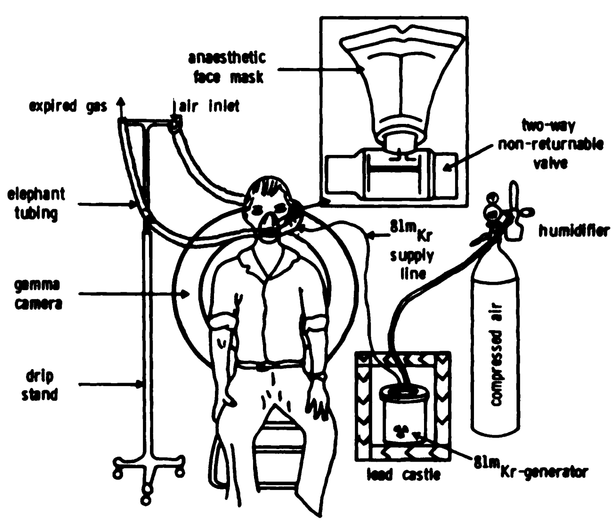

FIG. 1. Reservoir breathing system for delivery of Kr-81m gas to a patient.

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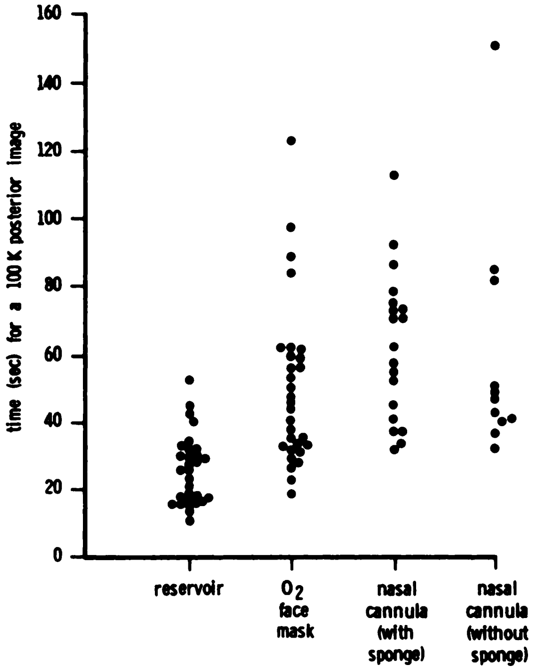

FIG. 2. Lung image collection times (100 Kcounts in total field of view) using four breathing systems.

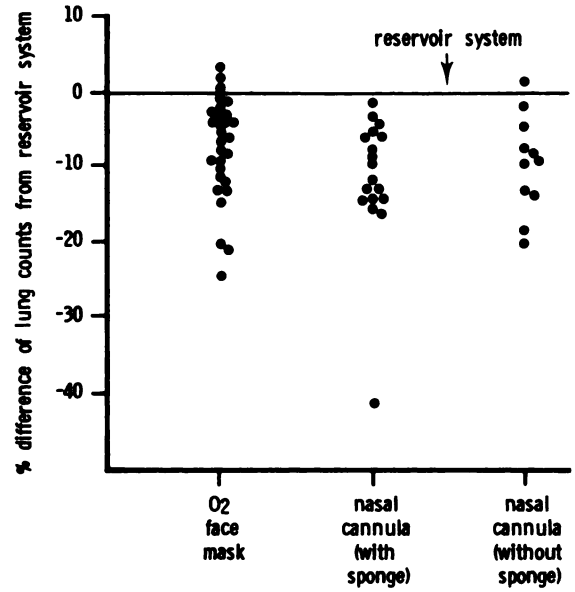

FIG. 3. Percentage difference between (a) total lung counts acquired with face-mask or nasal-cannula units and (b) those acquired with reservoir breathing system.

puter in 64 × 64 matrix. Each image collection time was recorded. Care was taken to avoid patient movement as breathing systems were changed. A fan was used to disperse the Kr-81m gas released from the breathing systems, to reduce the background in the field of view. A number of patients with severe shortness of breath could not comply with all breathing systems, especially the nasal cannula units.

The lung fields were delineated manually on a color television screen, and the total number of counts obtained within them. If the lung delineation for one breathing system did not fit accurately that of another, the latter was separately delineated. Total lung counts from each breathing system were subtracted from those of the reservoir system (found to be the most efficient) and the difference expressed as a percentage of the latter. The image collection time and the total lung counts of all breathing systems were compared using an unpaired Student's t-test, because of unequal number of data. However, paired t-test was performed on the data acquired with the reservoir and the face-mask breathing systems.

RESULTS AND DISCUSSION

The results are shown in Figs. 2 and 3 and in Table 1. Figure 2 shows a plot of the 100-Kcount image collection times of four breathing systems, and Fig. 3 the percentage difference between lung counts from three breathing systems and those of the reservoir system. The last is represented by a solid line set at zero. Table 1 shows the average counts in lungs, the image collection times for the four breathing systems, and their intercomparison using the unpaired Student's t-test.

The image collection time varies over a wide range but the variation is least in the reservoir system (Fig. 2), whose average image collection time is reduced by a factor of two or more compared with the three other breathing systems (Table 1). The reservoir system also delivers a greater quantity of Kr-81m gas (~10% more) to the lungs. Only in four tests did the face mask or the cannula unit perform better than the reservoir system (Fig. 3). Both the average lung counts and the image collection time of the reservoir system differed significantly ($p < 0.01$) from those of the face mask and the nasal cannula units. However, the latter three systems showed no significant statistical variation ($p > 0.05$)

TABLE 1. AVERAGE LUNG COUNTS AND COLLECTION TIMES FOR 100-KCOUNT IMAGES ACQUIRED BY THE FOUR BREATHING SYSTEMS.

Breathing systems	Number of patients examined	Average lung counts ± 1 s.d.	Average collection time(s) ± 1 s.d.
Reservoir system	30	79695 ± 4390	25.9 ± 10.1
Oxygen face mask	30	73430 ± 7078*	49.7 ± 23.5*
Oxygen nasal cannula (with soft sponge)	18	69353 ± 8316*	62.1 ± 21.9*
Oxygen nasal cannula (without sponge)	11	74202 ± 6291*	59.7 ± 34.6*

* Comparison with the reservoir system: Student's t-test, $p < 0.01$.

among them. Paired t-tests performed on the data acquired with the reservoir and the face-mask breathing systems showed even more significant variation ($p < 0.001$).

The achievement of greater efficiency with the reservoir system results because the patient breathes Kr-81m-air mixture from a reservoir that is replenished continuously by the flow of Kr-81m gas from the generator whether the patient is inspiring or expiring. By contrast, with the other three systems only a small volume of Kr-81m-air mixture becomes available to the patient before inspiration, and inspiration further dilutes the mixture with room air. In the expiration phase, however, the Kr-81m gas, delivered continuously from the generator, escapes from the system and is thus wasted. A greater proportion of Kr-81m gas delivered to the lungs by the reservoir system will produce lung images with better definition as a result of decreased background activity within the total field of view.

Tidal volumes vary from one patient to another. To match the requirement of individual patients, a reservoir system that can alter its volume so as to attain maximum specific activity of Kr-81m-air mixture may achieve even greater efficiency. We are currently investigating this.

The reservoir breathing system illustrated here has been used over the past year in our department. A large majority of the patients found it a satisfactory method of inhaling a Kr-81m-air mixture. Only a limited number, with severe shortness of breath, could not tolerate it. In such cases an oxygen face mask was used. Many patients found it difficult and uncomfortable to breathe via the nasal-cannula units; they caused sneezing in some cases.

We conclude that the use of a reservoir breathing system with a krypton generator of the kind described here will on average (a) improve the image collection time by a factor of 2 or more, and (b) deliver approximately 10% more Kr-81m gas to the lungs, thus reducing the background activity within the total field of view.

FOOTNOTES

* Pharma-Plast, Denmark.

† Supplied by Argyle.

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