

Left Heart Imaging Following Inhalation of ^{15}O -Carbon Dioxide: Concise Communication

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Accelerator-produced C^{15}O_2 ($t_{1/2} = 124$ sec) is a uniquely useful radio-pharmaceutical because it can be introduced rapidly and selectively into the left side of the heart by the simple noninvasive process of inhalation and breath-holding. A standard scintillation camera system was used to obtain images of the left heart by this technique. The procedure involves minimal radiation dose to the patient and may be repeated within a few minutes if necessary.

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Inhalation of C^{15}O_2 and breath-holding is a simple noninvasive method for introducing a radioactive tracer selectively into the left side of the heart, permitting the left heart to be imaged without interference from activity in the right heart. This facilitates clearer delineation of the left ventricular border and, because of the 511-keV photon from ^{15}O , yields images that are less vulnerable to absorption artifacts than those obtained with $^{99\text{m}}\text{Tc}$.

The diffusing capacity of the alveolar membrane for carbon dioxide is approximately 20 times that for oxygen or carbon monoxide (1-3). Inhaled C^{15}O_2 passes rapidly through the alveolar membrane and exchanges the ^{15}O label with water in the red cells of the pulmonary capillary circulation in a small fraction of a second (3-5). Subsequently, the tracer rapidly equilibrates with total body water.

In a healthy adult, one-half of the activity is cleared from the lungs in 2-5 sec. Delayed clearance has been observed in the presence of pulmonary edema (6). Studies of left heart hemodynamics with inhaled C^{15}O_2 have been reported (7-9). Previous attempts to image the left heart with a scintillation camera following C^{15}O_2 inhalation yielded unsatisfactory results (7), possibly because of insufficient millicurie dosage and inadequate collimation.

This report describes the methods used to obtain diagnostic-quality images of the left heart, following a single-breath inhalation of C^{15}O_2 , using a standard commercially available scintillation camera and com-

puter system. Calculated values of the related absorbed radiation doses are presented.

MATERIALS AND METHODS

Oxygen-15, a pure positron-emitter with a half-life of 124 sec, may be produced in an accelerator by bombarding nitrogen with deuterons in the reaction $^{14}\text{N}(\text{d}, \text{n})^{15}\text{O}$ or by bombarding oxygen with protons in the reaction $^{16}\text{O}(\text{p}, \text{pn})^{15}\text{O}$. The deuteron reaction method for the production of this radionuclide yields essentially carrier-free ^{15}O . Deuterons with energy 4 MeV or higher are suitable for the production of ^{15}O . In this work, both methods of production have been employed, using 26-MeV protons or 13-MeV deuterons from a medical cyclotron.

The ^{15}O is converted to C^{15}O_2 by passing the gas through an activated charcoal furnace at 500°C, followed by a cupric oxide furnace at 500°C to remove traces of carbon monoxide (10). The gas is then piped to the clinical area, a distance of 200 feet.

The imaging system consisted of a Dyna-4 camera interfaced to a Gamma-11 computer. Two 2.5-in.-thick medium-energy lead collimators with 1,900 hexagonal holes were stacked together with the holes aligned. The holes were $\frac{3}{16}$ in. across and the septa $\frac{1}{8}$ in. thick. This arrangement provides more than

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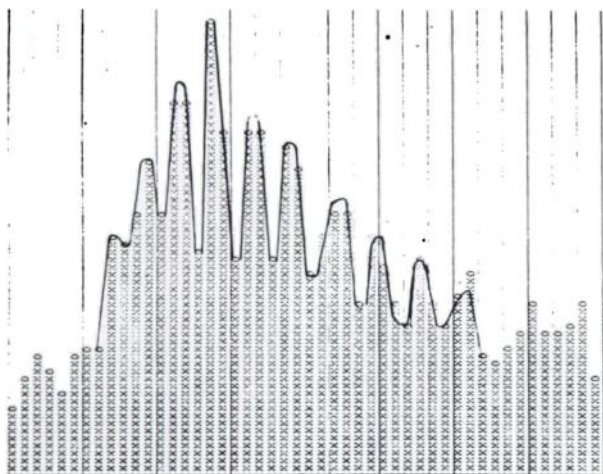


FIG. 1. Computer-generated histogram of count rate versus time for region of interest encompassing left ventricle, following inhalation of 40 mCi of $C^{15}O_2$. Time units are 0.2 sec. Peaks and valleys correspond to diastolic and systolic phases of cardiac cycle, respectively, and corresponding frames are summed to form diastolic and systolic images.

adequate collimation for the 0.511-MeV annihilation radiation from ^{15}O , giving a minimum septal thickness of $5.3\mu^{-1}$, where μ is the absorption coefficient and μ^{-1} is the mean free path (0.234 in.) of 0.51-MeV photons in lead. According to the Anger criterion (11), a minimum septal thickness of $3\mu^{-1}$, corresponding in this case to a collimator thickness of about 2.8 in., should be adequate to produce satisfactory images. A 20% energy window was used, centered at 0.51 MeV.

Forty millicuries of $C^{15}O_2$ was administered through a spirometer tube to a normal volunteer placed in the prone position over the camera. The activity, in 50 cm³ of air, was injected into the spirometer tube while the subject was at end tidal volume. A rapid inhalation to total lung capacity was then taken, followed by breath-holding for 10 sec to ensure that the activity diffused as completely as possible from the alveolar space into the capillary blood (4). Serial anterior images of the left heart were obtained and stored digitally on disk in a 64×64 matrix, at a rate of five frames per second for a total period of 10 sec after the inhalation.

Image processing was performed as follows: a region of interest was selected encompassing the ventricle, which begins to appear approximately 2 sec after inhalation, and a count-time histogram was generated for this region, as shown in Fig. 1, where the time units are 0.2 sec, the time for a single frame. The frames that correspond approximately to end-systole and end-diastole will contain the lowest and highest counts, respectively, and can be selected from the histogram. Nine systolic and nine diastolic frames selected in this way are indicated in Fig. 1.

RESULTS

The end-systolic and end-diastolic frames identified in Fig. 1 were summed separately and displayed as shown in Fig. 2. A single nine-point smoothing and 40% background subtraction have been applied to each image. These studies were performed on a normal adult male volunteer.

A second study was performed on an adult male volunteer with a documented history of idiopathic hypertrophic subaortic stenosis. The procedure used

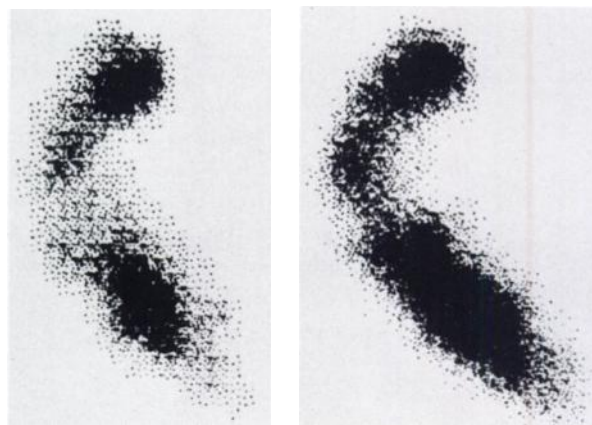


FIG. 2. Systolic and diastolic images of normal left heart following inhalation of 40 mCi of $C^{15}O_2$. Nine-point smoothing and 40% background subtraction have been applied.

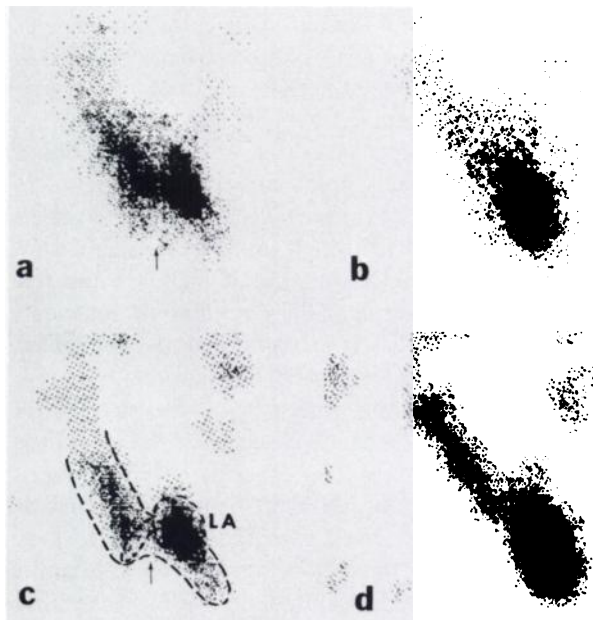
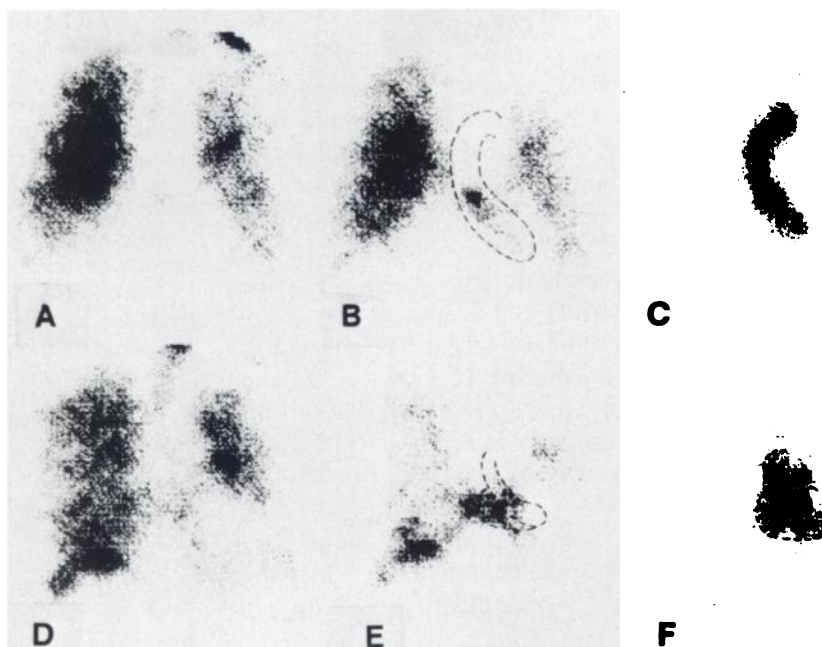


FIG. 3. Left anterior oblique views of patient with documented idiopathic hypertrophic subaortic stenosis, taken after inhalation of 40 mCi of $C^{15}O_2$. A and B are systolic and diastolic phase pictures. Total number of counts in diastolic image is 8,000. C and D show effect of applying a modified second spatial derivative filter to A and B to delineate edges only. Positions of left atrium (LA), aortic and mitral valve rings, and stenotic area are indicated.

FIG. 4. Sequential $C^{15}O_2$ images of normal subject (top) and patient with sinus venosus atrial septal defect (bottom) in anterior projection. Pulmonary-to-systemic flow ratio in patient with septal defect is 3. (A) Lung phase at time of inhalation. (B) Early left atrial filling phase at 1 sec after inhalation. (C) Left heart phase. Note absence of activity in right heart. (D) Lung phase. (E) Early left atrial filling phase showing simultaneous appearance of activity in pulmonary veins, right atrium, and left atrium with activity appearing in right ventricle prior to left ventricular filling. (F) Left heart phase with activity now filling all heart chambers because of shunt flow.



was the same, except that the images were taken in the left anterior oblique position. Figure 3 shows the processed images corresponding to systole and diastole. The asymmetric motion of the upper septal wall of the left ventricle may be appreciated from these images. The prominent appearance of the left atrium at end-systole, as compared with a typical ^{99m}Tc picture, is partly due to the much lower attenuation of the 511-keV radiation from ^{15}O .

A third study was performed on a patient with a documented sinus venosus atrial septal defect with a pulmonary-to-systemic flow ratio of 3. Figure 4 shows the resulting images and compares them with the corresponding phases of a normal study. Both studies were done in the anterior projection. The effect of shunt flow on the image is clearly seen.

The absorbed radiation doses resulting from this procedure are listed in Table 1. These were calculated for a 70-kg adult according to the methods and data in *MIRD Pamphlet No. 11*. The inhaled activity is assumed to leave the lungs as a single-exponential washout with a half-time of 5 sec. In addition, instantaneous uniform distribution and 100% retention in the whole body were assumed.

DISCUSSION

The feasibility of obtaining images of the left heart following a single-breath inhalation of ^{15}O -labeled carbon dioxide has been shown using a standard commercially available scintillation camera system. Such cameras have a low sensitivity for counting the 0.51-MeV photons from ^{15}O because the 0.5-in.-thick NaI(Tl) crystal has a photopeak efficiency of

only about 15% at 0.51 MeV, compared to almost 90% for the 140-keV photons from ^{99m}Tc . The necessity for thicker collimation than that used for the 140-keV photons further decreases the sensitivity. Despite these limitations and the very short time available for acquiring the data, diagnostic-quality images of the left heart were obtained. The resulting absorbed radiation dose was approximately equal to that which would have been received from 4 mCi of ^{99m}Tc -HSA (critical organ).

The selection of a sampling rate of five frames per second was dictated mainly by statistical limitations. A higher framing rate would be desirable to obtain images closer to true end-systole and end-diastole.

A collimator having a similar design to that used in this study, but 3.5 in. thick, would increase the sen-

TABLE 1. ABSORBED RADIATION DOSE FOLLOWING SINGLE-BREATH INHALATION OF $C^{15}O_2$ (70-kg MAN)

Tissue	Radiation dose (mrad/mCi)
Lung	5.0
Whole body	1.6
Testes	1.8
Ovaries	1.7
Blood	7.4

For comparison, the whole-body and blood doses from intravenously administered ^{99m}Tc -HSA are approximately 20 and 70 mrad/mCi, respectively (12).

sitivity by a factor of 2 (11). Using a wider energy window and a graded absorber to minimize scatter acceptance would yield a further increase in sensitivity by a factor of 2 (13). The maximum count rate observed in this study using the 5-in.-thick collimator and a 20% energy window in this study was 15,000 counts per second.

The procedure described for obtaining left heart images is rapid, safe, and noninvasive. Since there is no venipuncture, sterility and nonpyrogenicity of the tracer do not have to be established. Because of the very short effective half-time of ^{15}O , the radiation dose from 40 mCi of C^{15}O_2 is less than that received from a 10-mCi intravenous injection of $^{99\text{m}}\text{Tc}$ -HSA, and the procedure may be repeated within a few minutes if necessary.

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SNM TECHNOLOGIST SECTION 24th Annual Meeting

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SECOND CALL FOR PAPERS: NUCLEAR MEDICINE TECHNOLOGISTS PROGRAM

The Technologist Section has set aside time for a nuclear medicine technologists program at the 24th Annual Meeting in Chicago, June 20-23, 1977.

The Scientific Program Committee welcomes the submission of abstracts for 12-min papers from technologists for the meeting. Abstracts must be submitted on an official abstract form. The format of the abstracts must follow the requirements set down on the abstract form. These abstract forms are available only from the Technologist Section, Society of Nuclear Medicine, 475 Park Ave. South, New York, NY 10016.

In addition, the Program Committee invites abstracts for papers from students presently enrolled in schools of nuclear medicine technology. Special time will be set aside for a student session.

Accepted abstracts will be published in the June issue of the *Journal of Nuclear Medicine Technology*. Awards will be given for outstanding papers.

Send abstract form to Stephen A. Kuhn, Iowa Methodist Hospital, 1200 Pleasant, Des Moines, IA 50308. Telephone: (515) 283-6458.

DEADLINE: February 10, 1977