COINCIDENCE AND NONCOINCIDENCE COUNTING (^{81}Rb AND ^{43}K): A COMPARATIVE STUDY

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This paper compares the accuracy of imaging and resolution obtained with ^{81}Rb and ^{43}K using coincidence and noncoincidence counting. Phantoms and isolated infarcted dog hearts were used. The results clearly show the superiority of coincidence counting with a resolution of 0.5 cm. Noncoincidence counting failed to reveal even sizable defects in the radioactive source.

Within recent years a series of papers have been published dealing with heart imaging using radionuclides (*1–5*). The most frequently used isotopes are ^{43}K and more recently ^{81}Rb. The latter is more easily produced, its manufacture is less expensive, and it has a shorter half-life. The main difference between the two nuclides is that ^{81}Rb is a positron emitter that disintegrates at a high rate per unit of time and which emits high-energy gamma rays. Previous studies from this laboratory have demonstrated the advantage of using positron emitters with electron capture in combination with coincidence counting (*6,7*). However, none of the papers published on ^{81}Rb have made use of the properties of this isotope as a positron emitter and few reports have been published using coincidence counting in imaging of the heart (*8,9*).

It is the purpose of this report to compare imaging with ^{81}Rb with and without coincidence counting using phantom preparations and isolated arrested dog hearts. Special emphasis will be on the degree of resolution. These results will be compared with those obtained with ^{43}K.

MATERIALS AND METHODS

Rubidium-81-chloride was obtained as a cyclotron-produced, sterile, apyrogenic radiochemical from a commercial source (Medi-Physics, Inc., Emeryville, Calif.). Rubidium-81 decays with a 4.7-hr half-life to ^{81m}Kr and ^{81}Kr by electron capture (87% of the time) and positron emission (13% of the time). These positrons emitted from ^{81}Rb disintegrate by striking an electron; the positron and electron are annihilated and two 0.51-MeV gamma ray photons are produced that travel in opposite directions along a straight line away from the source (*10*). Because of the two photons traveling at the speed of light, they will reach nearby detectors essentially at the same instant.

The principal radiations arising from decay of ^{81}Rb and its decay products are 0.446 MeV (23.5% abundant), 0.511 MeV (67% abundant from positron emission), and 0.190 MeV (64.5% abundant) from decay of ^{81m}Kr. The decay energy amounts to 2.05 MeV (*10*). Rubidium-87, as shipped, contains appreciable amounts of ^{82}Rb (less than 0.33 mCi/ml) and negligible amounts of ^{83}Rb and ^{84}Rb at calibration time. However, the setting of the energy window in our system will accept all β^+ emitters.

Potassium-43 decays by negatron (β^-) emission to stable ^{43}Ca with a half-life of 22.4 hr (*10*). The principal gamma rays associated with this decay are 370–394 keV (103% abundant) and 590–610 keV (94% abundant).

The equipment used for these experiments permitted counting with and without coincidence. It included a pair of heavily shielded scintillation crystals coupled to photomultiplier tubes and connected to coincidence electronics (MDH Industries, Inc., Pasadena, Calif.). It must be emphasized at this point that the equipment used here is inadequate for imaging the beating heart in situ. This is because only two detectors are available in coincidence and because the uptake of rubidium by the heart remains constant only for a limited period of time (90–270 sec) (*7*). The use of only one pair of detectors precludes imaging of the whole heart in this short period of time. The detectors consisted of 5-cm-diam and 5-cm-high circular cylinders of NaI(Tl) scintillator connected to photomultiplier tubes and coincidence electronics. The active area of the detector was restricted to a circular window of 2 cm diam by a 5-cm-thick lead collimator to allow myocardial imaging with suffi-

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TABLE 1. COMPARISON BETWEEN COINCIDENCE AND NONCOINCIDENCE IMAGING OF THE HEART (^{81}Rb or ^{43}K)

Experiment (No.)	Isotope	Figure (No.)
Phantom experiments		
1	^{81}Rb	1 (Exp 1)
2a, b, c, d	^{81}Rb*	3 (Exp 2a)
3	^{43}K	2 (Exp 3)
4	^{43}K	
5	^{81}Rb	
6	^{81}Rb	
7a, b, c	^{81}Rb*	
8	^{43}K*	
Arrested excised heart		
9	^{43}K	5
10a, b	^{81}Rb	
11	^{43}K	
12a, b	^{81}Rb	4A, B

* Resolution experiment.

cient spatial resolution. In order to reduce sufficiently accidental counts, it was extremely important to shield the curved surfaces of each detector with 5 cm of lead; thus, each detector was surrounded by a 5-cm-thick lead cup.

Both detectors are connected electronically; the electronics provided a coincidence-resolving time of 40 nsec.

Using both coincidence counting and lead collimation, the field of view of the detectors is well defined and the dependence of counting rates and resolution on the distance between subject and detector is small. The opposing two detectors in coincidence exhibit a sensitivity of 38.4 cpm/μCi ^{81}Rb. The gamma-energy window was set to include both the 0.446- and 0.551-MeV photons resulting from decay of the β^+ emitters.

Phantom models. In experiments concerned with comparisons of coincidence and noncoincidence counting in phantoms (Experiments 1, 3, 4, 5, and 6, Table 1), a filter paper of 12.5 cm diam and with a center hole of 4 $\times$ 4 cm was soaked in 0.5 mCi of ^{81}Rb. The paper was then dried and placed in a Petri dish. Using ^{43}K, the filter paper was soaked in 0.2 mCi of this isotope. Every 1 cm of the filter paper was then counted in sequence using coincidence and noncoincidence counting. With ^{43}K, only noncoincidence counting was used since this isotope decays only by negatron emission.

When resolution experiments were carried out (Experiments 2, 7, and 8, Table 1), a filter paper of 12.5 cm diam was used. Square openings (2 $\times$ 2 cm) were cut into the paper and the distance between these openings was varied to from 0.5 to 3 cm. The filter paper was then soaked in ^{81}Rb or ^{43}K and 0.5 cm of the filter paper was counted passing through the center of both squares.

Isolated excised heart. Dogs anesthetized with an intravenous injection of sodium pentobarbital (30 mg/kg) were placed on artificial respiration using room air (Experiments 9–12, Table 1). After left thoracotomy in the fifth intercostal space, the left anterior descending coronary artery was ligated with silk threads distal to the origin of the main septal branch. Arrhythmias were prevented by an injection of an intravenous bolus of lidocaine (20 mg) followed by a slow drip (30 mg/hr). One to two hr after ligation of the coronary arteries, 2 mCi of ^{81}Rb or 0.8 mCi of ^{43}K were injected intravenously. The heart was excised and counted 2–3 min later. This was accomplished by placing the heart positioned as in situ on the table between the two detectors. The heart was then moved 1 cm on the table and counts were taken for 30 sec in each position. This continued until the whole anterior projection of the heart had been covered. Total counting usually proceeded for 2 hr. Since there was no exchange of rubidium to and from the blood, the counts remained stable over that period of time. The digital printout of the different counts was corrected for the decay rate of the isotopes.

RESULTS AND DISCUSSION

Results obtained on phantom models. Table 1 shows that five tests were carried out to study both the degree of resolution and to see how closely nuclide imaging reflected the aperture in the filter paper (Experiments 1–8). Figure 1 compares counts recorded with and without coincidence. The left half

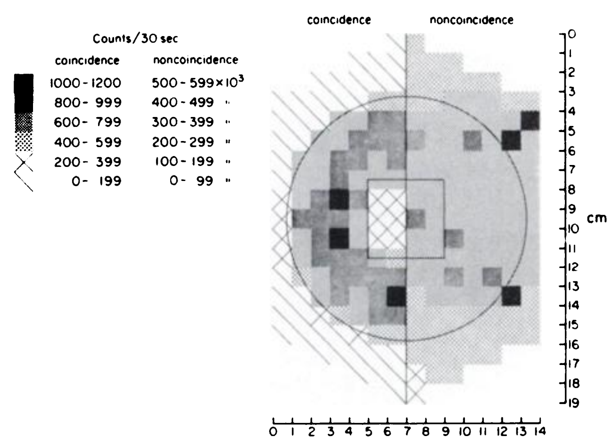

FIG. 1. Experiment 1. Comparison of coincidence with ^{81}Rb noncoincidence counting using phantom (filter paper without cutout square hole). Only left half of figure, as imaged by coincidence counting, shows cutout in filter paper. Circle shows outline of filter paper soaked in ^{81}Rb.

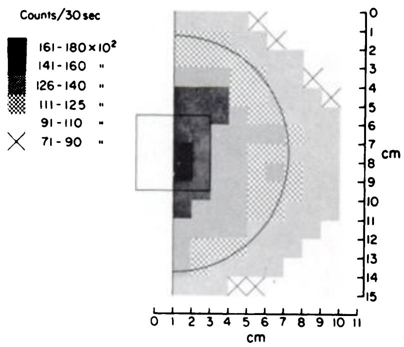

FIG. 2. Experiment 3. Phantom (filter paper soaked in ^{43}K with square cutout hole, noncoincidence counting). Cutout square is not imaged.

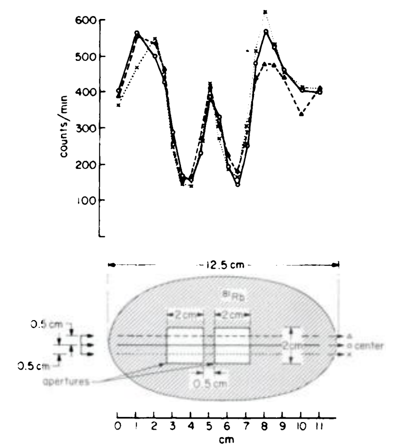

FIG. 3. Experiment 2a. Resolution on phantom using coincidence counting (^{81}Rb). Two square cutouts were made in filter paper soaked in ^{81}Rb. Distance between 2 cutouts is 0.5 cm. Counting was performed along three parallel lines at 0.5 cm distance passing through center of both squares (lower panel). Upper panel shows excellent resolution obtained, as indicated by sharp decline in counts/min over cutout, and rising counts obtained in small (0.5 cm) region of filter paper, separating cutouts.

of the figure, as imaged in coincidence, clearly delineates the aperture in the filter paper. In contrast, counting with a single detector (noncoincidence) completely fails to image the square opening in the paper. The use of the same technique employing ^{43}K also fails to show any contrast between the emitting filter paper and the cutout square (Fig. 2).

Figure 3 illustrates the degree of resolution obtained with ^{81}Rb (Experiments 2a, b, c, and d; 7a, b, and c; Table 1). In Fig. 3 the distance between the two square openings is 0.5 cm. It can be seen in the upper panel of this figure that the square cutout in the filter paper coincides with a sharp fall in counts and that the presence of as little as 0.5 cm of radiating source (filter paper) between these two cutouts is reflected in a sharp rise in counts. In contrast, in separate experiments resolution tests using ^{43}K with single detectors failed to image the two cutouts (Experiments 7a, b, and c).

Results obtained on the infarcted heart. These observations find further confirmation in experiments in which the infarcted, arrested, and excised heart was counted (Experiments 9–12, Table 1). Figures 4A and B illustrate typical experiments. Figure 4A shows that counting in coincidence with ^{81}Rb sharply delineates the infarcted region; by contrast, as illustrated in Fig. 4B, it is difficult to recognize the infarcted region using noncoincidence counting with ^{81}Rb. As shown in Fig. 5, imaging of the excised and arrested dog heart with ^{43}K fails to show the infarcted region with noncoincidence techniques.

These results clearly illustrate the superiority of coincidence counting. They demonstrate that coincidence counting permits clear delineation of a "cold spot" with a resolution of as little as 0.5 cm. Counting without coincidence does not discriminate small "cold spots" in the model and fails to outline the infarcted area in the arrested excised heart. It is unlikely that the use of multicrystal detectors or scintillation cameras counting not in coincidence would be sufficient to increase the resolution. In our experiments, in principle, multicrystal imaging was carried

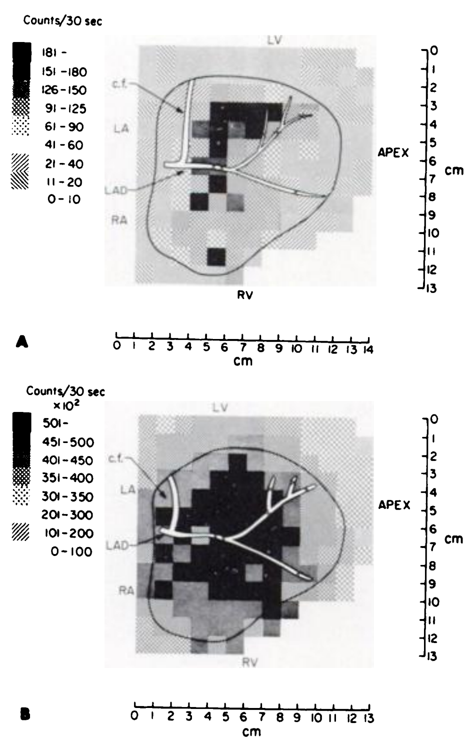

FIG. 4. (A) Experiment 12a. Result of imaging of excised arrested dog heart. Rubidium-81 (2 mCi) injected intravenously into dog 3 min prior to removal of heart. Two hr prior to this, main descending branch of left anterior descending coronary artery and side branches were ligated. Diminution in counts in region supplied by ligated arteries is shown. (B) Experiment 12b. Imaging of heart identical to (A) except that counting was not carried out in coincidence. Infarcted region is not visualized.

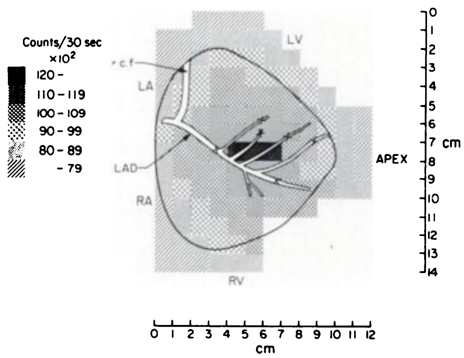

FIG. 5. Experiment 9. Result of imaging of excised, arrested dog heart with ^{43}K injected 3 min prior to excision of heart. Two hr before, the main left anterior descending coronary artery and its side branches were ligated. Infarcted region is not visualized.

out since the object (phantom or heart) was moved in sequence beneath a single crystal.

With these results in mind, it is difficult to see how, using noncoincidence counting in the beating heart in situ, any "cold spots" can be detected using either ^{43}K or ^{81}Rb. Unfortunately, limitations in our equipment (use of only two detectors) makes comparison of coincidence with noncoincidence counting in the beating heart in situ difficult, since the uptake of ^{81}Rb by the heart remains constant only for from 90 to 270 sec (*7*). Therefore, the use of only one pair of detectors precludes imaging the whole heart in this short period of time.

It is certain that the difficulties in resolution encountered with noncoincidence techniques would also have been present under in vivo conditions. Smith and associates have already demonstrated the advantage of a high-resolution multicrystal positron camera interfaced with a computer system (*8,9*). Their studies in a canine experimental model have shown that intravenous injection of $^{13}NH_4^+$ results in myocardial uptake permitting high-resolution tomographic images (*9*).

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