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# What is the Purpose of Emission Computed Tomography in Nuclear Medicine?

Is radionuclide emission computed tomography (ECT) a mathematical and physical concept, an instrument, a radionuclide tracer technique, a research or diagnostic procedure, a new or old concept? Is it a,b, etc., none of the above, or all of the above? To a greater extent it is or will be all of the above.

Computed tomography (CT) goes by many names composed of combinatons of words: section, tomography, transverse, transverse-axial, transaxial, computed, computerized, reconstruction, etc., but probably the most important terms are reconstruction and tomography. This can be appreciated from the fact that the fundamental approach of CT is exact (or near exact) three-dimensional reconstruction of a tomographic section from a series of one-dimensional projections of an object. Reconstruction can be accomplished in the transaxial or longitudinal direction or at any angle between these two extremes. The mathematical techniques (algorithms) and assumptions of reconstruction tomography are common to both x-ray and radionuclide CT and are reviewed elsewhere *(1-3)*.

The important physical factors which must be taken into account in ECT are: (i) the requirement of uniform or near uniform detector resolution and response (efficiency) with depth; (ii) accurate correction for photon attenuation; (iii) removal or significant reduction of scatter radiation to assure detector response represents the linear sum of activity viewed and provides high contrast and sensitivity; (iv) accurate detector positioning and sampling (both linear and angular) to provide optimum reconstructed image quality; and (v) detection system with high efficiency to meet the demanding statistical requirements of CT. While these factors have been presented in the literature, the explicit and quantitative relationships among them and the manner in which they affect the quality of the ECT image have yet to be determined.

A number of ECT systems have been or are being constructed at this time (Table 1). These systems can be separated into two categories: (a) systems which employ single photon counting (SPC) such as scanners and cameras for $^{99m}$Tc, $^{131}$I, $^{123}$I, etc., and (b) systems which employ annihilation coincidence detection (ACD) of positron-emitting radionuclides. During the past several years there have been many discussions, presentations, and published papers which have discussed advantages and disadvantages of each of these techniques. From all of this there are several points which appear to be more clear than others. Approximately an equal number of investigators and commercial companies have chosen to pursue each approach. To date, in human subjects, SPC systems have been used primarily for brain, whereas ACD has been used for whole-body studies. This primarily results from the fact that the methods for maintaining a relative constant resolution with depth (e.g., summing or geometric mean of opposing views) and approximation methods for attenuation correction with SPC have so far been demonstrated only in small, uniform, and symmetrical objects like the head *(1, 4-6)*. Theoretical methods that may prove acceptable have been developed for the attenuation correction problem *(1)*. The ACD provides a method in which attenuation is fundamentally a slow varying function, correctable by an exact or near exact technique even as object size and local variation in attenuation become large *(7,8)*. Annihilation concidence detection also provides resolution and high contrast that is depth independent as the object size increases *(7-10)*. The unique capability of ACD to collect data with the high geometric efficiency *(7-11)* of a fan beam (transaxial CT; data collection in x, $\theta$) or a cone beam (direct three-dimensional tomography; data collection in x, y, $\theta$, and $\phi$, where $\phi$ is perpendicular to angle of rotation, $\theta$) consistent with the assumptions of reconstruction tomography is also advantageous.

On the other hand, SPC has the advantage, as discussed by Kuhl et al. *(4)*, Keyes et al. *(5)*, Jaszczak et al. *(6)*, and others, that it can be used with either existing or new radiopharmaceuticals labeled with $^{99m}$Tc and other commercially available radionuclides. This is contrasted to the disadvantage of ACD of requiring an on-site accelerator for studies employing $^{11}$C, $^{13}$N, and $^{15}$O. As has been discussed earlier *(12)*, this disadvantage may be offset to some degree by the availability of a commercial generator system of $^{68}$Ge-$^{68}$Ga, the generator system of $^{82}$Sr-$^{82}$Rb, and $^{18}$F (commercially available). These positron-emitting radionuclides could be used to label a wide variety of presently uti-

**TABLE 1. EMISSION TRANSAXIAL TOMOGRAPHS***

| Institution or company | Application | | Detection† mode |
|---|---|---|---|
| Univ. of Penn. (MARK IV) | Head | Sq. array scanner | SPC |
| Univ. of Aberdeen | Body | Single head camera | SPC |
| Mark IV | Head | Sq. Array Scan | SPC |
| Univ. of Michigan | Body | Single head camera | SPC |
| Donner Lab., Univ. of Calif. | Body | Single head camera | SPC |
| Univ. of Aberdeen | Body | Sq. array scanner | SPC |
| Univ. of Aberdeen & J & P Engineering Co. | Body | Dual array scanner | SPC |
| Searle & Baylor Univ. | Head | Single head camera | SPC |
| UCLA & Ortec Inc. (ECAT) | Body | Hexagonal array | ACD |
| Washington Univ. (PETT III, IV) | Body | Hexagonal array scanner | ACD |
| Massachusetts Gen. Hosp. & Cyclotron Corp. | Body | Dual head multiple detector | ACD |
| UCLA (CRTAPC) | Body | Circ. array scanner | ACD |
| Brookhaven Natl. Lab.‡ | Head | Circ. array scanner | ACD |
| Donner Lab., Univ of Calif. | Body | Circ. array scanner | ACD |
| Searle & Univ. of Chicago | Body | Dual head camera | ACD |

* Adapted from Ref. 3. Table 2.
† SPC represents Single Photon Counting as employed in conventional scanners and scintillation cameras. ACD represents Annihilation Coincidence Detection of positron emission.
‡ Presently at Montreal Neurol. Institute.

lized radiopharmaceuticals and for development of new labeled compounds to be used with the imaging advantages of ACD.

Cost is certainly another factor which must be considered. Keyes et al. *(5)* state that one of the reasons for using a camera for ECT is the lower cost resulting from the use of conventional technology *(5)*. But as if a complete systems are considered, there may be no cost differences between SPC or ACD tomographs, since the majority of cost factors are common to both systems. Cost does become a significant factor when one considers the desire to have an on-site capability for producing $^{11}C$, $^{13}N$, $^{15}O$, etc. This matter must be resolved by clearly and definitively establishing the true bottom-line cost for a compact, self-shielded, reliable, simple-to-use cyclotron (or some other type of accelerator) consistent with the criteria and needs of a clinical environment (e.g., not a flexible research machine).

Keyes et al. *(5)* discuss the advantage of being able simultaneously to record multiple slices with the gamma camera. This is a cost design decision, however, as to whether the total system efficiency is oriented to maximize it in the two-dimensional projection (e.g., like the camera) or the transaxial plane (e.g., like most specifically designed transaxial tomographs). The latter has the potential advantage of being able to perform a single slice rapidly to minimize movement artifacts and the general advantage of maximizing the detector efficiency to the organ of interest (e.g., much of a camera field of view includes regions above and below the organ that may not be important and thus a portion of system efficiency is lost). Even though all ECT systems have the capability (or potential) to provide a conventional two-dimensional projection image also (e.g., two-dimensional scan), the camera systems typically provide a higher efficiency and a stationary full field view in this imaging mode.

At this point there still remain advantages and disadvantages to SPC and ACD tomography and more definitive data are needed to clarify the individual points of concern. If we assume that the physical factors, instrument design, and cost factors have been resolved, however, one must ask what is the objective of ECT. Is it to produce a better instrument, improve image contrast and spatial description of lesions, improve detection rates, etc.? The answer to this question may rest in the understanding of what ECT allows one to do that couldn't be done before. Probably the most important factor is the capability to section an organ tomographically into a map of *quantitative* tracer concentration with high resolution and accuracy. This, added to image improvement from the removal of the superimposition of information in two-dimensional imaging and improvement in image contrast, is a means to measure physiologic

function that has not existed in the past. Emission computed tomography can be thought of as a technique for performing "in vivo autoradiography." The physiologic ECT models for this technique can be derived from autoradiographic and other existing models that can be put into a form consistent with the criteria of ECT.

The question of whether ECT can perform dynamic studies has arisen frequently. In the conventional approach to dynamic studies such as blood flow with rapid time sampling, the answer is probably negative because of statistical limitations. It should be remembered that in tomography one is trying to detect accurately the activity in very small volumes (e.g., 1- or 2-cm cubes). In a conventional cerebral blood flow study with a scintillation camera, the image of the whole organ is severely limited statistically without imposing the added requirement of approximately an equivalent number of counts for each selected transaxial slice of the organ. If tomographic studies of dynamic processes are to be accomplished by rapid time sampling, the ECT must be able to (i) collect all necessary angular and linear samples in a time short compared to tracer clearance rate, (ii) collect the required number of counts per plane to form an acceptable image, and (iii) simultaneously record all planes required or subject patient to multiple isotope injections.

Thus it would appear that conventional dynamic studies and ECT are somewhat at odds. The term "dynamic studies" refers, however, to a broader category of function measurements accomplished by approaches which are consistent with ECT. This can be achieved by (a) rearranging the present dynamic models (differential equation rate models) to an accumulation (integral equations) model. Many of these models exist in the field of quantitative autoradiography and others can be developed by reformulation of existing dynamic models. For example the MARK IV tomograph has been successfully used to measure the cross-sectional distribution of the cerebral glucose metabolic rate in milligram units of glucose utilized/min/100 gm with $^{18}$F-2-deoxyglucose *(13,14)*; (b) using labeled compounds which accumulate and are retained in tissue in proportion to blood flow, metabolism, etc., in which tissue concentration is static or slowly changing at time of measurement; (c) maintaining a static distribution with steady-state infusions; (d) using dynamic models when the rate of the process is slow compared to ECT measurement time; and (e) using multiple short time sampling of repetitive motion of the heart.

The advent and rapid growth of transmission CT has posed a significant challenge to nuclear medicine. The approach to CT can be divided into two categories: (1) *morphologic tomography* with transmission CT and (2) *physiologic or function tomography* with ECT. Useful application of the former is advanced well ahead of the latter and efforts should be put forth to develop the unique capabilities of ECT to provide quantitative information about blood flow and volume (vascular perfusion, vasodilation, vasoconstriction, vasoparalysis, autoregulation, etc.), metabolism (cell viability, metabolic shunts, aerobic/anaerobic ratios, metabolic acidosis, etc.), substrate and ion transport, and a wide variety of other function indicators. The success of this approach is very much dependent on the availability of labeled compounds whose properties are consistent with the above objectives. This aspect lends support to the concept of developing an accelerator-based generator system for routine production of $^{11}$C, $^{13}$N, and $^{15}$O because of the capability to synthesize chemically a wide variety of labeled natural substrates, analogs, drugs, etc., with biosynthetic (enzymatic and photosynthetic) and organic reactions. Thus, the chemical labeling capabilities and the types of labeled compounds produced will also play a determining role in the success of ECT and the selection of SPC or ACD.

Emission computed tomography is a mathematical and physical concept, an instrument, a radionuclide tracer technique, and a research procedure and it is certainly both an old (Kuhl began his work in the late 1950s) and a new concept. It also has great and unique potential as a diagnostic technique. The concept of "physiologic or function tomography" provides a technique to advance the original charter of nuclear medicine in the use of radionuclides for the measure of metabolism and physiologic function.

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