LETTERS TO THE EDITOR

PET = Positron+Electron Transmutation

Historically, Einstein taught us 75 years ago (*1*) that matter and energy are but different forms of the same physical entity. The proportionality constant he derived to relate them is the velocity of light squared, and the equality becomes $E = mc^2$. This famous simple equation implies that, under appropriate conditions, matter may be transmuted into energy, and vice versa. A minuscule bit of matter disappears as such by transmutation *spontaneously* into any of the various forms of energy, the manifestations of which make the nuclear disintegrations of radionuclides useful to us in "nuclear" medicine. In fact, Einstein implied in his brief paper (*1*) that proof of his theory might be found in radium salts where the changes in mass may be sufficiently great to be demonstrable.

And even Newton is said to have commented (*2*) centuries before Einstein upon the delight of nature in transmutations in respect to the changing of bodies into light, and light into bodies when he posed the question as to whether gross bodies and light are convertible one into the other.

Instruments and technologies rapidly are emerging that depend upon *events that follow* the emission of a positron, usually. The discovery of this mode of radioactive decay was involved coincidentally with the discovery of artificial radioactivity by F. Joliot and I. Curie in Paris in 1934 (*3*) when they found that phosphorus-30 and nitrogen-13 emitted positrons. Whenever a positron is emitted from the nucleus of a "positron emitter" [$^{+}\beta$-nuclide] into matter, such as tissues and organs, it very *rapidly* loses its kinetic energy by repeated encounters with negative electrons until it coalesces transiently with one of them and the positron+electron pair then transmutes from matter into energy. Predominantly, this energy manifests itself as two $^{\pm}\gamma$-quanta each of which usually has an energy of 511 keV, the energy equivalent to the mass of an electron, in accordance with Einstein's equation, $E = mc^2$. Here, m is 9.1×10^{-28} g, the mass of each electron, at rest. To conserve momentum, the two $^{\pm}\gamma$-quanta are emitted "back-to-back" at 180 ± 0.3 degrees to each other. Obviously, then, *transmutation* of matter into energy occurs; but "annihilation" does not, for we continue to recognize the same entity *in another physical form.* Obviously, too, the term, "annihilation," is a misnomer, although it has come into fairly common usage. In a consideration of the word, *transmute,* in a standard dictionary (*4*), Gerard Piel states ... "energy converts into matter as naturally as matter transmutes into energy."

Exploitation of the inherent "directionality," usually available incidental to emission of the two $^{\pm}\gamma$-quanta to locate the positions taken by accumulations of $^{+}\beta$-nuclides in biomedical matter, first was advocated and demonstrated three decades ago (*5*). Several advances in the pertinent instrumentation have taken place since then (*6*) and a plethora of terms have appeared to symbolize the same phenomena.

Since the basic physical process involved is the *transmutation* of a positron+electron pair predominantly into the two 511-keV $^{\pm}\gamma$-quanta, it seems appropriate that the acronym, PET, might be adopted to serve as a suitable succinct symbolic abbreviation for the compound term, "Positron+Electron Transmutation." "PET camera" more realistically indicates the inherent physical phenomena upon which the instrument depends than does "positron camera." "PET Tomography" (*6*) also more aptly expresses the nature of the process, which rapidly is becoming a significant part of nuclear biomedicine, than does "Positron Emission Tomography." To be sure, the emission of a positron is involved; but, it is the transmutation *subsequently* of the positron+electron pair into the $^{\pm}\gamma$-quanta pair, which is the essential central feature of the process that interests us.

Then, out of respect for, and our appreciation of, the intuition of Einstein (*1*), as we enter the second century following his birth, the current historian of The Society of Nuclear Medicine suggests that we annihilate "annihilate" from our terminology when we wish to indicate the occurrence of "Positron+Electron Transmutation" by adopting the acronym, PET, to symbolize the phenomenon. It seems desirable that we would wish to choose a symbolism that approaches as nearly as possible to "where the action is" of the physical process we are exploiting.

In this way we will avoid the pitfalls stemming from loose terminology, described long ago (*7*) ... "Come, let us go down, and there make such a babble of their language that they will not understand one another's speech." ... Incidentally, this historian was unable to find an *earlier* reference to support his point of view.

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Formatter Linearity

The recent publication of the Nuclear Section of the Diagnostic, Imaging and Therapy Systems Division of NEMA represents a major stride toward industry uniformity with their publication, *The NEMA Standard Publication/No NU 1-1980 "Performance Measurements of Scintillation Cameras."* The industry has long needed such a set of standards for reference for the manufacture, sale, and maintenance of scintillation cameras.

Workers in the field realize that spatial resolution, field-flood uniformity, and spatial linearity are important parameters for the

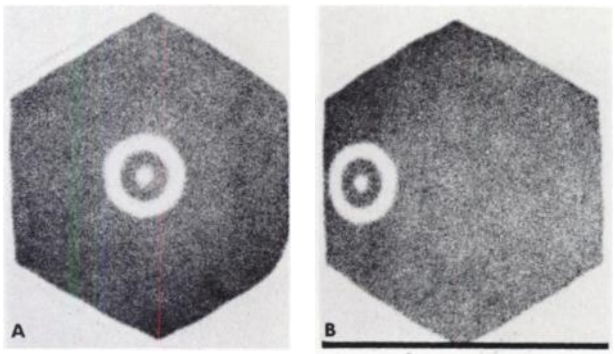

FIG. 1. Example of our most severe formatter nonlinearity. Co-57 field flood with 10-cm (outer diameter) disc. Single-image format and 1 million counts/image. Camera linearity was within specifications. (A) Disc in center has no distortion. (B) Disc in periphery has distortion in x-axis. When positioned in other peripheral areas, this distortion changed and in some places affected y-axis linearity.

evaluation of the performance of quality imaging in the clinical setting. It is essential when viewing an imaging system, however, not to look only at the detector. The image formatter is one of the critical elements in the total imaging system and when evaluation of the hardcopy device is excluded, any discussion of camera performance is deficient.

Recently we were reminded of this fact when at each of our institutions several of our vendors' image formatters, when carefully evaluated, showed a 7–25% distortion on the peripheral, yet useful, field of view (Fig. 1). A detector linearity of ±1% is quickly overshadowed by a formatter nonlinearity of 10%. As far as we could determine, most manufacturers have no specifications for formatter linearity. It is important that the industry recognize this shortcoming and establish strict manufacturing, sales, and maintenance specifications for all hardcopy devices. With this more encompassing information the nuclear medicine laboratories will have a method for the evaluation of imaging systems as a whole rather than for the detector alone.

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Re: ECG Gating: Does It Adequately Monitor Ventricular Contraction?

In his editorial on ECG gating (*1*), P. H. Murphy complains that ". . . commercial systems today reject cycles following the one irregular beat." Which "is ordinarily accepted." The implication is obviously that the contraction that precedes the extra systole (ES) is abnormal. This would be the case, however, only if the heart itself knew that an ES would follow.

Actually, if the average cycle is 16Δ, and if the ES occurs at the time $n\Delta T<16\Delta T$, all the data collected between 0 and $n\Delta T$ are those of an average but interrupted cycle. No data are obtained for that beat during the interval $n\Delta T$ to $16\Delta T$. The net result is an undersampling in the later intervals but not an error in the earlier intervals.

Correction can easily be made by recording the number of average cycles sampled in each interval and normalizing on this basis. No blurring should result. A clue to the apparent confusion is given by a paper in the same issue (*2*). In their computer simulation these authors assumed three RR intervals, each of them corresponding to a complete sinusoidal contraction. This model differs from reality by simulating the behavior of a heart adapting to an event that has not yet occurred. In truth, the heart does not know that an ES will follow.

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2. BRASH HM, WRAITH PK, HANNAN WJ, et al: The influence of ectopic heart beats in gated ventricular blood-pool studies. *J Nucl Med* 21: 391-393, 1980

Reply

The comments by Dr. Goris on my teaching editorial on ECG gating are interesting and most appreciated. He proposes a mechanism for partial compensation of the errors contributed by the collection of irregular cycle lengths in the composite ventricular volume curve. As discussed in my paper, there are several mechanisms for correcting data obtained from nonuniform cycle lengths, but usually they require list-mode acquisition and subsequent data framing. Most nuclear medicine computer systems do not include mechanisms for correction of irregular cycle lengths in their cardiac protocols. Dr. Goris states that I "complain" that commercial systems today reject cycles following the initiating irregular cycle (which is accepted). This is the case, and even if the contraction phases of this cycle are normal, the addition of this data to the composite cycle distorts the curve shape and causes inaccuracies in the calculation of the ejection fraction. In the paper by Brash, et al. that Dr. Goris references these errors are emphasized (*1*). In fact, Brash et al. state several times that the ectopic beats and the postectopic accentuated beat must be excluded from the analysis in order to avoid errors in the shape of the volume curve and the value of the ejection fraction. Dr. Goris suggests that "correction can easily be made by recording the number of average cycles sampled in each interval and normalizing on this basis." This position assumes that the ventricular contraction up to the beginning of the extra systole is completely normal with respect to its time distribution, and it also assumes that there is never an initiating irregular cycle that is longer than the the selected R-to-R range. In the context of R-wave gating irregular beats relate to the time interval of the R-to-R interval and not to the characteristics of the muscular contraction itself. The computer measures only the R-to-R interval, and therefore rejection or acceptance of a beat is based only on this time measurement. It appears that the concept proposed by Dr. Goris that "the heart does not know when an extra systole will follow" is true, and his correction scheme would be valid in the most common circumstances of irregular cycle lengths, i.e., premature ventricular contraction, but not as a universal solution to the problem.

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