Nuclear Medicine Imaging: An Encyclopedic Dictionary

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Preface

This set of expanded definitions of terms is intended to encompass those popular in planar, SPECT, and PET imaging protocols of nuclear medicine. It includes both nuclear-based scanner operations and intimately associated popular data analyses approaches. Other imaging modalities, such as x-ray, CT, MRI and a number of other modalities used in an encompassing field of molecular imaging, except for common terms, are beyond its scope – each requiring a dictionary of its own. The nuclear medicine imaging component of medical physics is intended to be exhaustively treated from a terminology standpoint. However, general biological, physiological, and pharmaceutical terminology, while also associated with scans, are not covered. These are already well summarized in various medical dictionaries, encyclopedias, and texts. A limited number of mathematical concepts likely to be somewhat frequently encountered in nuclear medicine imaging are included. Where terms have multiple meanings or can be somewhat general and generic, it is just their relevance to nuclear medicine imaging that is emphasized here.

A deliberate somewhat pedantic approach is used to explain what would otherwise be terse definitions. These include many examples. In these, the mathematical nature of nuclear imaging is deliberately kept very simple. No pretense is made to standardize any terminology. In fact colloquial usages, common in the literature, are identified as such even if ambiguous or ill-chosen when taken out of context, as noted in the Appendix.

Many definitions are based on and adapted from the authoritative National Cancer Institute (NCI) Thesaurus and Metathesaurus.[1] Effort is made when needed to orient these toward imaging uses. The author is indebted to personnel of the NCI for mutually beneficial contacts, and to Dr. Karl F. Hubner of the University of Tennessee Medical Center for helpful suggestions.

Comments and suggestions are invited.

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[1] NCI Thesaurus, National Cancer Institute, http://ncit.nci.nih.gov. Accessed September 30, 2011.

Contents

A

2D mode

The property of being measured and described using two orthogonal directions. As applied to a *PET scanner*, it describes a measuring process with shielding *septa* restricting detectors' coincidences. It is generally referred to as simply 2D. Detectors' coincidences are restricted to just *lines of response* being those in the same ring of detectors. *Reconstruction* is then simplified with this directional restriction. However, there is a loss of count information due to the absorptions. See also *3D mode*.

3D mode

As applied to a *PET scanner*, description of a measuring process without any shielding *septa* restricting detectors' coincidences. It is generally referred to as simply 3D. The *lines of response* can be defined by detector pairs whether both are in the same or different ring of detectors. By making more efficient use of detectors than does the *2D mode*, scanner *sensitivity* can be increased.

4D

Denoting a process that involves all three spatial dimensions and in addition some type of time information. It can be used to designate/characterize *dynamic scan* and *gated scan* protocols.

Absorbed dose

The amount of *energy* from any type of ionizing *radiation* (e.g., alpha, *beta*, *photons*, neutrons, etc.) deposited in any medium (e.g., water, tissue, air). This designates energy deposition by the radiation without regard to the type of matter or any

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biological considerations. Radiation measuring instruments, operating independently of the type of surrounding medium, indicate strictly absorbed dose. Its units can be *gray* and *rad*. See also *equivalent dose*.

Accuracy

1. The quality of nearness to the truth or the true value. A numerical value may also be ascribed to accuracy. This may be the difference between a measured value and the true value. See also *bias* and *precision*.

Example: Some *semiquantitative* analyses are performed on data from a *scanner* which has not measured its *calibration factor* for some time. In making *reproducibility* checks of expectedly unchanged *SUVs* on the same patient within a month, it was found that these are always within 10% of one another. This indicates good precision. However, for all of these an outdated calibration factor is used in obtaining *activity concentrations* for these SUV calculations. Historical records show that it is possible for this factor to vary over many months by as much as 15%. Because of this, all SUVs have an unknown bias which could even be this much. The accuracy of the reported SUVs might conservatively be stated as the simple sum of 10% and 15%, that is, 25%. This would be about the most any particular reported SUV might differ from its true value.

2. When applied to diagnoses, the fraction of these that are correct when a certain methodology is applied to a number of cases. This is a quantitative concept and calculated as (number of correctly diagnosed positive or abnormal cases + number of correctly diagnosed negative or normal cases) ÷ (total number of cases diagnosed). This measure is useful in comparing effectiveness of diagnostic methodologies in a given population composition. See also *sensitivity*.

Acquisition time

Temporal specification associated with a *frame*. Beginning and ending frame times after the start of injection completely specify a *scan's* acquisition times. When sequential frames are acquired without interruption, as in a *dynamic scan*, it is typical and convenient to specify merely a sequence of frame durations.

Activity

1. Parameter used to quantify *radioactivity* and represents *radioactive source* transformations, that is, disintegrations or emissions, per unit time for the source. Since *isotopes* are continually *decaying*, then except for rather long *half-life* isotopes, the time at which a quantifier is given must also be stated or understood.

In *scanning*, a generally unstated convention is to correct all activities (e.g., *injected doses*) to be as of a standard time taken to be the start of scan's injection. See also *disintegration rate*. Units are Bq and Ci.
2. A colloquial usage for *activity concentration*.

Activity concentration

The amount of *activity* in a unit of containing volume. In colloquial usage, this term is often contracted to simply activity when it is clear that amount per unit volume and not amount is meant. Typical units can be kBq/ml (or μCi/ml). Activity concentration is a special case of the *specific activity* concept when volume is used.

Example: 111 MBq (= 3 mCi) activity is added to a container which is to have 4 l of solution within it for purposes of future use in a *phantom* for subsequent *scanning*. It is desired to have a known activity concentration in advance in order to check a scanner's performance. This is (111 MBq)/(4 l) = 27.75 MBq/l = 27.75 kBq/ml (= 0.75 μCi/ml). Records would identify the time at which this activity was measured.

ALARA

As low as is reasonably achievable (or more concisely as low as reasonably achievable), when in reference to a *radiation dose* that could be encountered in a working environment. Brought about from encouragement from governmental guidance, this good practice entails taking whatever measures are deemed practical to keep doses to personnel working with radiation low. This approach is supplementary to various imposed quantitative limits on radiation doses that stem from health effects studies.

Algorithm

A defined procedure for achieving a goal which is often solving a problem. Its instructions can be typically implemented mathematically, which includes software executed by a computer. This includes mathematical expressions, computer programs or procedures, and flowcharts involving combinations of mathematical formulae. The goal of an algorithm is to provide a satisfactory result from input data upon executing a well-thought-out and well-defined, often mathematically oriented, process.

Example: In the example given for *Monte Carlo*, an algorithm is implemented for purposes of determining a *sensitivity* of the *slope* of a straight line fitted to its data. After performing this specific set of numerical calculations, the result shows the uncertainty of the slope that is due just to the uncertainty in one of the data points.

Anger camera

The original *gamma camera* invented by H. O. Anger over 50 years ago and its subsequent generations. Its principle of operation consists of a single large crystal (typically 25–50 cm in diameter) in which *gamma* rays are converted to scintillations of light. Here, a limited number of *scintillation detectors* view these through a *collimator* to provide information for an *image*.

Annihilation

Process occurring in *PET* when a *positron* from an emitting *tracer* travels a very short distance and encounters an *electron*. The result is the conversion of the masses of these particles to *energies* of two 511-keV *photons*. The latter, forming a line as they travel in opposite directions, make possible the *electronic collimation* then used in subsequently constructing an *image.*

Anterior

Denoting the front surface of the body, and thus often used to indicate the position of one structure relative to another (as opposed to *posterior*).

Area under the curve

The area between a section of the x-axis and a plotted curve representing a function. It is equal to the definite *integral* of a function between *x* values defining this section. In the field of *pharmacokinetics*, the area under the curve (*AUC*) is that below a curve in a plot of *concentration* of a drug in plasma against time. AUC is commonly given for the time interval zero to infinity, unless other time intervals are indicated. Symbolically, this is indicated by an *integral* as $\int Q dt$ where the integrand Q in *imaging* can be a time-varying *activity concentration.* The dimensions of AUC are the product of those of the graph's two axes. It can be seen that this concept of area is a generalization of geometric area encountered if the two axes of a plot were both dimensioned as distances.

Example: A blood activity concentration curve in Fig. A.1 rises from 0 at initiation of injection to 60 kBq/ml at 1 min. Thereafter it exhibits *clearance*, that is, *decaying* away as body tissues extract its *tracer*. Sampled values are indicated by the 13 data points after injection.

The concept of an area under a curve may be illustrated by the sum of 170 small areas. Each small area is a square (not shown) associated with one of the 170 dots below the curve of Fig. A.1. Each such small square has an area of (2 kBq/ml) × (1 min). The total 0–60 min area by this approximate method is 2 × 170 = 340 kBq min/ml.

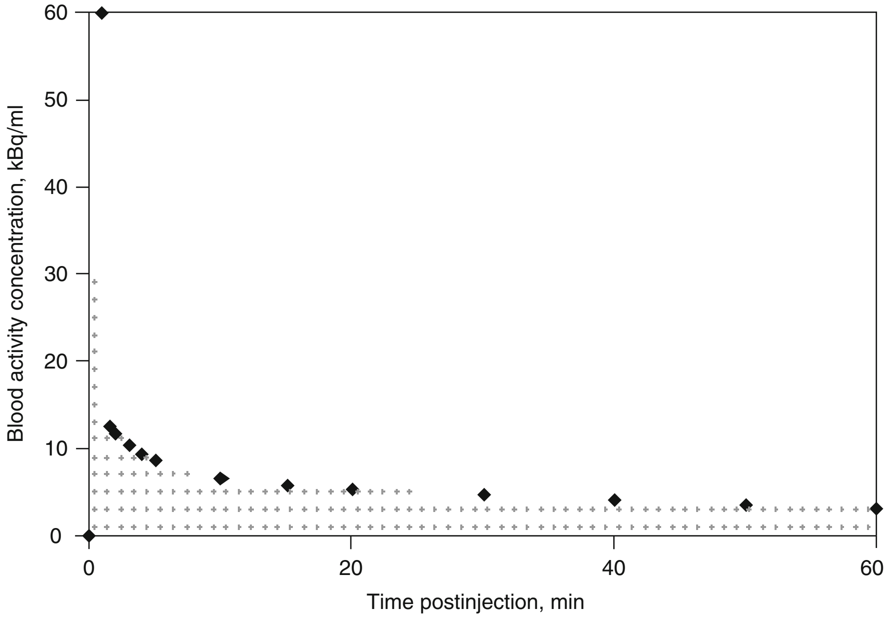

Fig. A.1 Data points along a blood *time–activity curve*. The dots are centers of small invisible squares that fill the entire area under the curve

The 0–60 min area between a curve through the 13 data points and the time axis may more readily be numerically computed from the sum of trapezoid-shaped areas for the individual 13 time intervals. Each area is (average of activity concentration values at beginning and end of the interval) × (time duration of the interval). The first such area is $[(0+60)/2]\times 1=30$ kBq min/ml; the 13th is $[(3.6+3.2)/2]\times 10=34$ kBq min/ml. The sum of all 13 is 334 kBq min/ml as the desired AUC.

Artifact

A structure or appearance that is not naturally present but has been introduced though manipulation. For an *image*, this is a feature within that does not conform to the subject and this departure being a consequence of the *scanner's* and associated software's design capabilities. Thus, a streak having the appearance of a wide scratch would be an artifact since there would be no known long sliver associated with the subject.

Asymmetry index

A *normalized* measure of a difference between two quantities expected to be somewhat similar in value when encountering circumstances of somewhat geometrical balance and correspondence as in almost mirrored structures. It is typically expressed

A

as a fraction though sometimes as a percentage. Any of the following definitions for this fraction may be encountered:

$$(x_2 - x_1)/(½[x_2 + x_1])$$

$$(x_2 - x_1)/(x_2 + x_1)$$

$$(x_2 - x_1)/(\text{either } x_2 \text{ or } x_1)$$

$$x_2 / x_1$$

where relative locations of *image* quantifiers, x_1 and x_2, would also be defined. An often encountered usage is in comparing *activity concentrations* in symmetrically located left and right regions, such as in the brain. It is seen that small numbers for the first three definitions, and near unity for the last, would tend to suggest normal expected conditions.

Atom

The smallest unit of matter that retains its properties. An atom consists of a *nucleus*, made up of protons and neutrons, surrounded by a number of *electrons*.

Attenuation

A weakening in intensity. This process occurs when *radiation* passes through and interacts with matter on its way to a detector. With losses occurring during this passage, the detector receives less than would otherwise be the case. See also *attenuation coefficient*.

Attenuation coefficient

The fraction of beam intensity being lost per unit length of the transmitting material in a chosen x direction. Thus $\Delta I/I_{avg}/\Delta x$ is the linear *attenuation* coefficient μ. Here the fraction of beam intensity I lost, $\Delta I/I_{avg}$, occurs due to a small transmission distance Δx through the attenuating material. When this attenuation coefficient is constant over some distance x, the factor by which the *radiation* decreases is $\exp(-\mu x)$. The value of μ depends on the attenuating material and the type of radiation transmitted including its *energy*. See also *CT number*.

Example: It is known that 511-keV *photons* from *positron annihilation* have $\mu = 0.096\ \text{cm}^{-1}$ in water. If a detector has an unattenuated *count rate C* from a region of positron emission and then 2 cm of water is interposed, the lower count rate would be $C \times \exp(-0.096 \times 2) = 0.825C$. In the event it would be desired to determine an unknown μ from such data: $\Delta C = C - 0.825C = 0.175C$, $C_{avg} = 0.913C$, and $\Delta x = 2$ cm. The result is then $0.175C/0.913C/(2\ \text{cm}) = 0.096\ \text{cm}^{-1}$.

Attenuation correction

Adjustment for the effect of tissue thicknesses and densities through which *photons* travel from an *activity concentration* origin to a *scanner's* detectors. The *count rates* of a detector are adjusted according the amount of *attenuation* along the photon's path. This makes possible accurate *quantitatio*n in *image* analysis. This is because whether the origin of the photon was deep in the subject or near the surface, it will be properly represented in the final image. Information needed for making an attenuation correction may come from a special *transmission scan* of a *radioactive source* and the subject, or the use of attenuation information from a *CT* scan of the subject.

AUC

Area under the curve.

Autoradiograph

The *image* from a photographically sensitive surface or a sensor array used in an *autoradiography* process.

Autoradiography

A technique used to locate *radioactively* labeled molecules, or fragments of molecules, within a subject by recording on a photographically sensitive medium or equivalent the *radiation* emitted by *radioactive* material within a subject. This *image* produced, an *autoradiograph*, contrasts with the type of processes in x-ray radiography and industrial *gamma* radiography. These latter depend on an external radiation *source* rather than the subject's intrinsic radiation. Also, the technique is distinct from and less sophisticated than that of devices using *collimation* or involving *rectilinear scanning*. Autoradiography historically has commonly been used for sacrificed animals, as where specimens of specific tissues of interest can be readily obtained for placement on the plate.

Axial

Situated on or along or in the direction of an axis. In a *scanner* this axis is a line through the longest part of the subject's body. The *plane* perpendicular to this axis is called the axial plane as well as the *transverse plane* as shown in Fig. A.2.

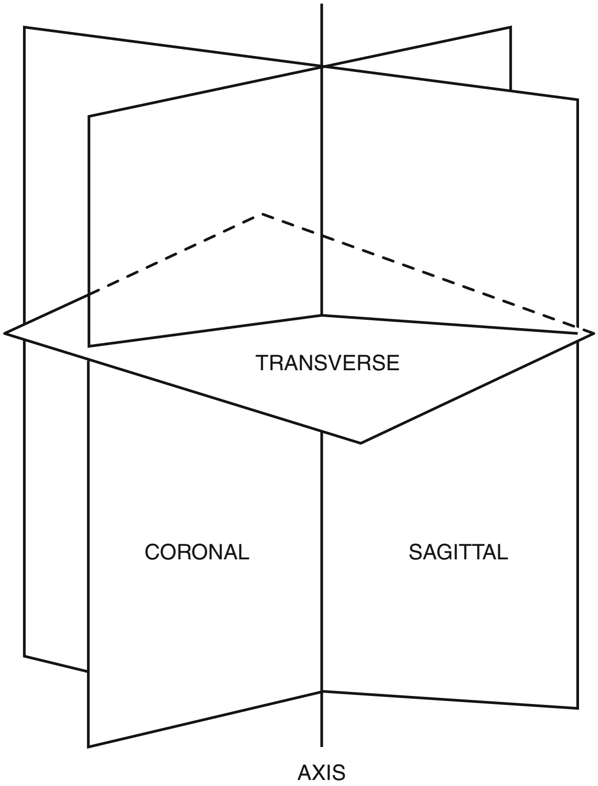

Fig. A.2 Three mutually perpendicular planes and the axis through a subject associated with these, as viewed looking somewhat down on a subject lying on a scanner *bed*. The *coronal* plane is viewable from above; the *sagittal* plane is viewable from the side. The axis is parallel to the horizontal movement of the scanner bed

B

Background

Existing conditions, especially those that would be confused with the phenomenon to be observed or measured. As background *radiation*, it could be an existing measure of *radioactivity* before any additional would be introduced at that location. Sources of such can include cosmic rays and prior contaminations of an environment. Sometimes the term is used to identify some quantifier of an uninteresting region surrounding a *hot spot* of interest.

Background correction

A method to adjust a *radiation* detector's output to correct for *background* effects. This usually involves simply a subtraction of a background measure of *radioactivity* from a measurement that includes both it and that from the object of interest.

Example: A counter with a somewhat constant background of 400 *cpm* gives a gross *count rate* of 10,000 cpm when a sample is being counted. The net count rate for the sample alone is obtained by making a background correction: 10,000 – 400 = 9,600 cpm.

Backprojection

Filtered backprojection.

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Baseline

A standard state or condition to which things may be compared. A common practice in *imaging* strategy is to deliberately plan a *scan* in which the subject is at a baseline condition, such as a normal condition. This is in anticipation of another imaging at a different condition expected to have changes to be studied. The first scan would be referred to as a baseline scan. When monitoring the effectiveness of a therapy or progression of a disease, the first scan in a series of two or more could be the baseline scan and need not be a normal healthy condition.

Becquerel

The SI unit of *activity* of a *radionuclide*, equal to one *nuclear* disintegration or other nuclear transition from a particular *energy* state occurring in an amount of a radionuclide during a 1-s-long time interval. SI stands for Système International d'Unités (International System of Units), with its core units of the meter, kilogram, and second. With worldwide acceptance of its units, the becquerel is now preferred over the historically used *curie* (= 3.7×10^{10} Bq). Abbreviation is Bq.

Bed

A *scanner's* narrow horizontal platform on which the subject lies to be moved *axially* within the *gantry* in order to position appropriate subject sections within the scanner's *field of view*. Figure P.4 shows the bed associated with a *PET/CT*.

Bed position

A designated location of the *bed* as it is moved through the *scanner* for purposes of positioning a desired part of the subject in the *field of view*. During *whole body scans*, several bed positions would be used. In each of these an *image* would be acquired.

Beta

Beta particle.

Beta particle

Electron or *positron* upon its emission from an *atom*. Streams of these are called beta rays.

Bias

Any systematic, that is, not random, deviation of results or inferences from the truth, or processes leading to such deviation. In a clinical trial this can be a flaw in the study design or method of collecting or interpreting information. Biases can lead to incorrect conclusions about what the study or trial showed. In making measurements, bias designates systematic error in a result beyond effects from the random errors that are equally likely in their positive and negative effects on magnitude. See also *accuracy*.

Example: *Standardized uptake values* of a certain tissue are measured in *FDG-PET* for a particular population dominated by obese patients whose body fat content is rather high. Examination of the traditional formula for calculating the *SUV* shows proportionality to the total patient body weight. The latter here includes weight also from fat which is known to have rather low FDG *uptake* relative to average body tissues. Hence, for these obese patients, the SUV is biased upward when being compared to SUV data obtained from other patient populations with fat content in a normal range. However, the biased SUVs would not result if some refinement in the weight (e.g., such as employing the lean body mass) were used in all SUV calculations.

Binding potential

A quantity used in *tracer* studies of *receptor* density in certain biological processes where this binding potential, as a characteristic of the receptor's *uptake*, is proportional to the receptor density and its affinity for the drug having the tracer. Typically such processes involving transmitters and receptors would be *modeled* for interpreting *dynamic scans*. Methods of determining binding potential include calculations from: *rate constants* measured in *compartmental model* fitting to data, *slopes* in *Logan plots*, and sometimes just *activity concentrations* of regions with and without receptors. Acronym is *BP*.

Biological clearance rate

The rate at which an exogenous substance is removed or cleared from the whole or part of a subject. In colloquial usage it can be curtailed to *clearance*. As a quantifier of *washout*, it is the amount (quite often volume) of a substance leaving a system per unit time with dimensions then as amount/min or amount/s (such as ml/min or ml/s).

This concept of clearance rate can also be applied to a *tracer* in the blood, as a specific part of the subject then entering into some other part of the subject. The product of this clearance rate and tracer *concentration* in the blood, *Cp*, is the amount leaving per unit time – but just into some designated part of the subject. Note that this partial or local clearance rate concept may be distinguished from the concept of clearance rate from the subject as a whole.

In *compartmental modeling*, as in the example of Fig. C.3, it can be convenient in describing local processes to define clearance rate in terms of a *distribution volume* (rather than just volume) leaving per unit time, the dimensions then being ml/g/s. If such a clearance rate is designated K_1 for some organ of interest, then K_1Cp would be the amount quantifier, as *activity* per unit mass, that leaves the blood per unit time and enters this organ.

Biological half-life

Time for an administered substance, with no further additions occurring, to be reduced by a factor of 2 in its *concentration* by natural physiological processes. This is entirely separate from any *radioactive* decay that may or may not be present. See also *biological clearance rate*, *effective half-life*, and *half-life*.

Blank scan

Scan without any subject or *attenuating* material, but with a *source*, present. *Quality control* checks involving blank scans may use a uniform source or a *transmission* source. Also with the latter, it is useful to obtain ratios of a blank scan and a subject-present scan for the various *lines of response*. These give *attenuation correction* data.

Blood flow

1. Indicating volume blood flow rate, the volume of blood per unit time passing through a specified location, such as a point in a blood vessel or an entire organ. Units are ml/s.

Example: A typical *stroke volume* of blood pumped into the aorta in each of the resting 72 beats that occur in a minute is about 70 ml. This results in a volume blood flow rate at this point of (72 beats/min) × (70 ml/beat) = 5,040 ml/min = 84 ml/s.

If 15% of this, namely, 756 ml/min, flows to the 1,400-g brain, then brain tissue *perfusion* on average is (756 ml/min) ÷ (1,400 g) = 0.54 ml/min/g.

2. Used colloquially to designate perfusion.

Blood volume

In *compartmental modeling*, it is the local fraction of tissue occupied by blood. It can also be the volume of blood per unit of tissue amount in a region. These usages in *image* analysis designate a blood volume fraction or a blood *specific volume*.