Quantification of Amplitude Images of Gated Radionuclide Heart Studies: A New Universal Method

Rolf Weller, Eberhard Henze, Malte Clausen, and Willi-Ernst Adam

Division of Nuclear Medicine, University of Ulm, Germany

Absolute quantification in nuclear medicine is difficult because of the individual shape, size, and position of human organs. In this study, a general data processing procedure is presented that allows inter-individual comparison and definition of normal count density pattern of unevenly shaped scintigraphic structures. This new method is demonstrated on Fourier amplitude images of gated heart studies. The information contained in the original irregularly shaped left ventricular amplitude scans was transformed into a standard sized circle by interpolating the radiant profiles of varying length from the original left ventricular ROI into the radii of the standard circle using 720, 360, 180, and 72 sampling angles. Retransformation of the individual left ventricular amplitude image from the standard circle area is feasible with only ~1% error with the 180, 360, or 720 sampling steps. As a first application of this new method 20 normal amplitude studies were transferred into the standard circle, which allowed the definition of a statistically normal reference image against which individual left ventricular amplitude images may be compared for documenting areas of significantly depressed amplitudes quantitatively. This simple and unique approach may be applied to most organ-related scans such as brain, kidneys, lung, and liver both in planar and tomographic studies to first create a normal reference image and second, to quantify the significance of locally increased or decreased activity in routine scans automatically.

J Nucl Med 30:1393–1398, 1989

Although most of the radionuclide studies of various organs are digitized nowadays and lend themselves to quantification, for example by region of interest (ROI) techniques, it is nearly impossible to establish reference matrices of a normal count density distribution pattern that would allow quantitative comparison of the individual study against that normal matrix. This shortcoming is the result of the wide variation of shape, size, and position of human organs and, accordingly, of the radionuclide scans. Thus, individual studies cannot be superimposed accurately enough for computing an organ or scan related normal matrix. Only recently, a pixel matrix of normal for the distribution of thallium-201 (^{201}Tl) in myocardium during exercise on a polar coordinate display of single photon emission computed tomography (SPECT) studies was established (*1*) and further developed for quantification of washout (*2*) and extended to resting blood flow distribution with display of an ischemia image (*3,4*) and attempts were undertaken to create reference matrices, for example for planar brain studies (*5*) in the past.

In this technical note, a new and simple procedure is presented that allows the transformation of essentially any digitized nuclear medicine study into a standard reference matrix without loosing information. The same procedure can be used to compute—out of a normal data base—a normal reference image against which the individual studies can be compared in terms of significantly abnormal regional count distribution. This procedure is illustrated using the amplitude heart image as a first application.

METHODS AND RESULTS

Radionuclide Angiography

The procedure applied at our institution for data acquisition and processing has been described in detail previously (*6, 7*). The image used for this new procedure is a common pixel by pixel Fourier transformation amplitude image in a 64 by

Received Oct. 17, 1988; revision accepted Apr. 12, 1989.

For reprints contact: Eberhard Henze, MD, Div. of Nuclear Medicine, University of Ulm, Robert Koch Str. 8, D-7900 Ulm, West Germany.

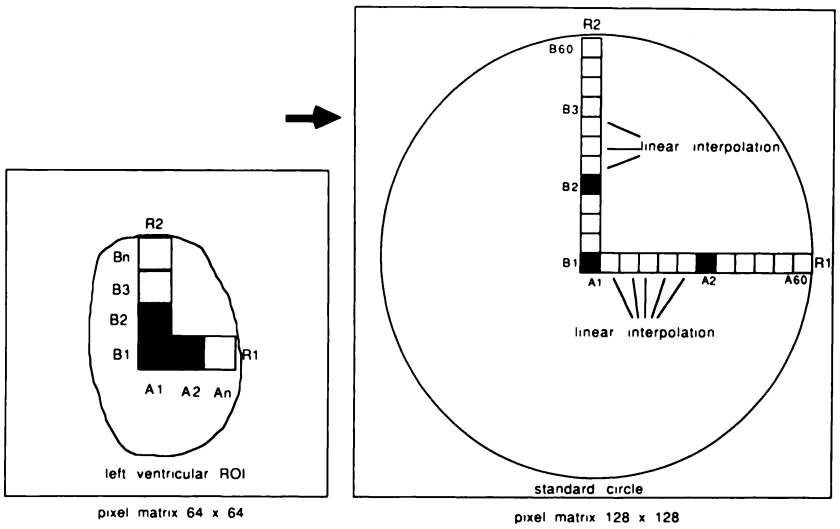

FIGURE 1
Transformation of a left ventricular amplitude scan from a 64 × 64 matrix into a standard reference circle with a diameter of 120 pixels into a 128 × 128 matrix. The profiles of the radii of the original left ventricular ROI are interpolated linearly to fit into the radius of the reference circle.

64 matrix. In this presentation, the left anterior oblique (LAO) studies were processed, but any type of a digitized amplitude image can be used.

Reference Circle Transformation

The objective of this method is the transformation of an individual scan into a standard sized reference circle matrix. The algorithm was programmed on a common Nuclear Medicine computer system (Siemens Max Delta system). The point of gravity inside the left ventricular ROI on the amplitude scan was determined. From this point, the count density profiles of the radii, which are of various length, were obtained in 720, 360, 180, or 72 sampling angles and were transformed into a 128 by 128 matrix, with the diameter of the standard circle being 120 pixel in size as shown in Figure 1. Seven-hundred twenty angle steps as upper limit was chosen because the number of pixels on the outer circumference of a 120-pixel diameter circle is more than 400. The radii were 1 pixel thick, and the profiles of each angle were transferred into the equivalent radius profile of the reference circle by simple linear interpolation to fit the individual profile to the radius of the reference circle as also illustrated in Figure 1. The different number of sampling angles was chosen to determine the minimum number of angles needed to cover all pixels of the outer edge of the left ventricular ROI.

Thus, the whole information of the unevenly shaped left

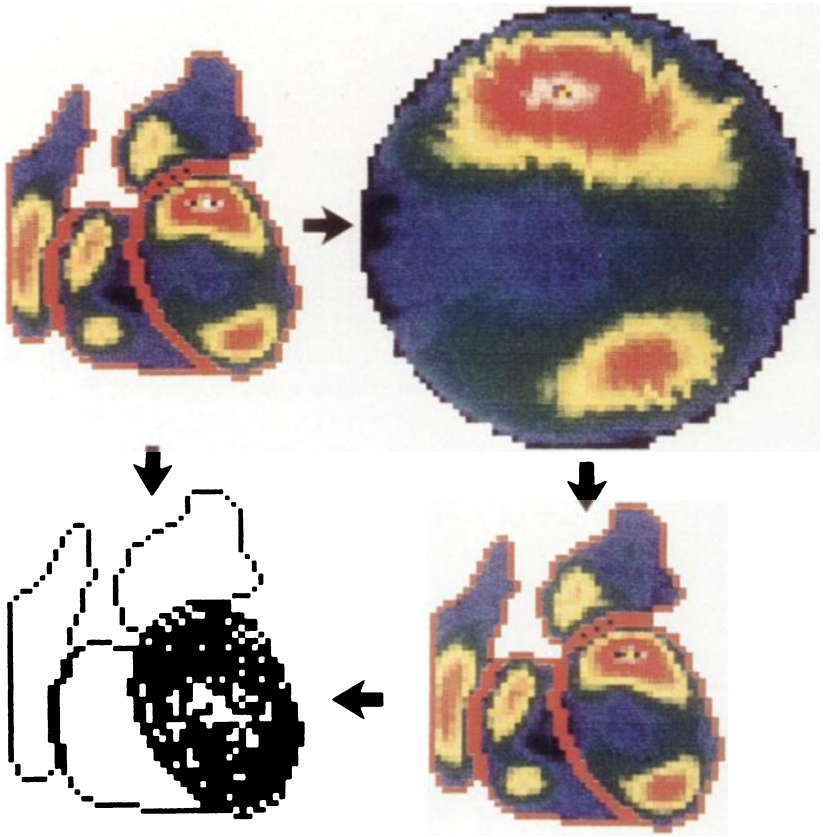

FIGURE 2
Transformation of a left ventricular amplitude study with anterior hypokinesis (upper left) into the reference circle image (upper right) and retransformation into the original ROI (lower right). Note that there is hardly any loss of information by this procedure as quantified by subtracting the retransformed from the original image (lower left). The difference is in the 1% range (see results).

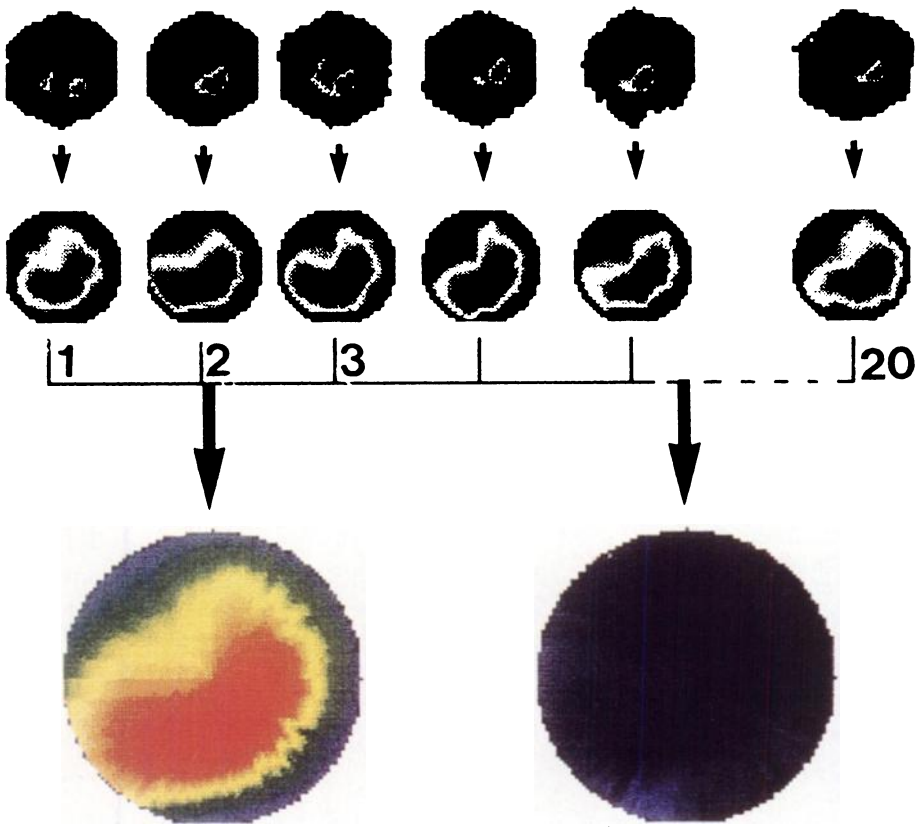

FIGURE 3
Computation of a normal reference matrix of left ventricular amplitude. Twenty individual normal amplitude studies (upper row) were transformed into their corresponding reference circles (middle row). These were summarized and divided by the number of normals resulting in a mean normal amplitude matrix (lower left) and allowing pixel by pixel computation of a standard deviation image (lower right). Note the small standard deviation distribution in this normal group.

ventricular region is transformed radius by radius into the reference circle. The total counts of the reference circle were normalized to 1500k for standardization. The whole procedure is completely reversible without loss of information as shown in Figure 2 in a study with a decreased amplitude in the anterior myocardium. The reversibility and, thus, the accuracy is documented quantitatively by subtracting the retransformed image from the original image. Averaging this differences of all images retransformed and subtracted from their originals a in this study, i.e., 20 normals and one example, resulted in only 1.2 ± 0.3% for 360-angle sampling, in 0.9 ± 0.5% for the 180-angle steps but in 5.9 ± 6.4% for the 72-angle transformation. The latter was significantly ($p < 0.001$) different to 720-, 360- and 180-sampling. Although 360- or 180-sampling angles were sufficient in most instances in two cases with dilated left ventricles—and thus larger outer ROI circumferences—only 720-sampling did cover the whole information and was thus used for all further processing.

Computation of a normal amplitude image matrix: Out of our normal data base 20 LAO resting studies were transformed into the reference circle and were superimposed and added. The resulting image was divided by the number of normal subjects resulting in a pixel by pixel "mean" image. The same procedure allows to compute the standard deviation image of normal amplitude distribution for each pixel which can be displayed on the same scale as the mean normal image. The whole procedure and the results are shown in Figure 3.

Application of the Normal Amplitude Image

The great value of the normalization procedure described in this paper in terms of objectively identifying regional wall motion abnormalities is illustrated in a patient study with anterior infarction shown in Figure 4. The individual amplitude study was transformed first into its reference circle image. The individual amplitude matrix of the reference circle was then compared to the normal reference circle by subtracting it from the normal reference circle and by dividing the difference by the standard deviation image. Any pixel having an amplitude value below normal will show up and can, in addition, be color-coded. This was accomplished in our algorithm in a way that all pixels with counts below 1 to 2 s.d. were color-coded in blue, below 2 to 3 s.d. in green and below 3 s.d. in red. This statistically encoded reference circle of the original study was then retransformed into the original ROI thereby displaying the extent and the magnitude of a significantly depressed wall motion in the original scale.

DISCUSSION

Objective interpretation of nuclear medicine studies is a desired goal as shown by the useful application of

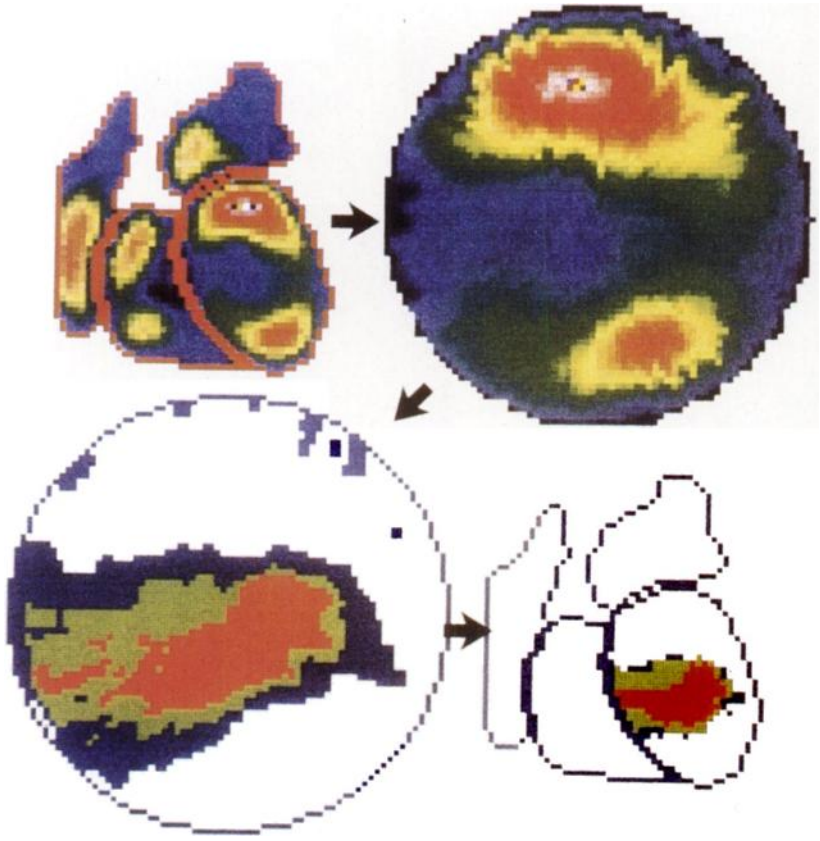

FIGURE 4
Application of the normal reference circle technique for verifying and quantifying a regional wall motion abnormality. First, the individual study (upper left) is transformed into its reference circle image (upper right) and compared to the normal circle matrix (see Fig. 3) by subtracting the mean normal matrix and dividing the difference by the standard deviation matrix (out of Fig. 3). This results in a color-coded circle image that shows all pixels below 1–2 s.d. in blue, below 2–3 s.d. in green and below 3 s.d. in red (lower left). This coded circle image can be retransformed into the original ROI (lower right) thereby displaying the size and magnitude of the wall motion abnormality quantitatively in the original LAO projection.

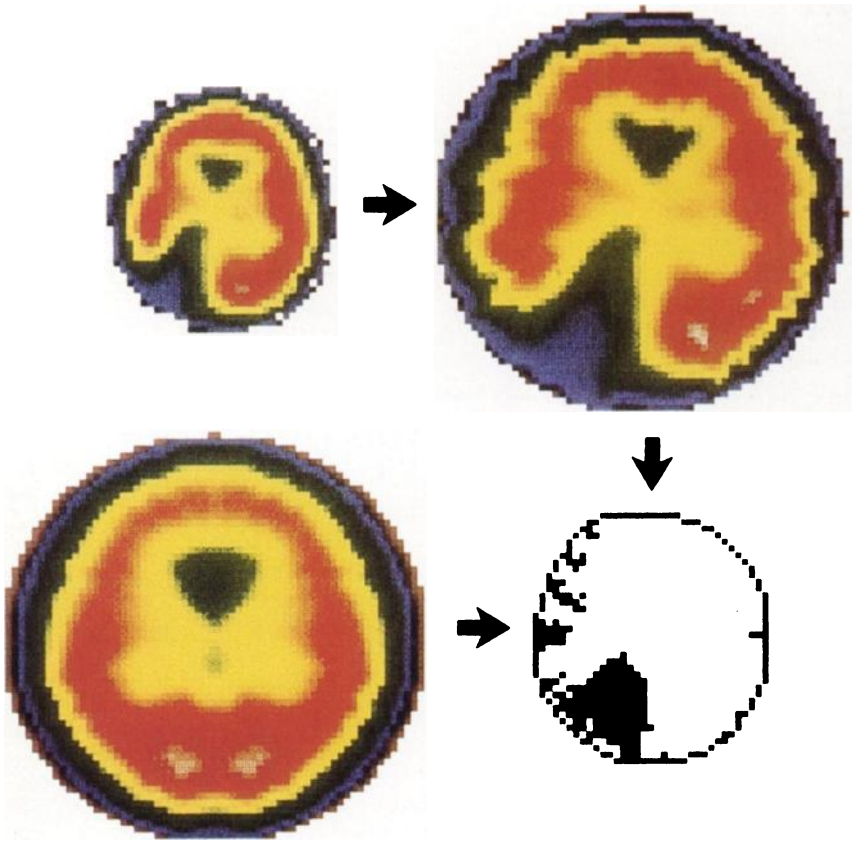

FIGURE 5
Application of the reference circle technique for verification and quantification of depressed regional brain blood flow in the parieto-occipital region in an individual [^{99m}Tc]HM-PAO SPECT study, in this example slice 3, (upper left) by transforming it first into its reference circle image (upper right), comparing it to the standard normal reference circle obtained from slice 3 of ten normal studies (lower left) and retransforming it into the original ROI encoded with the areas of depressed blood flow. The color coding of blood flow depression was graded as in Figure 4.

parametric images, such as amplitude and phase images of heart studies, factor analysis images and polar coordinate images of myocardial perfusion studies. However, all these parametric images were designed for processing very specific studies and no procedure is available so far that would allow to compare any digitized nuclear medicine study with another quantitatively or to create a standard reference image of normal with the exception of the polar coordinate image, the so-called bull's-eye display (*1–4*).

The simple approach described in this technical note allows the transformation of any irregularly shaped and variable sized organ scan into a standard sized image, which is a circle in the sample used in this paper. By this easy to perform and easy to program transformation algorithm essentially no information is lost; the transformation step is fully reversible, with an error of only ~1% if using more than 180 sampling angles. 720 angle steps might be recommended to be on the safe side in cases of very large ventricles.

This new technique was applied first for objectively quantifying regional wall motion abnormalities because the objective definition of a wall motion abnormality from gated heart studies is still difficult. Since there is no standard heart amplitude image many approaches have been postulated, such as regional ejection fraction (*8*) and regional decrease of amplitude (*9–11*). However, most of the proposed methods have the shortcoming of dividing the left ventricle into a definite number of sectors (*8–11*). If a wall motion abnormality extents substantially into two adjacent sectors, it might escape detection when the sector size is large in relation to the size of the wall motion abnormality, and increasing the number of sectors decreases the count statistics for each sector. Our approach allows the computation of a normal amplitude image as shown in Figure 3. This "intelligent" normal image is encoded with the statistical information to decide whether an individual patient's amplitude image contains areas of significantly depressed wall motion. Each radionuclide laboratory is able to define its own normal matrix out of a normal data base retrospectively, and it would be possible to compare the normal matrices of various laboratories worldwide despite different techniques used and definition of a wall motion abnormality could become common standard.

Other ways than the radial transformation such as the Cartesian conversion of a left ventricular ROI to the circle are conceivable. Further, in the case of the left ventricle or tomographic brain studies a standard ellipse could be used instead of a circle to minimize the magnitude of potential distortion.

Finally it should be mentioned that this method can be applied to any organ scan, such as brain SPECT and positron emission tomography studies, since there is no standard so far for a normal count distribution in the individual technetium-99m (^{99m}Tc) HM-PAO, ^{123}I amphetamine or fluorine-18 fluorodeoxyglucose studies. Like the heart, many approaches with hand-drawn ROIs (*12*) or multiple squared ROI's (*13*) have been proposed to normalize or quantify regional brain uptake, especially important for scientific studies. The same approach as described above for the heart, shown in Figures 3 and 4 can be performed, and one example for this application using [^{99m}Tc]HM-PAO studies based on data of ten normals is shown in Figure 5.

Other potential applications might be establishing a normal lung perfusion and ventilation matrix and definition of a normal phase matrix of gated heart studies. This method also allows the transformation and superimposition of radionuclide scans with other digitized images obtained with ultrasound, nuclear magnetic resonance (NMR) or x-ray organ studies, for example from the thyroid, coronary angiography, brain computed tomography or NMR tomograms, etc, for quantitative comparison and computation of correlative functional images. The latter might gain major attention with the forthcoming installation of picture archiving and communicating systems (PACS).

REFERENCES

1. Garcia E, VanTrain KF, Maddahi J, et al. Quantification of rotational thallium-201 myocardial tomography. *J Nucl Med* 1985; 26:17–26.
2. Stirner H, Buell U, Kleinhans E. Three-dimensional ROI based quantification of rest/stress Tl-201 myocardial SPECT. *Nuklearmedizin* 1986; 4:128–133.
3. DePasquale EE, Nody AC, DePuey EG, et al. Quantitative rotational thallium-201 tomography for identifying and localizing coronary artery disease. *Circulation* 1988; 77:316–327.
4. Clausen M, Weller R, Henze E, et al. Separate display and quantification of myocardial scar versus ischemia in polar coordinates for myocardial ECT. *NucCompact* 1988; 19:50–52.
5. Winkler C, Knoop R. Computerscintigraphischer Nachweis von Hirntumoren durch statistische Vergleichskalkulation anhand einer Normmatrix. In: Camera-Scintigraphie, DKFZ Bericht, Heidelberg, 1968: 44–49.
6. Adam WE, Tarkowska A, Bitter F, et al. Equilibrium (gated) radionuclide ventriculography. *Cardiovasc Radiol* 1979; 2:161–170.
7. Henze E, Tymiec A, Delagardelle C, Adam WE, Bitter F, Stauch M. Specification of regional wall motion abnormalities by phase analysis of radionuclide angiograms in coronary artery disease and non-coronary artery disease patients. *J Nucl Med* 1986; 27:781–787.
8. Douglas KH, Links JM, Chen DCP, et al. Linear discriminant analysis of regional ejection fraction in the diagnostic of coronary artery disease. *Eur J Nucl Med* 1987; 12:602–604.
9. Bonow RO, Viale OF, Bacharach SL, et al. Asynchronous left ventricular regional function and impaired global diastolic filling in patients with coronary artery diseases: reversal after coronary angioplasty. *Circula-*

tion 1985; 71:287–307.
10. Pavel DG, Byrom E, Lam W, et al. Detection of regional wall motion abnormalities using phase analysis of gated cardiac studies. *Clin Nucl Med* 1983; 8:315–332.
11. Standke R, Hoer G, Maul FD. Fully automated sectorial equilibrium radionuclide ventriculography. Proposal of a method for routine use. *Eur J Nucl Med* 1983; 8:77–83.
12. Podreka I, Suess E, Goldenberg G, et al. Initial experience with Tc-99m HM-PAO brain SPECT. *J Nucl Med* 1987; 28:1657–1666.
13. Perani D, Di Piero, Vallar G, et al. Technetium-99m HM-PAO-SPECT study of regional cerebral perfusion in early Alzheimer's disease. *J Nucl Med* 1988; 29:1507–1514.