SIMPLIFIED METHOD FOR DETERMINING THE MODULATION TRANSFER FUNCTION FOR THE SCINTILLATION CAMERA

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The modulation transfer function (MTF) has long been accepted as an index of scintillation camera system resolution, but the technique necessary for the derivation of the MTF has discouraged its widespread acceptance because of its tedious and time-consuming nature. We have shown that the generation of LSFs for input into computer programs for MTF generation can be accomplished very easily and in short periods of time by using a simplified method. Establishment of the validity of this simplified procedure should contribute to more widespread utilization of the MTF in routine quality control programs as a check for crystal deterioration, electronic circuitry degradation, and/or collimator damage.

The modulation transfer function (MTF) is currently accepted as the best parameter for the description of the resolution characteristics of imaging systems (*1*). The determination of MTF for a scintillation camera system necessitates the generation of a line-source response function (LSF) for each region of interest on the camera face, but the central point is commonly used as representative of the system resolution.

The generation of an LSF for a source at a given distance from the camera face requires the use of a line source placed in a plane at that distance. Count rates are determined with the line source positioned beneath the central point and at fixed lateral displacements in the plane of interest. The LSF for the central region of interest of the camera face is derived from the count rates obtained as a function of lateral displacement of the line source. The MTF at a specified distance from the camera may then be computed from the LSF using the Fourier theorem (*1*).

This procedure is both tedious and time consuming since determinations of count rate for the region of interest must be made for each position of the line source. If it can be assumed that a scintillation camera system exhibits a uniform response across the entire crystal, then the response at a peripheral locus on the crystal face from a centrally located line source should be the same as the response at the central region from a laterally displaced line source. Thus, the LSF can easily be obtained by merely imaging a centrally placed line source only once and determining the LSF from the count rates in picture elements across the crystal face.

In order to establish the validity of this simplification experiments were performed to compare the results of MTF curves generated by both methods using a variety of collimators and radionuclides.

METHODS

The line sources used in these experiments were constructed from Kimble No. 46485 KIMAX® capillary glass tubing (0.7–1.0-mm o.d., 0.2-mm wall thickness, 85-cm length). A 26-gage needle was used to inject 0.1–0.2 cc of ^{99m}Tc, ^{131}I, or ^{85}Sr solution. The ends of the tubing were then sealed with capillary tube sealing clay. One to four millicuries of solution were used. Counting times were sufficiently long so as to render negligible statistical fluctuations in the counts due to the random nature of decay.

Classical method. Counts in the central point of the camera were obtained from a Nuclear Data 50/50 Data System® by displacing the line source sequentially in 0.25-cm increments laterally across the plane parallel to the face of the Searle Radiographics Pho/Gamma HP® scintillation camera. Because of the short half-life of ^{99m}Tc it was necessary to take careful note of time elapsed from the beginning of the experiment to correct for line-source decay during the sequential determinations.

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TABLE 1. SAMPLE COMPUTER OUTPUT OF SPATIAL FREQUENCY (ν) AND MTF_ν

Frequency	MTF ordinate
0.00	1.000
0.05	0.976
0.10	0.905
0.15	0.799
0.20	0.669
0.25	0.530
0.30	0.397
0.35	0.280
0.40	0.186
0.45	0.117
0.50	0.071
0.55	0.041
0.60	0.024
0.65	0.013
0.70	0.005

The area under the curve would be given by:

$$\text{Area} = \text{MTF}(0.00) + \text{MTF}(0.05) + \text{MTF}(0.10) + \cdots + \text{MTF}(0.70)$$
$$= 1.000 + 0.976 + 0.905 \cdots + 0.005$$
$$= 6.01$$

Simplified method. Camera response was adjusted using a sheet source so that as nearly a uniform response as possible across the crystal face was obtained. The line source was placed directly beneath the central point of the crystal face and a single LSF was obtained directly from the digital output of the data system. The spatial distance represented by adjacent channels of the data system output was determined by imaging two parallel line sources placed exactly 10 cm apart and counting the number of data points between the peaks of the images of these sources.

After correction for line-source decay (when applicable) the LSF data were entered into a FORTRAN computer program which generated the MTF data. The parameter for comparison of the classical and simplified methods was the area under the respective curves. These integrations were accomplished by summing the MTF ordinates at 0.05-cycle/cm increments from 0 cycle/cm to the same frequency value on each set of paired (classical versus simplified) data. The endpoint of integration was taken to be the point where the MTF was 0.0 or the frequency 1.0 cycle/cm, whichever was reached first. The curves for different collimators were not necessarily integrated to the same frequency value endpoint; hence, no comparison of performance among the various collimators should be made. An example of the computer output is shown in Table 1.

Reproducibility. Three temporally separated experiments were performed using a single radioisotope–collimator–vertical-distance configuration, with MTF areas determined by both the classical and simplified methods. The coefficients of variation for each set of three determinations were calculated.

Line-source positioning effects. In order to evaluate the effects of minor variations of line-source placement on the calculated MTF area for the simplified method, LSFs were obtained at the center of the crystal face and at differing lateral displacements from the center. A ^{99m}Tc line source, the 140-keV high-resolution collimator, and a vertical distance between collimator and source of 10 cm were used for this experiment, with the MTF areas calculated by our simplified method. An analysis of variance of these data was then performed to determine agreement among the different line-source placements.

Classical versus simplified method. To validate our hypothesis that there is no statistically significant difference between the data obtained from the simplified method compared to the classical method, LSFs were obtained at vertical distances from the line source of 10 and 20 cm. Six collimators were evaluated with ^{99m}Tc, four collimators with ^{131}I, and two collimators with ^{85}Sr. An unpaired t-test was performed on each collimator comparing the two methods, and for each radioisotope the collimator data were grouped by method and an unpaired t-test performed on these grouped data (*2*).

RESULTS

Reproducibility. Demonstration of the ability to reproduce MTFs from run to run using either the

TABLE 2. MTF INTEGRALS FOR VARYING LINE-SOURCE LOCATION USING SIMPLIFIED METHOD

Lateral displacement (cm)	Replication 1	Replication 2	Replication 3	$\bar{X}$	s.d.	Coefficient of variation (%)
0.0	8.05	9.44	9.58	9.02	0.85	9.4
0.5	9.27	10.05	10.07	9.80	0.46	4.7
1.0	9.90	10.10	10.02	10.01	0.10	1.0
1.5	10.37	9.89	11.61	10.62	0.89	8.4
						Average = 5.9

TABLE 3. COMPARISON OF CLASSICAL VERSUS SIMPLIFIED METHODS OF DETERMINING MODULATION TRANSFER FUNCTION (^{99m}Tc LINE SOURCE)

Collimator	Vertical distance Z (cm)	MTF integrals: Classical method	MTF integrals: Simplified method	n	t	p
140-keV high-sensitivity	10	7.38	6.85	2	0.23	NS
	20	4.87	4.80			
140-keV high-resolution	10	8.64	8.05	2	0.58	NS
	20	7.29	6.82			
250-keV 4,000-hole	10	7.78	6.55	2	0.50	NS
	20	5.28	5.05			
Pinhole	10	11.78	13.21	2	0.93	NS
	20	8.86	10.88			
140-keV diverging	10	6.79	7.89	2	0.27	NS
	20	4.89	4.79			
140-keV converging	10	5.21	6.02	2	2.13	NS
	20	4.66	5.51			
Overall data		6.95	7.20	12	0.26	NS

classical method or the simplified method was felt to be a primary consideration. The coefficient of variation of the three curve areas for the simplified method was 5.9% (Table 2) whereas for the classical method replicate determinations were 6.01, 8.64, and 8.62, yielding a coefficient of variation of 19.5%, 3.3 times that of the simplified method.

Line-source positioning effects. Although theory requires that the response of the crystal be uniform across the crystal face, the difficulties in crystal construction and balancing of the photomultiplier tube circuits make it unlikely that the ideal situation exists. Since our proposed simplified method provides for only a single imaging of the line source, minor variations in source placement relative to the crystal face must not introduce significant error into the day-to-day or run-to-run value of MTF. Using the simplified method, LSFs were obtained at the center of the crystal face and at differing lateral displacements from the center. Table 2 is a tabulation of the MTF areas from three separate replications and at four different locations. An analysis of variance was performed on these data to determine agreement among different line-source locations; this also provided another demonstration of reproducibility among replicate determinations. The simplified method showed no significant differences from slight deviations of source placement; differences among replicates were also not significant.

Classical versus simplified method. Having shown the ability to reproduce MTFs between runs, and having also shown that exact placement of the line source is not critical in the simplified method, the two methods were compared using a variety of collimators and radionuclides. Table 3 is a compilation of MTF areas using a ^{99m}Tc line source. There were no significant differences demonstrable between the simplified and classical methods for any of the collimator-distance combinations tested. Similar results were obtained using a ^{131}I line source with the pinhole and 360-keV parallel-hole diverging and converging collimators, and an ^{85}Sr line source with the pinhole and 550-keV parallel-hole collimators.

DISCUSSION

Any measure of scintillation camera system resolution intended to be used as an important part of a quality control program must be reproducible from day to day and must not be affected by minor variations in technique. The coefficient of variation of the classical method (19.5%) was over three times that of the simplified method (5.9%). This is because reproducibility of results in the classical method is dependent upon exact repositioning of the line source in its laterally displaced position in the plane of interest for each replication. This exact repositioning is difficult to effect unless one uses a jig (which also must be repositioned precisely). In contrast, the simplified method does not necessitate movement of the line source and we have demonstrated that placement of the line source in the exact center of the crystal is not critical to the derivation of reproducible MTFs. The source should, however, be aligned with the major axes of the collimator holes.

The classical and simplified methods of line-source placement were then used to derive MTFs for various combinations of radionuclides, collimators, and collimator–source separations. Among all the combinations tested none exhibited a statistically significant difference between the two methods; the grouped data for each radionuclide were likewise not significantly different. Thus, the simplified method was shown to be less time consuming, less technically exacting in the collection of data, reproducible between successive replications, and equivalent to the classical method in the generation of the MTF. Thus, elaborate jigs and source-positioning devices are not necessary for determination of the MTF, since the validity of the simplified method has been demonstrated herein and this method may be utilized easily for a daily quality control program.

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