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Optimum Fourier Filtering of Cardiac Data: A Minimum-Error Method: Concise Communication

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Random fluctuations limit the accuracy of quantities derived from cardiac time-activity curves (TACs). To overcome this problem, TACs are often fitted with a truncated Fourier series giving rise to two sources of error: (a) the truncated series may not adequately describe the TAC shape, causing errors in parameters calculated from the fit: and (b) successive TACs acquired from the same subject under identical circumstances will fluctuate due to limited counts, causing the Fourier fits (and parameters derived from them) to fluctuate. These two errors, respectively, decrease and increase as the number of harmonics increases, suggesting the existence of a minimum in total error. This number of harmonics for minimum error (NHME) was calculated for each of six common parameters used to describe LV TACs. The "true" value of each parameter was determined from TACs of very high statistical precision. Poisson noise was added to simulate lower count rates. For low-count TACs, use of either a smaller or a larger number of harmonics resulted in significantly greater error. NHME was found to occur at two harmonics for the systolic parameters studied, regardless of the noise level present in the TAC. For diastolic parameters, however, NHME was a strong function of the noise present in the TAC, varying from three harmonics for noise levels typical of regional TACs, to five or six harmonics for high-count global TACs.

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The analysis of cardiac left-ventricular (LV) time-activity curves (TACs) yields useful data concerning LV function. The reliability of this information, however, depends on the statistical precision of measurement. In an effort to improve statistical precision, the LV TAC can be fitted with a truncated Fourier series, i.e., one filtered with an abrupt high-frequency cut off (*1–4*). Parameters such as ejection fraction, filling rate etc., may then be calculated from the resulting smooth Fourier-series approximation to the LV TAC, rather than from the more "noisy" TAC itself. Such calculations are subject to two sources of error that depend on the number of harmonics used in the fit: (a) in the absence of "noise" due to limited counts, the truncated Fourier series may not adequately describe the shape of the TAC, causing errors in parameters calculated from the fit; and (b) in the presence of "noise" caused by counting fluctuations, TACs acquired from the same subject under identical circumstances will fluctuate, causing the Fourier fits (and parameters derived from them) to fluctuate. These two sources of error, respectively, decrease and increase as a function of harmonic number, suggesting the existence of a minimum for the total combined error. The number of harmonics at which such a minimum occurs can be considered the optimum number to be used in fitting a TAC. Use of either fewer or more harmonics to describe the TAC would be expected to increase the total error.

The goal of this paper was to predict the number of harmonics for minimum error for each of six parameters

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descriptive of LV TACs: ejection fraction (EF), time to end-systole (TES), peak ejection and filling rates (PER, PFR), and their times of occurrence (TPER, TPFR). To achieve this goal, two separate experiments were necessary.

First, an investigation was carried out to determine the "shape" error, that is, the error caused by the inability of a truncated Fourier series to describe adequately the shape of a TAC. To this end, 16 TACs of extraordinarily high statistical precision were obtained. Because these TACs contained so many counts, parameters derived directly from them (such as EF, PER, etc.) could be computed with negligible random fluctuations. These parameters could then be compared with parameters calculated from Fourier fits to the same TACs. The difference between the value of a parameter calculated directly from the TAC and one calculated from its Fourier fit would then be a measure of the ability of the truncated Fourier series to describe adequately the shape of the TAC. The high total counts in each TAC ensured that these measurements would be uninfluenced by counting fluctuations.

In the second experiment, the influence that counting fluctuations have on the Fourier fits to the TACs was investigated. In particular, it was desired to discover how the Fourier fits to a TAC might vary due to counting fluctuations in the TAC. To accomplish this, TACs of successively decreasing total counts were simulated by adding successively increasing amounts of Poisson noise to each of the high-count TACs. In this way the degree to which counting fluctuations influenced the Fourier fits (and the parameters derived from them) could be measured.

Each of the above experiments produced a measurement of one of the two errors caused by calculating parameters from the Fourier fit to a TAC, rather than from the TAC itself. The first experiment yielded the error caused by the inability of the Fourier fit to describe the shape of the TAC, the second experiment yielded the error in the fit due to counting fluctuations present in the original TAC. These two independent errors were then combined to allow prediction of the number of harmonics for minimum error (NHME) as a function of the relative amount of statistical noise due to counting fluctuations present in the TAC. Finally, a single, easily calculable, index of random noise present in a TAC was developed and tested, in order to make the prediction of NHME generally applicable. By computing this noise index for a particular TAC, one is able to determine the optimum number of harmonics that should be used in fitting that TAC with a partial Fourier series.

METHODS

Eighty-two subjects were studied. They were divided into two groups: a "probe group" of 16 subjects in whom TACs with very high count rates were produced using a nonimaging probe, and a "camera group" of 66 subjects studied only with a conventional Anger camera. The probe group consisted of seven subjects with angiographically documented coronary artery disease (CAD), five subjects with aortic regurgitation (AR), one with mitral regurgitation (MR), and three normal subjects with no evidence of heart disease. The camera group consisted of 16 subjects with CAD, 14 with asymmetric septal hypertrophy, 15 with AR, 15 with MR, and six with aortic stenosis. In all subjects, the blood pool was labeled in vivo with 15–20 mCi Tc-99m, and all were studied at rest.

The subjects in the camera group underwent equilibrium gated blood-pool ventriculography, using a 35° LAO view with a 15° caudad tilt. The sampling rate for the camera group was either 50 or 100 images per second, depending on heart rate. Each of the 66 studies in the camera group was analyzed to produce an LV TAC. The average total counts in the LV TAC of the camera group was 930,000.

The sixteen subjects comprising the probe group were studied using a nonimaging detector (7.5-cm diameter field of view), equipped with a parallel-hole collimator, placed over the LV. In order to position the probe properly, each probe study was immediately preceded by a gamma camera study performed in the manner described above. The resulting images were than used to position the probe over the LV with the same orientation as for the camera. The high-sensitivity collimator used with the nonimaging probe, coupled with long acquisition times (512 beats) resulted in gated LV TACs of very high statistical precision (mean total counts of ~40 million) for the probe group. Each of the 16 probe TACs was sampled at 10 msec per point.

The TACs from both the probe and camera groups were produced only from cardiac cycles lying within a narrow range of cycle lengths (average temporal window of ± 80 msec about the mean R-R interval). Within this beat-length window, the technique of "reverse gating" (*5*) was used to prevent count falloff at the end of the cardiac cycle. For the purposes of this study, it was not necessary to correct the TACs for background activity. The algorithms used to calculate each of the six parameters of interest and their associated random counting errors have been described in detail elsewhere (*6*). Briefly, for the unfitted TACs, TES was found from the time to minimum counts of the smoothed (50-msec unweighted sliding smooth) TAC. End-systolic counts were obtained from the raw data by averaging the counts in a 30-msec window about TES. PFR, TPFR, PER, and TPER were found by repeatedly fitting a third-order polynomial to a successively narrower range of LV points. Despite the high total counts in the probe group TACs, PER, PFR, and their times of occurrence could not be calculated from a direct point-by-point derivative

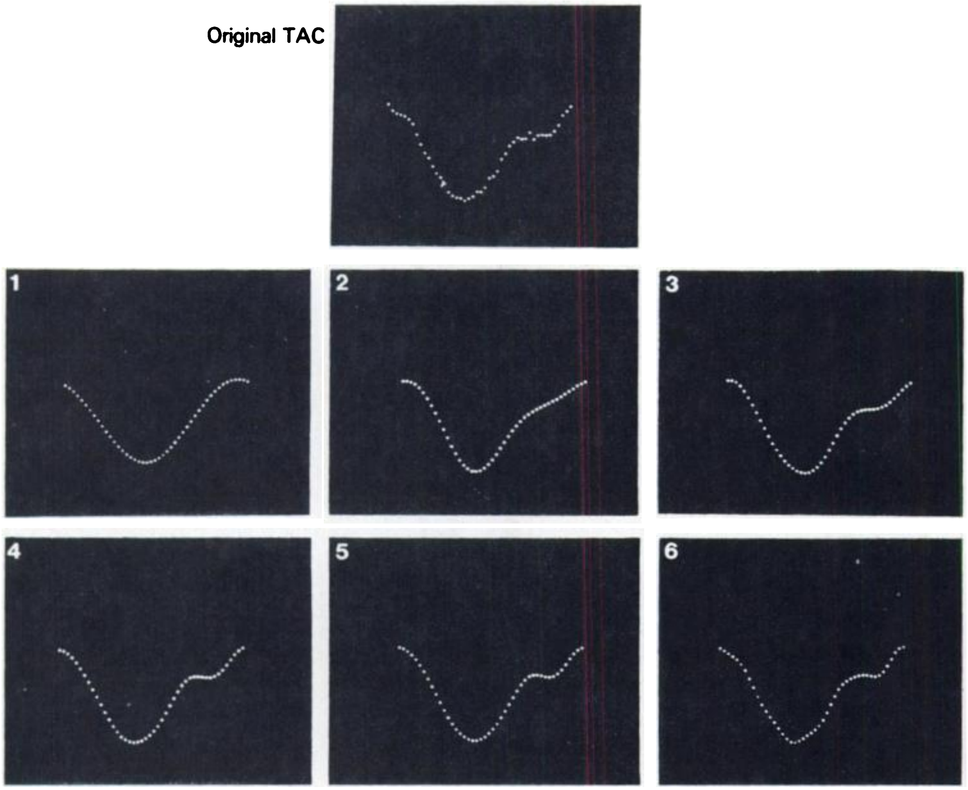

FIG. 1. Typical LV time-activity curve, and approximations to it using 1 through 6 harmonics in Fourier series.

without incurring too much fluctuation. The Fourier fits to each TAC, on the other hand, were perfectly smooth, permitting either direct point-by-point calculation of the six parameters or calculation by the methods used for the unfitted TAC. Both methods, when applied to the Fourier-fitted TACs, gave similar results, differing only by an amount consistent with the expected calculational errors.

RESULTS

Adequacy of Fourier fits. The first experiment investigated the ability of a truncated Fourier series to fit the LV TAC adequately, i.e., to describe its shape. Initially, only the 16 subjects in the probe group were studied in this experiment. From each of the very-high-count-rate probe TACs, six additional TACs were produced: a one-harmonic Fourier fit to the TAC, a two-harmonic fit, etc., up to six harmonics. Figure 1 illustrates this procedure. The ability of a truncated Fourier series to describe a TAC adequately is a function of the particular parameter one wishes to calculate from that TAC. For a particular parameter the adequacy of fit can be determined by comparing the parameter calculated from the original TAC with the same parameter calculated from the Fourier fit to the TAC. This comparison is shown in Fig. 2. Each ordinate of this plot is the mean absolute difference (expressed as a percentage) between a parameter value obtained from the original TAC and a value obtained from a Fourier fit to that TAC for all 16 subjects. In the absence of counting fluctuations, the ordinate gives the mean "mistake" one makes in calculating a parameter from a Fourier fit to a TAC, and is therefore referred to as "percent error due to fit" in the figure. The I-beams surrounding each point in Fig. 2 show the spread (1 s.d.) in this "percentage error due to fit" caused by subject-to-subject variations. For example, referring to the PFR panel of Fig. 2, the average error in PFR due to using a one-harmonic fit is about 23 percent, while for some subjects (those whose TACs closely resemble a single cosine in shape) the error may be much lower. The ordinate values of Fig. 2 are assumed to be due only to the inadequacies of the Fourier fit, an assumption that is true only if the original TACs are free from counting fluctuations. It is for this reason that the data for Fig. 2 were produced from the 16 subjects in the high-count probe group. The probe-group TACs, while containing many counts, are not statistically perfect. This imperfection is shown in each panel of Fig. 2 as the small residual error due to counting fluctuations (referred to as "residual error" in the figure). As harmonic number increases, the percentage error due to fit is expected to go to zero in the absence of counting fluctuations. In Fig. 2, as harmonic number increases the ordinate values and the width of the error brackets will not approach zero, but rather will approach the "residual error."

The analysis necessary to produce Fig. 2 was also carried out for the 66 camera subjects. The data for low

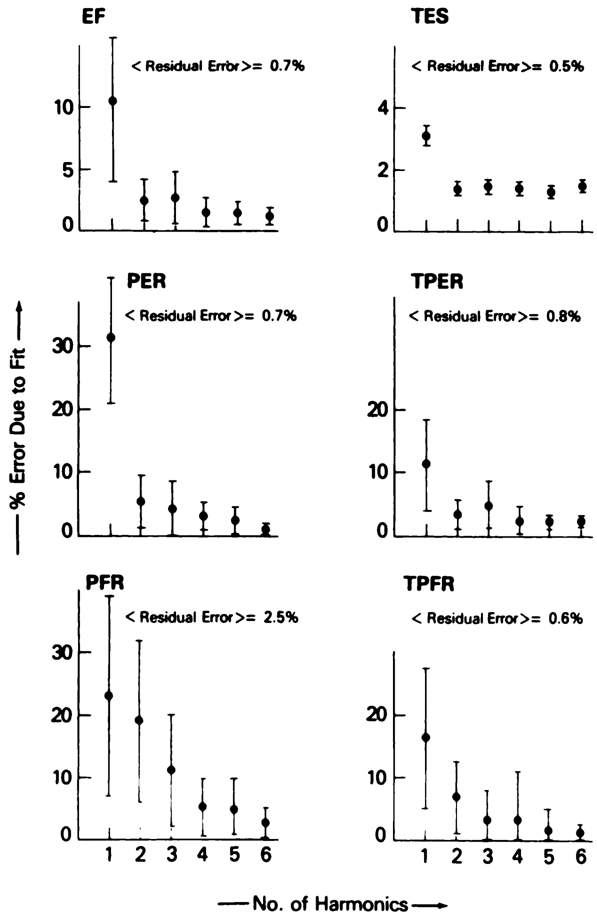

FIG. 2. Errors caused by using too few Fourier harmonics to describe adequately the shape of time-activity curve (TAC), plotted as function of harmonic number, for each of six parameters of interest. Vertical bars indicate intersubject fluctuations (1 s.d.). Values shown assume TAC with no random counting fluctuations. Also shown are actual residual errors due to counting fluctuations. Parameters are ejection fraction (EF) time to end-systole (TES), peak filling and ejection rates (PFR, PER), and their times of occurrence (TPFR, TPER).

harmonics overlayed those shown in Fig. 2, whereas for high harmonic numbers the ordinate values and error brackets did not decrease below the much larger "residual error" resulting from the comparatively low total counts in the camera TACs.

Fluctuations in Fourier fits. One might be tempted to conclude from Fig. 2 that the larger the number of harmonics used, the better. The presence of counting fluctuations in a real TAC makes this an erroneous conclusion. To investigate the effects of counting fluctuations, a second experiment was carried out using the 16 subjects in the probe group. Ideally this experiment would entail performing repeated low-count studies on a given subject. Thus from a single subject one would produce a large number of TACs each of which is identical to every other except for the effects of counting fluctuations. Each TAC would then be fitted with a Fourier series. Because of the effects of counting fluctuations, each Fourier fit would be slightly different, resulting in fluctuations in the parameters (such as EF, PER, etc.) calculated from the Fourier fits to these otherwise identical TACs. By measuring these fluctuations, one could determine the magnitude of the second type of error that results from the use of Fourier fit—the error due to counting fluctuations. The ideal experiment described above was simulated, initially using only the 16 probe subjects. The simulation was performed in the following manner. Each probe TAC was replicated 64 times. Poisson noise (corresponding to a certain level of total counts) was then added to each of these TACs, resulting in 64 TACs differing from one another only as would be expected on the basis of counting statistics. The TAC was made noisy by replacing each point on the TAC with one drawn at random from a Poisson distribution. The mean of the Poisson distribution corresponded to the count level desired at that point. A one-harmonic Fourier fit was then made to each of the 64 noisy TACs. Although the underlying curve shape was identical for each TAC, the presence of random noise caused each of these one-harmonic Fourier fits to differ from the others. The six parameters of interest were calculated from each of the 64 Fourier fits, and they also scattered, for the same reason. By measuring the fluctuations in the 64 calculated values of each parameter, the influence of limited counts on the Fourier fitting process could be assessed. The observed standard deviation of these fluctuations for each parameter was taken as the error in the Fourier fit due to counting fluctuations. Henceforth, this error will be referred to as "the error in the fits due to noise." Similarly two-, three-, four-, five-, and six-harmonic fits were evaluated. This entire process was repeated for seven levels of random noise, i.e., for seven different levels of counts. Figure 3 shows the results of this computation (mean of all 16 subjects in the probe group) as a function of harmonic number at three levels (of the seven levels studied) of random counting noise. Note that the percentage error due to counting fluctuations increases with increasing harmonic number. That is, although a single harmonic may not adequately describe the shape of a TAC (e.g. as in Fig. 2), a single-harmonic fit is less sensitive to the presence of counting fluctuations than is a higher-harmonic fit.

Signal-to-noise index. In order for the results of this study to be generally applicable, we sought a single index that could describe how the counting fluctuations present in a TAC would produce error in all of the parameters calculated from the original TAC. Such an index would be useful. It would permit the results of this paper to be applied to TACs produced in other subjects, as will be demonstrated below. Unfortunately, there is no single index that will precisely predict the error in every parameter. Each parameter's error has its own unique dependence on counting fluctuations and on curve shape.

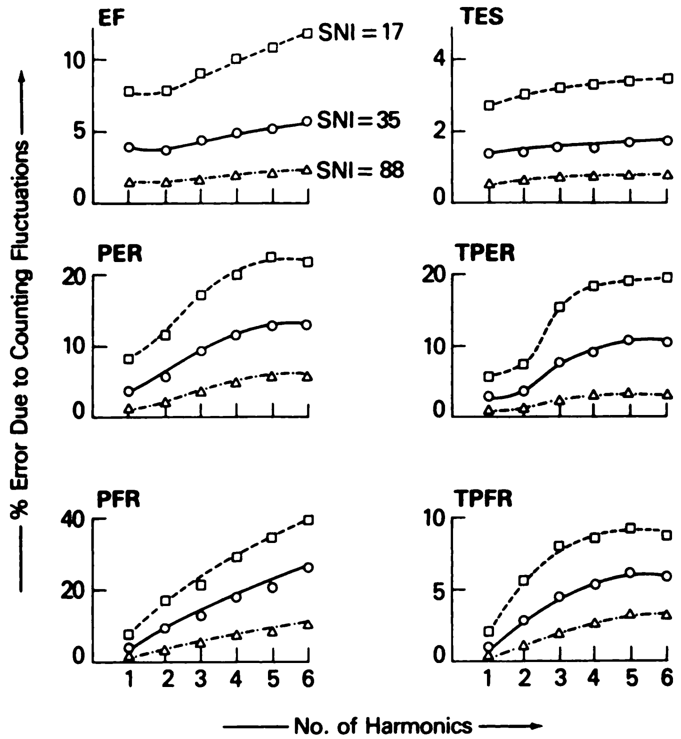

FIG. 3. Ordinate: error due to counting fluctuations in parameters calculated from Fourier fits to TACs. Abscissa: number of harmonics used in fit. Squares, circles, and triangles indicate data from TACs with successively increasing noise (defined by signal-to-noise index, SNI, described in text). Parameter abbreviations as in Fig. 2.

It was postulated, however, that an index similar to the standard "signal to noise" ratio would at least approximately describe the magnitude of the errors due to counting statistics. This postulate was empirically tested for the index referred to here as the signal-to-noise index (SNI), defined as:

$$\mathrm{SNI} = \frac{A_1}{\sqrt{\bar{c}}/\sqrt{N}}, \quad (1)$$

where A_1 = amplitude of first Fourier harmonic,
$\bar{c}$ = mean counts in TAC,
N = number of points in TAC.

Note that this expression is similar, but not identical to the usual approximation to the quantity called signal-to-noise ratio. The numerator of SNI is simply the first-harmonic amplitude—which is a reasonable approximation to the signal, since it has been reported (*8,10*) that usually 80% or 90% of the power is in the first harmonic. The denominator for SNI contains the standard error (SE), defined as:

$$= \sqrt{\frac{\sum_i \{LV(i) - C(i)\}^2}{N}} \Big/ \sqrt{N}, \quad (2)$$
$$= (\text{standard deviation})/\sqrt{N},$$
$$\cong \sqrt{\bar{c}}/\sqrt{N},$$

where: LV(i) are the "true" counts at point i,
C(i) are the measured counts at i and
$\bar{c}$ is the mean counts over all N points.

Using standard error rather than standard deviation in the denominator of SNI makes the resultant expression independent of sampling frequency (i.e., of frame rate). Note that one samples the LV time-activity curve by integrating the counts over the duration of each frame. Thus, doubling the frame rate causes the amplitude of the TAC curve to fall 50% (each frame will contain half the counts). The standard error will also fall by a factor of 2 (as seen from Eq. (2), noting that $\bar{c}$ falls by a factor of 2 and N increases by a factor of 2), hence SNI will remain unchanged by frame rate. Mathematically this is seen by realizing that one is sampling with an aperture equal to T/N where T is the cardiac period and N the number of points. Thus, because we increase sampling rate only by increasing or decreasing the sampling aperture, the total information content remains the same (provided the sampling is sufficiently above the Nyquist value).

It was postulated that SNI would allow a rough estimation of error in each parameter when calculated from an unprocessed TAC. This postulate was tested in the 66 subjects comprising the camera group. All six parameters of interest were calculated from each of the 66 original TACs. In addition, using the usual propogation-of-errors formulae, the uncertainty (one s.d.) in each of these values (due to counting fluctuations) could be estimated. Note that all parameters and error estimates were calculated from the original TACs—no Fourier fitting was performed in this experiment. The value of SNI was also computed from each of the 66 TACs. To put the SNI values into clinical perspective, a value of 17 might correspond to a TAC with 30K–40K total

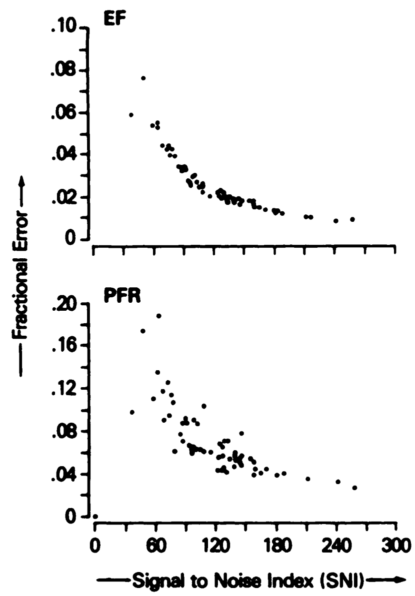

FIG. 4. Fractional errors in computing ejection fraction (EF) and peak filling rate (PFR) from unprocessed time-activity curve, as function of signal-to-noise index.

counts (depending on TAC shape), while a value of SNI = 88 might correspond to a TAC with 1-2-million counts.

The percentage error in each parameter, as calculated from the original TACs, was plotted as a function of SNI. It was found that measurement of SNI allows a rough estimation of the error in a parameter when the parameter is computed from the raw TAC. Figure 4 illustrates this for two typical parameters. From these data one can conclude that SNI is an approximate descriptor of the "noise" in a TAC as it affects the error in a parameter. For this reason, in Fig. 3 the level of counting fluctuations present in a TAC is given by the value of SNI.

Number of harmonics for minimum error. The data from Fig. 2 show the error made by using only a finite number of Fourier harmonics to describe the shape of a TAC that has negligible counting fluctuations. The data of Fig. 3 show the additional error that is made if the TAC being fitted contains counting fluctuations. The total error can be calculated by assuming the two errors

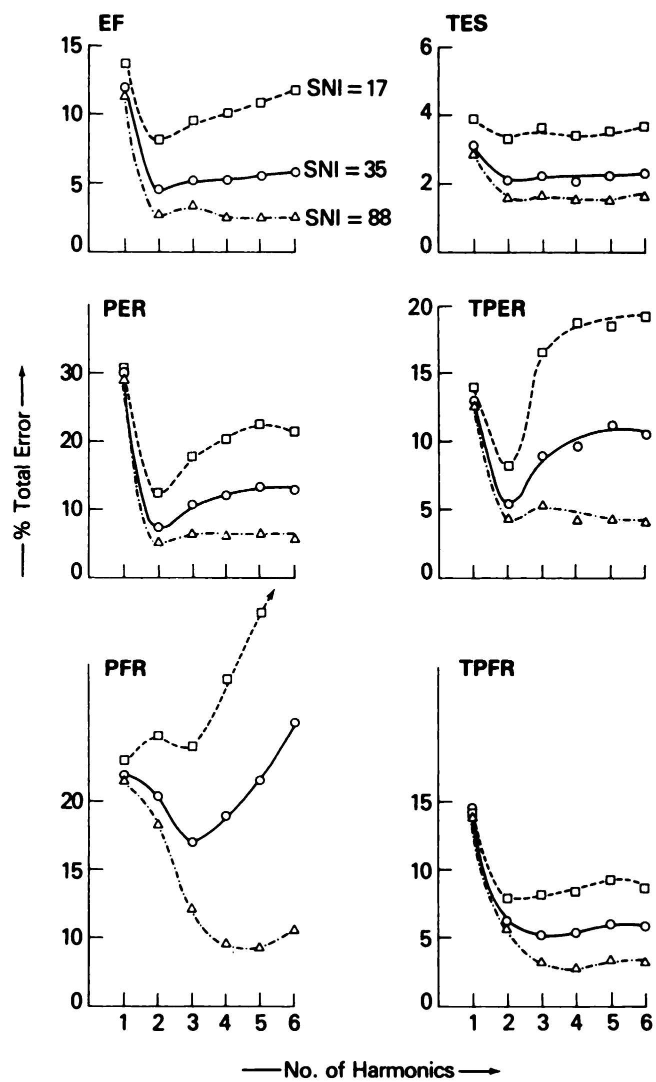

FIG. 5. Total error in calculating a parameter from Fourier-fitted time-activity curve, as function of number of harmonics used in fit. Location of minimum error defines optimum number of harmonics. Parameters abbreviated as in Fig. 2.

are independent. Thus:

$$\text{Total error} = \sqrt{E_1^2 + E_2^2},$$

where E_1 = error due to the inability of Fourier series to describe a TAC (Fig. 2), and
E_2 = errors in Fourier fit due to counting fluctuations (Fig. 3).

In Fig. 5 this total error is plotted as a function of harmonic number, for three different levels of counting fluctuations (defined by the SNI value). The levels of counting fluctuations shown range from values typical of low-count TACs (e.g., gated over only one or a few beats, SNI = 17.5) to values typical of global TACs from 6-min rest studies (SNI = 88). Note that a local minimum in total error is evident in most of these plots, especially for "noisy" TACs (low SNI values).

It is seen that EF, TES, PER, and TPER all have their minimum error at two harmonics, regardless of SNI. At low SNI (e.g., for low-count TACs) the penalty in total error is heavy for using either too few or too many harmonics. At high SNI the curves no longer increase much as harmonic number increases. Thus one may compute these four parameters using larger number of harmonics without significant increase in total error, providing SNI is 88 or greater. At still higher SNI values, the curves for EF, TES, PER, and TPER do not differ significantly in form from the curves at the highest SNI values shown.

PFR and TPFR behave somewhat differently from the systolic parameters, as seen in Fig. 5. As SNI increases, the harmonic number for minimum error progressively increases. The value of NHME at all seven levels of SNI studied are listed in Table 1. The asterisks in this table are reminders that harmonic numbers greater than six were not studied.

TABLE 1. OPTIMUM NUMBER OF HARMONICS FOR CALCULATING DIASTOLIC PARAMETERS, FOR VARIOUS LEVELS OF COUNTING NOISE. PFR AND TPFR ARE PEAK FILLING RATE AND ITS TIME OF OCCURRENCE

Signal-to-noise index	No. harmonics for minimum error	
17	3	2
35	3	3
52	4	4
70	4–5	4
88	5	4
132	5–6*	4
175	6*	4

DISCUSSION

Several previous studies (*7–11*) have addressed the question of how many harmonics are required to describe a TAC. These other studies have concentrated on the overall frequency content of TACs and have provided much useful information concerning the power spectrum of a TAC. The practical problem of how many harmonics are necessary to compute a particular parameter accurately has not been addressed, and is not easily extracted from knowledge of power spectra. For example, it has been reported that more than 90% of the power spectrum of an LV TAC is contained in the first two Fourier harmonics. It is false to conclude, however, that a TAC is always adequately described by two harmonics. If the parameter one is interested in happens to be dominated by frequencies in the "missing" 10% of the power spectrum, two harmonics will obviously not suffice. Such is the case for PFR and TPFR. Higher harmonics, although contributing only a small amount to the total power spectrum, were found to make a very large contribution to these diastolic parameters.

One must go further than simply determining the number of harmonics necessary to describe the shape of a TAC. It is also necessary to understand the penalty in error that one pays by increasing the number of harmonics used in a fit. By explicitly evaluating the effects of counting fluctuations on parameters extracted from Fourier fits to TACs, the disadvantage of using too many harmonics has been quantified. This information is especially important for the analysis of beat-by-beat TACs, or in the production of functional images from temporally filtered cardiac image sequences. In applying these data to single-pixel TACs, however, one must remember that the shape of global TACs (as used to produce Fig. 2) may be different from the shape of single-pixel TACs. Such differences may be especially pronounced in dyskinetic pixels or those near an edge.

The principal results of this paper are contained in the data of Fig. 5. From this plot one can predict the optimum number of harmonics that should be used to fit any TAC (with the exceptions noted above). This optimum number depends on two factors—the parameter that has been chosen for study, and the magnitude of the counting fluctuations in the TAC (i.e., the value of SNI). To apply the data in Fig. 5, one need only decide upon the parameter of interest, calculate SNI using Eq. (1), and select the appropriate harmonic from Fig. 5 or Table 1. Note that in creating Fig. 5 we used the mean values of "percent error due to fit" from Fig. 2. One could, with equal justification, choose the value of mean plus one s.d., in order to ensure that few subjects will be inadequately fitted by the Fourier series. This will have the result of shifting all the minima in Fig. 5 slightly to the right. A reader interested in doing so may easily use the data in Figs. 2 and 3 to recompute the optimum number of harmonics in this manner.

Systolic parameters. In general, all the systolic parameters have a minimum total error at two harmonics.

This is probably a reflection of the fact that the systolic portion of the cardiac cycle is quite cosine-like in shape. The only deviation from this occurs in TACs with a pronounced pre-ejection period. It is probable that more than two harmonics would have been required to describe a parameter indicative of the TAC shape during the pre-ejection period. Indeed, visually, the modest pre-ejection volume relation shown in Fig. 1 is poorly reproduced by even a six-harmonic fit.

Examining EF, PER, and TPER in Fig. 5, we see that at low SNI values (i.e., under poor counting statistics) the minimum is quite pronounced. That is, using either fewer or more harmonics than the "optimum" gives markedly larger errors. As SNI increases (i.e., better counting statistics) the curves of Fig. 5 become flatter at high harmonic numbers: there is less penalty in using more harmonics than the optimum. In fact, as SNI approaches infinity (i.e., as the effects of counting fluctuations go to zero) one expects Fig. 5 to approach the shape of Fig. 2. Thus, for high-count data, systolic parameters may be more accurately measured using more harmonics. The difference between using two harmonics and (for example) six is, however, seen to be insignificant at large SNI.

Diastolic parameters. The two diastolic parameters chosen for study (PFR, TPFR) have minimum total error at progressively higher harmonic number as SNI increases. Thus, unlike the systolic parameters, the diastolics are not adequately described by two harmonics except for TACs with low SNI (large counting fluctuations). The reason for this may be twofold: (a) peak filling rate is frequently greater than the peak emptying rate, and (b) more importantly, the diastolic portion of a resting TAC is distinctly more complex in shape than is the systolic portion. It is not surprising that PFR and TPFR require higher harmonics, occurring as they do in close proximity to the flat, diastasis period and the atrial contraction portion of the TAC. One may speculate that other diastolic parameters might similarly require more than two harmonics at rest.

These data emphasize that there is no single "best" Fourier fit to an LV TAC. Instead, each portion of the TAC may be described optimally by a harmonic fit of a different order. This optimum is a balance between using few enough harmonics to smooth out statistical fluctuations while maintaining sufficient harmonics to approximate the underlying signal. Such a balance will depend on the specific information to be extracted from the fitted TAC (i.e., on the parameters with which one wishes to describe the TAC). These considerations must be kept in mind when creating functional images of parameters derived from regional or limited-count TACs. Ideally, the SNI of the limited-count TAC (e.g., from a single cardiac cycle) would be computed, and the appropriate number of harmonics selected from Fig. 5. Fortunately, for the systolic parameters studied, two harmonics are optimum over a wide range of SNIs. For diastolic parameters, however, the situation is more complex, requiring different numbers of harmonics for the different SNIs of each TAC.

It should be emphasized that only resting TACs were studied. At exercise it is known that much of the complexity in shape of the resting TAC disappears: the diastasis period shrinks, atrial contraction blends together with passive filling, and the pre-ejection period shortens. In all, the distinctive features that require higher harmonics at rest are diminished during exercise. It is probable, therefore, that fewer harmonics would be necessary under exercise than at rest. Further work would be necessary to test this assertion.

CONCLUSION

We find that a truncated Fourier series will describe a cardiac left-ventricular TAC optimally only when the effects of counting fluctuations are balanced against the necessity for adequately describing the underlying signal. For the systolic parameters investigated here (EF, TES, PER, TPER) two harmonics are optimum over a wide range of noise levels (i.e., SNI values). For TACs with large fluctuations (e.g., single-beat TACs) a large source of error is introduced by fitting with either fewer or more than two harmonics. With TACs containing more total counts (i.e., larger SNI values), increasing the number of harmonics above two changes the total error only negligibly. Diastolic parameters require from two to six harmonics for optimum Fourier fitting, depending on the noise and signal content of the TAC.

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