Dynamic Arrhythmia Filtration for Gated Blood-Pool Imaging: Validation Against List Mode Technique

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Normal resting heart rate variations distort the diastolic portions of left ventricular time-activity curves, altering calculated measures of diastolic function such as peak filling rate. Diastolic filling parameters obtained by two methods of arrhythmia removal—list-mode acquisition and a new approach, dynamic arrhythmia filtration (DAF)—were compared. In DAF, data are evaluated for cycle length in real time and accepted or rejected immediately according to preset, operator-determined cycle-length criteria, eliminating the need for postprocessing of data and for large mass data storage. We prospectively determined EF, time to end-systole, peak filling rate, and time to peak filling on gated blood-pool studies of 25 patients. Identical camera and ECG data were sent simultaneously to two computers and analyzed using list mode and DAF, with an R-R interval of 5–6% of mean heart rate. Excellent correlation between list mode and DAF was seen in peak filling rate ($r = 0.94$), EF ($r = 0.99$), and time to end-systole ($r = 0.97$). Lesser correlation seen in time to peak filling ($r = 0.65$) may be due to inherent problems in measuring this parameter reliably, possibly lessening this parameter's clinical usefulness. DAF is less time consuming and less technically demanding than list mode, and provides results which correlate closely to those obtained by list mode.

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The principle of gated blood-pool imaging assumes that images from corresponding portions of the cardiac cycle are added together to enhance counting statistics, usually using an ECG gate for synchronization. In patients with a narrow range of R-R intervals, comparison of single beat time-activity curves with curves derived from gated images has shown an adequate correspondence for systolic parameters in a majority of patients (*1*).

Gated images, however, have been shown to occasionally underestimate left ventricular (LF) function parameters, with greater errors in diastolic function parameters than in systolic parameters (*1,2*). These differences can be attributed in part to physiologic variation in the shape and length of the LV time-activity curve, with subsequent distortion in the shape of the curve when individual cycles are summed. Such differences will be greatest when the heart rate varies most widely during data acquisition. In patients with arrhythmias and varying R-R intervals, frames an equal distance from the ECG gate may represent different portions of the various cardiac cycles. Furthermore, due to variation in cycle length, later frames in the image sequence will have fewer cycles contributing counts to them than do earlier frames, resulting in the declining counts at the end of the time-activity curve often seen in clinical studies.

One approach to minimizing the distortion induced by varying heart rates is dynamic arrhythmia filtration. Dynamic arrhythmia filtration (DAF) is a frame-mode-based technique in which the data from the cardiac cycle being acquired is temporarily buffered in memory. Once that cardiac cycle is complete, its length may be analyzed and compared with a preset cycle length acceptance interval, and data from that cycle can then be rejected or added to the image frames. In systems with sufficient memory, images corresponding to such multiple intervals or "windows" may be collected simultaneously, allowing analysis of an alternate window if the heart rate changes during the study. This has an advan-

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tage over the older technique of list mode cycle length windowing in that it requires less data storage space and does not require time-consuming postprocessing of data. DAF does not, however, permit retrospective window selection or postbeat rejection. The object of this study was to examine dynamic arrhythmia filtration in a sample population, and validate it against the commonly used list mode acquisition technique, using ejection fraction and diastolic function parameters for comparison.

MATERIALS AND METHODS

Twenty-five consecutive patients having gated blood-pool studies at our institution were included in the study. There were no special inclusion or exclusion criteria. All patients had 12 lead ECGs obtained prior to the study and ECG monitoring throughout the study, and all patients were in sinus rhythm. Following i.v. injection of stannous pyrophosphate, patients underwent in vivo labeling with 20–25 mCi of technetium-99m pertechnetate (*3*). Electrocardiogram gated scintigraphic images were obtained from a modified "best septal" left anterior oblique view. Each study consisted of at least 32 frames of no longer than 20 msec per frame (*4*).

Count and positioning signals from the gamma camera were sent simultaneously to two computers along with identical ECG gating information. One computer processed the information using dynamic arrhythmia filtration, while the other acquired in list mode*. The patients were observed for 1 to 2 min and a cycle length histogram generated. The center of the R-R interval acceptance window was chosen at the histogram peak by the dynamic arrhythmia program, and an identical center was used for subsequent list mode analysis. Data from Chen and Juni (*5*) suggest that images from narrow cycle length windows provide more accurate diastolic function data in the face of heart rate variability, subject to the limitations of counting statistics and acquisiton time. They simulated heart rate variability in a setting with known diastolic and systolic parameters; comparison of results from different window widths showed significantly improved results using narrower windows. For this reason, the smallest practical windows were chosen in this study, 6% and 5%, respectively, for dynamic and list mode (i.e., ± 3% and ± 2.5% from histogram peak); the small difference was due to software limitations. For comparison with earlier studies, one cycle postbeat rejection was performed on list mode analysis. The two systems received the same cycles, although because of the technical differences noted above, the two systems accepted a slightly different subset of beats. Results will therefore also indicate how sensitive the derived parameters are to the exact technique used.

All studies were analyzed in an identical manner by technologists blinded to the data acquisition technique. Ejection fraction was determined with commercial software†, using a combined second derivative and threshold method of edge detection with a variable region of interest. This region generation technique was applied separately for images acquired through list mode and with dynamic arrhythmia filtration. The algorithm automatically identified a background region adjacent and slightly inferior to the left ventricle. Background activity was subtracted from left ventricular activity in each frame to produce the LV time-activity curve. Forward gating only was employed, as a recent paper comparing multiple gating methods demonstrates that this technique produces the most accurate diastolic function measurements (*5*).

For smoothing purposes, the background subtracted time-activity curves were reconstructed from their first three Fourier harmonics prior to determination of diastolic function parameters (*6,7*). Peak diastolic filling was identified using a (−1, 0, 1) derivative filter. The point on this smoothed curve with the fewest counts was identified as end-systole. Intervals were computed in milliseconds as per Fig. 1.

Results from the two methods were plotted and correlation coefficients obtained using Pearson's correlation coefficient.

RESULTS

The systolic parameters ejection fraction and time to end-systole (Figs. 2 and 3) had excellent correlation between the two techniques, with correlation coefficients of 0.99 and 0.97, respectively. The diastolic parameters, on the other hand, are more sensitive to variations in cycle length, and may provide a better measure for comparing arrythmia filtration between the two techniques. As there are minor differences in the acquisition techniques, analysis will also reveal the relative sensitivity of the diastolic parameters to this slight variation in technique. Peak filling rate had a correlation coefficient of 0.94 (Fig. 4). Time to peak filling had a lesser degree of correlation, with $r = 0.65$ (Fig. 5); however, when measured from a fitted curve using two rather than three harmonics, correlation was higher at 0.86.

DISCUSSION

Several approaches have been taken toward minimizing the distortion introduced by variation in cardiac cycles (*8,9*). In frame mode techniques, count data is

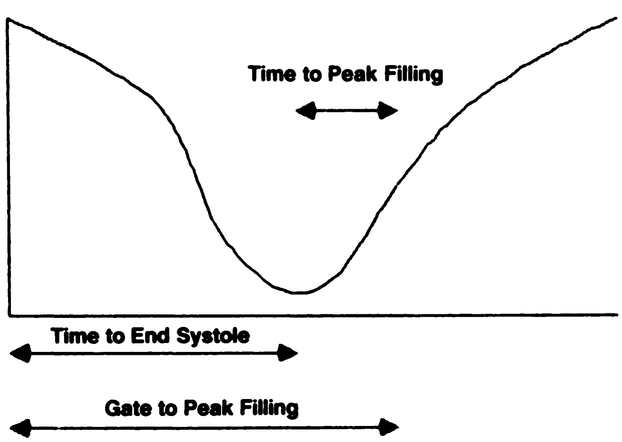

FIGURE 1
Curve representing activity in region of interest over left ventricle in gated blood-pool study, with standard intervals indicated

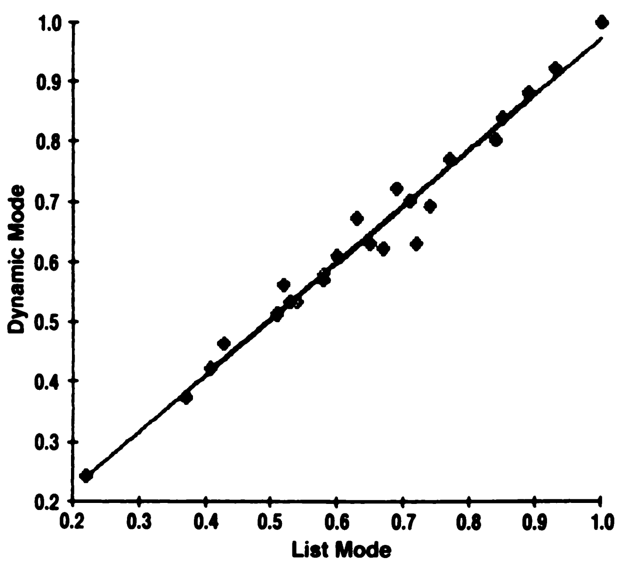

FIGURE 2
Graph of ejection fraction in 25 patients, comparing results from dynamic arrhythmia filtration with list mode windowing for each patient (r = 0.99)

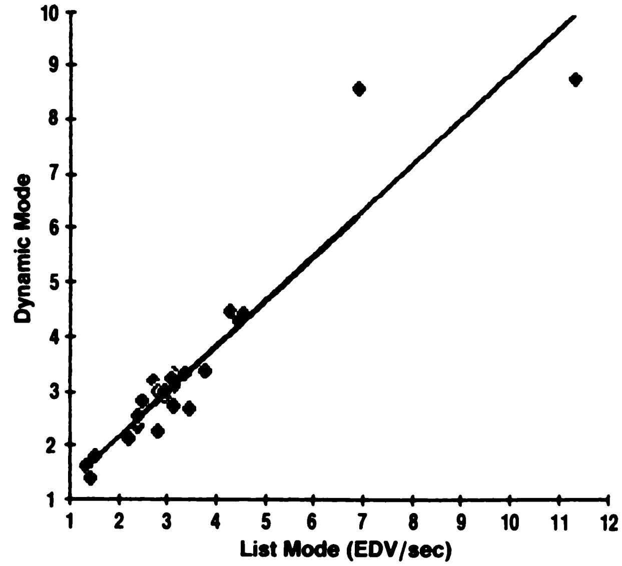

FIGURE 4
Graph of peak filling rate in 25 patients, comparing results from dynamic arrhythmia filtration with list mode windowing for each patient (r = 0.94)

usually added to the image as it is collected, making it difficult to remove that count data retrospectively if a cycle terminates early with a resultant abnormal cycle length. Beats following a premature ventricular contraction have been shown to have an abnormal degree of contractility (*10*). On the assumption that there will be distortion of the time-activity curve of the beat following a beat of unusual length cycle, the technique of postbeat rejection has evolved, where one or more beats following an abnormal cycle are not included in the study. Another approach involves collection of all count data and timing information onto a magnetic disk or tape. This is commonly referred to as list or serial mode. List mode acquisition allows several forms of postprocessing to be performed. After the acquisition is completed, each cycle can be examined to determine if it falls within a preselected R-R interval, and only those cycles that fall within this range have their images added together to form the final gated study. Many systems also offer postbeat rejection.

Diastolic function parameters, such as peak filling rate and time to peak filling, have been shown to have significant value in the diagnosis of coronary artery

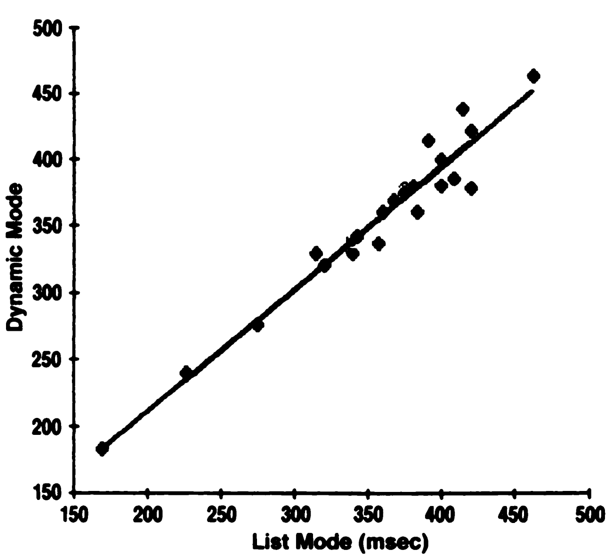

FIGURE 3
Graph of time to end-systole in 25 patients, comparing results from dynamic arrhythmia filtration with list mode windowing for each patient (r = 0.97)

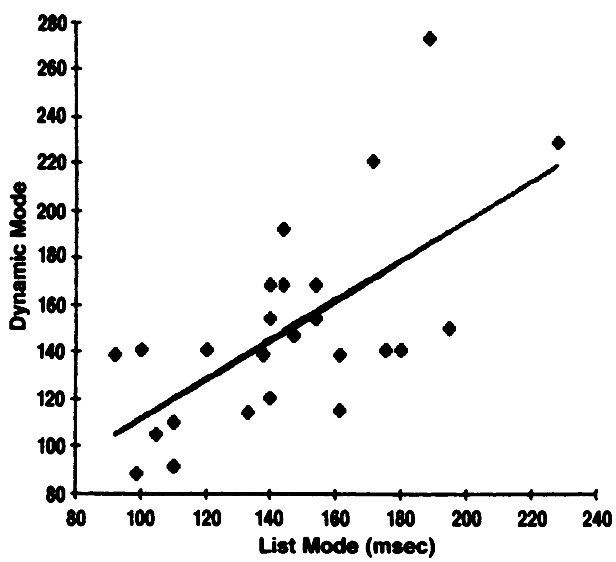

FIGURE 5
Graph of time to peak filling in 25 patients, comparing results from dynamic arrhythmia filtration with list mode windowing for each patient (r = 0.65)

disease (*11,12*), yet, as noted above, these parameters are sensitive to variation in cardiac cycles. A study by Juni et al. (*13*) examined the effect of normal heart rate variability on the measurement of diastolic function parameters. In this study, patients in normal sinus rhythm were examined, and data were sent simultaneously to two computers to allow the same blood-pool count data to be examined by two different techniques. Postbeat rejection alone was compared with a combination of list mode windowing using a 5% window and postbeat rejection. While ejection fraction was essentially the same by either technique (r = 0.92), there was little correlation between the two techniques for diastolic function parameters, with a correlation coefficient for peak filling rate of only 0.32. Thus, even in sinus rhythm, normal variation in beat length was sufficient to "blur" the time-activity curve when multiple cardiac cycle lengths were superimposed.

Despite these findings, list mode acquisition is not routinely performed in clinical practice. It requires both a large amount of data storage and a substantial amount of processing following the acquisition. These factors limit its utility.

Dynamic arrhythmia filtration is a frame mode technique with the advantage of being able to select a narrow R-R interval, but without the storage requirements or postprocessing time of list mode acquisition. In its simplest form, cycles are acquired alternately into dual memory buffers in computer memory. After the entire cycle is acquired, the cycle length is analyzed, and data from that cycle is added to the final image only if it falls within a preselected R-R range. By using two buffers, data from the next cycle can be acquired while the analysis of the last cycle is taking place, thus avoiding data loss due to processing time.

Figure 6 shows a sample cycle length histogram from a patient with a widely varying heart rate, with time-activity curves done through usual techniques utilizing

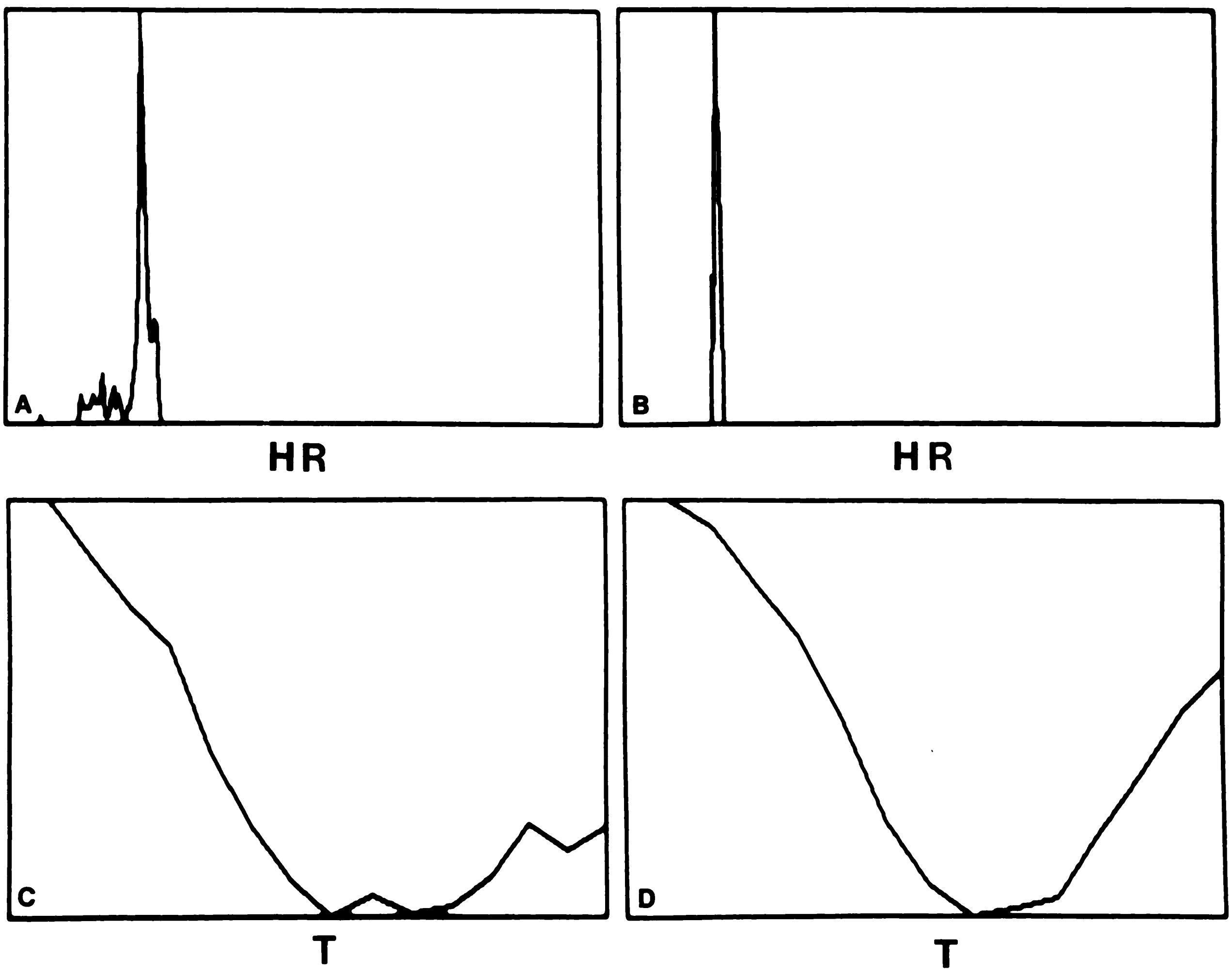

FIGURE 6
A: Cycle length histogram (plotted as number of cycles vs. heart rate) showing heart rate variation in patient who has varying R-R interval. B: Time-activity curve (plotted as background subtracted left ventricular counts vs. time) from same study where all cycles are included to form the image. C: Histogram showing cycles included in narrow (6%) cycle length window about peak. D: Time-activity curve from narrow cycle length window in same study (r = 0.94)

all cycles (Fig. 6B) and with selection of a narrow window R-R interval (Fig. 6D).

The fall in the terminal portion of the curve in Fig. 6B cannot represent a physiologic process. If this truly represented the relative volume of the left ventricle, it would indicate that the ventricle is emptying but not refilling. This type of artifact is attributable to combining cycles of varying lengths. Either method of arrhythmia filtration (dynamic or through list mode) helps eliminate this type of artifact.

The results of this study, illustrated in Figs. 2–5, show generally excellent correlation between list mode windowing and dynamic arrhythmia filtration. The small variation in ejection fraction, peak filling rate, and time to end-systole can be attributed to the slight difference in window size and hence in cycles utilized. Postbeat rejection, utilized in the list mode analysis, may have also had a contribution to the small differences between the results from the two techniques. For practical purposes, the excellent correlation between the two techniques for these parameters is sufficient to allow the use of dynamic arrhythmia filtration for collection of this data in clinical studies of patients in sinus rhythm (the role of cycle length windowing in other populations is currently being evaluated). The larger variation in time to peak filling found in this study, however, merits further discussion.

Analysis of time to peak filling differs from the other parameters in that it requires two points within the time-activity curve; it represents the time interval between end-systole and the subsequent point with the greatest first derivative (Fig. 1). The two components of this were examined separately. Time to end-systole, as noted earlier, had excellent correlation, with r = 0.97. The time from the gate to the point of peak filling, when examined alone as shown in Fig. 7, also has good correlation with r = 0.94. When subtracting the two time intervals to produce the time to peak filling, the small differences between the two techniques are added, resulting in a lesser degree of correlation. In addition, the variation of this parameter with small changes in the "smoothness" of the time-activity curve (as exemplified by the improved correlation with a two harmonic fit) may make this parameter less useful in evaluating individual patients.

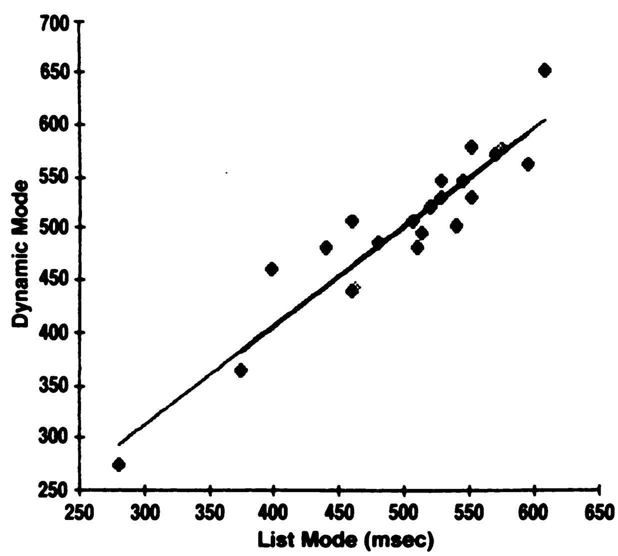

FIGURE 7
Graph of time from gate to peak filling in 25 patients, comparing results from dynamic arrhythmia filtration with list mode windowing for each patient (r = 0.94)

CONCLUSION

Variation in heart rate during gated blood-pool studies may cause errors in calculation of ejection fraction and diastolic filling parameters. Both list mode acquisition and dynamic arrhythmia filtration provide methods of removing cycles of an unusual length. Dynamic arrhythmia filtration correlates well overall with list mode techniques, and has the advantages of requiring less time and data storage space. Lesser correlation seen in the time peak filling may be due to inherent problems in measuring this value reliably, possibly lessening this parameter's clinical usefulness.

FOOTNOTES

* MDS A3 system was used for the dynamic arrhythmia filtration and MDS A2 system was used for list mode acqusition.

† Medical Data Systems, Ann Arbor, MI.

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