show that either a single, fixed end-diastolic ROI over each ventricle, or six ROIs (end-diastolic, end-systolic, and background ROI for each ventricle), can be used for determining the severity of valvular regurgitation. The fixed ROI method showed less variability in normals (F = 12.4, p < 0.01). Both methods deviated from the expected value of unity in normals. The fixed ROI method usually gave LV/RV ratios > 1 and the variable ROI method usually gave ratios < 1. The lower ratios in normals and regurgitation given by the variable ROI method were probably related to 1) better separation of the right atrium and right ventricle during systole, but continued overlap during diastole; 2) inadvertent exclusion of a portion of the right ventricle in the systolic ROI; 3) greater systolic overlap of the left atrium and left ventricle than the right atrium and right ventricle; or 4) a combination of these factors. Comparison with quantitative measures of valvular regurgitation is needed to determine whether the fixed or variable ROI method for obtaining LV/RV ratios is best. We chose the fixed ROI method because of its simplicity and reproducibility.

A Comparison of Simultaneous Measurements of Systolic Function in the Baboon by Electromagnetic Flowmeter and High Frame Rate ECG-Gated Blood Pool Scintigraphy

Michael V. Green, M.S., Harold G. Ostrow, M.S.E.E., Richard N. Scott, M.D.
Margaret A. Douglas, B.A., James J. Bailey, M.D., and Gerald S. Johnston, M.D.

SUMMARY Left ventricular (LV) systolic timing and relative volume variations were simultaneously measured by electromagnetic flowmeter (EMF) and high frame rate ECG-gated blood pool scintigraphy in five baboons. No significant differences (p > 0.1, paired t test) were observed in the time (from R wave) to peak aortic flow (maximum LV ejection rate), time to cessation of aortic flow (end-systole) or in the duration of aortic flow (LV ejection time). A small (~15 msec) but significant systematic difference (p < 0.02) was noted in the time to onset of aortic flow.

The shape of each scintigraphic time-activity curve during systole was compared to an equivalent curve synthesized from 10 EMF flow profiles obtained in the same baboon. Comparison of these paired curves over systolic ejection yielded an average correlation of r = 0.95 (range 0.90–0.99). The ratio of peak flow to stroke volume determined from these data did not differ significantly (p > 0.05).

In the baboon, quantitative high temporal resolution ECG-gated scintigraphy appears to reflect closely the detailed timing and relative magnitude variation of LV volume during the entire period of systolic ejection. We conclude that the assumptions underlying the scintigraphic method are valid in the baboon during the ejection interval.

HIGH FRAME RATE ECG-gated blood pool scintigraphy yields a scintigraphic image sequence that spans an average cardiac cycle.1 The time course of net total counts over the left ventricle in such a sequence is thought to reflect closely the time variation of left ventricular (LV) volume throughout the cardiac cycle; if true, this method not only offers the possibility of visualizing cardiac movement when the image sequence is cyclically displayed,1 4 but also provides a noninvasive method for routinely measuring intrasystolic and intradiastolic events, e.g., peak ejection and filling rates.

The quantitative accuracy of multi-image equilibrium studies in the measurement of such detailed, rate-related phenomena has not yet been established. Moreover, we are unaware of studies in which the assumptions underlying the scintigraphic method have been directly tested by experiment in vivo.

The present work addresses these issues (in part) by comparing simultaneous scintigraphic and electromagnetic flowmeter (EMF) measurements of instantaneous systolic LV function in the baboon.

Methods

Five male baboons (average weight 24 kg) constituted the study group. Under anesthesia and with controlled ventilation, a left anterior thoracotomy was performed through the fourth intercostal space. The ascending aorta was dissected free and one of several previously calibrated EMF flow probes installed about the aorta as near as possible to the aortic valve. The probe that most closely fit the aorta without compromising aortic flow was chosen. The probe electrical leads were exteriorized through a separate puncture

From the Department of Nuclear Medicine, Clinical Center, and the Division of Computer Research and Technology, NIH, Bethesda, Maryland.
Address for reprints: Michael V. Green, M.S., Department of Nuclear Medicine, Room 1B48, Building 10, National Institutes of Health, Bethesda, Maryland 20014.
Received April 10, 1978; revision accepted February 21, 1979.
wound. After installation of a chest drainage tube and layered closure of the wound, the baboon was transported to the nuclear medicine laboratory for study. Anesthesia and controlled ventilation were maintained during all subsequent procedures. As schematically illustrated in figure 1, the baboon was positioned supine in the field of view of a conventional scintillation camera equipped with a high-resolution, parallel-hole collimator. The exteriorized EMF probe leads were then connected to the flowmeter whose output (instantaneous aortic flow) was fed to one channel of a two-channel strip chart recorder.

Three additional leads were affixed to the baboon’s chest and thence to an ECG R-wave detector. Upon detection of the R wave in the ECG signal, the trigger emits a pulse both to the analog-to-digital converter of a minicomputer system and to the second channel of the strip chart recorder. Inspection of the recorder output thus permitted the time of occurrence of the R-wave trigger signal to be determined in relation to each subsequent EMF flow profile.

Ten milliliters of $^{99m}$Tc-human serum albumin were administered intravenously and sufficient time was allowed (>10 minutes) for the material to be uniformly distributed throughout the baboon’s blood volume. With the scintillation camera’s field of view masked by lead to a 6-inch diameter, a series of ungated scintiphotos of the cardiac blood pool were obtained to establish the optimal heart-camera orientation. The orientation that showed the greatest visual separation between the left ventricle and surrounding structures (normally modified left anterior oblique) was selected for data collection. A representative (gated) end-diastolic-end-systolic image pair, obtained in the baboon in this projection, is shown in images 2A and B. There are no appreciable (relative) anatomic or functional differences between these images and similar images obtained in man in approximately the same projection. The absolute size of the ventricular chambers in the baboon is, however, substantially smaller than in adult humans.

After these preliminary maneuvers, data were collected for approximately 20 minutes, while the EMF and R-wave trigger signals were sampled with the recorder at 5-minute intervals for at least five consecutive beats.

Scintigraphic data were collected continuously throughout the 20-minute interval. These data, acquired in LIST mode, consisted of the time of occurrence of each R wave, x-y coordinates for each valid scintillation event and timing marks generated by the internal computer clock at the rate of 100/sec. These data were recorded on magnetic tape by means of the minicomputer system.

After a study, the magnetic tape record would normally contain more than 5 million scintillation events acquired during some 2,000 cardiac cycles.

**Data Processing**

To reduce the amount of analog flowmeter data to manageable proportions, and yet retain the ability to observe systematic changes in LV function, five consecutive flow profiles acquired during the first 5 minutes of data collection and five profiles from the last 5 minutes of collection were selected for quantitative analysis. Selection of these beats was predicated only on the condition that the zero (flow) baseline of the EMF was constant during each five-beat interval. No other criterion was applied. Profiles obtained at intermediate times were used to monitor
the baboon for precipitous changes in LV function that might result from the experimental conditions; however, no such changes were observed. Thus, a total of 10 flowmeter profiles preceded by the R markers constituted the EMF results for each baboon.

The magnetic tape record of the scintigraphic portion of the study was analyzed with a large-scale computer system using a previously described technique. The scintillation data were organized into a high temporal resolution (10 msec/frame = 100 frames/sec) image sequence representing a single, average cardiac cycle. Each image in the sequence contained 4096 picture elements (64 × 64). The image sequence was then written back onto magnetic tape and returned to the minicomputer for analysis (fig. 1).

With the light pen facility of the minicomputer display, a region of interest (ROI) was identified to the computer, as shown in figure 2C. This region was selected by visual inspection of the end-diastolic image, the end-systolic image and the image formed by subtracting the latter from the former (the “difference” image). The ROI was drawn such that it overlay the left ventricle at end-diastole, the largest projected image of the left ventricle during the average cycle. At the same time, care was taken to avoid including non-LV structures within this region. Once the ROI was defined, the computer plotted the total counts within this fixed region for each image in the sequence. The resultant time-activity curve (TAC), not corrected for LV background, constituted the scintigraphic result of each study. For the five studies the total counts in this region averaged approximately 8000 events/10-msec frame at end-diastole.

The systolic portion of the scintigraphic TAC obtained by this process and the EMF data admit of two interdependent types of comparisons: 1) the time of occurrence of various systolic events, and 2) the relative magnitude variation of LV volume during systolic ejection.

Timing

Three time intervals, each measured from the R wave and readily identifiable in the flowmeter profiles, were selected for comparison (fig. 3A): 1) the time to onset of aortic flow (TTO), which approximates the preejection period (less a constant factor), 2) the time to peak aortic flow (TTP), which approximates the time to peak LV ejection rate, and 3) the time to cessation of aortic flow (TTC), which approximates the time to end-systole. A fourth quantity, the duration of aortic flow, which approximates the LV ejection time (LVET), was also derived from these data as the difference (TTC − TTO). Each of these timing quantities was individually determined in each of the 10 beats and averaged for each baboon.

Analogous timing quantities were defined for the scintigraphic TACs (after smoothing with a moving three-point average) as shown in figure 3B. The onset of ventricular ejection (TTO) was assumed to occur at the first point at which the TAC began a smooth, continuous and uninterrupted descent toward the TAC minimum. The time to peak LV ejection rate (TTP) was obtained by taking the first time derivative of a moving nine-point quadratic fitting function at each point on the (raw) curve. The time from the first point on the TAC (the R wave) to the point on the curve possessing the peak (maximum negative) slope was taken as the time to peak LV ejection rate. The time to the cessation of ventricular ejection (TTC) was defined as the time from the R wave to the nadir of the TAC. LVET was again calculated as the difference (TTC − TTO).

Volume Variations

The ratio of peak aortic flow (PK) to stroke volume (SV), determined by both measurement methods, was selected for comparison. This ratio was chosen for four reasons: 1) PK/SV is, in itself, an index of ventricular performance and expresses the maximum rate of ejection in SVs/sec; 2) this ratio is absolutely comparable between methods because the units of measurement are the same (sec⁻¹); 3) this ratio is a potentially sensitive indicator of methodologic differences, because for the scintigraphic method, PK is related to the slope of the tangent line to the ejection portion of the TAC; and 4) comparison of this ratio determined from the EMF data in several different ways (see Discussion) permits the effects of fluctuation in systolic timing to be assessed.

PK and SV are defined for the EMF in figure 4A. PK was assumed to be measured by the maximum excursion of the profile above the baseline. SV was obtained by numerical integration of the profile over the ejection interval and is equivalent to determining the area under the profile.

The ratio of PK to SV was determined from the 10

![Figure 3](https://example.com/figure3.png)
EMF profiles obtained in each baboon in two different ways. With the first method, PK was measured in each of the 10 profiles and averaged (PK). SV determined in these same profiles was similarly averaged (SV) and the ratio PK/SV constructed.

In contrast, with the second method, the R-wave markers preceding each of the 10 profiles were first aligned to the same moment in time and the 10 profiles averaged together point by point throughout the ejection interval. The result of this process was a single "composite" EMF profile, similar in appearance to the profile shown in Figure 4A, but representing the R-wave-aligned, time-averaged instantaneous variation in aortic flow during the ejection interval. PK and SV were again assumed to be the maximum vertical excursion of and the area under the composite profile, respectively. The single values of PK and SV determined from each composite were then used to calculate the ratio of PK to SV. The process for creating the composite EMF profile (R-wave alignment, pointwise averaging) is identical to that used to construct the scintigraphic TAC.

While PK/SV is a suitable parameter for comparison, this quantity represents only a single morphometric measurement at one instant in time. The ability of the scintigraphic TAC to follow LV volume changes throughout the entire ejection interval can be assessed through a further manipulation of the composite EMF profile. The composite EMF profile represents, in principle, the instantaneous time derivative of the scintigraphic TAC during the ejection interval. Thus, progressive integration of the composite EMF profile would be expected to yield a curve whose shape is identical to that of the TAC over the entire ejection interval. Accordingly, each composite EMF profile was numerically integrated over the ejection interval. The resultant "volume-change curve" (fig. 4B) represents, at each moment, the instantaneous difference between LV volume and end-systolic volume during ejection. The shape of the volume-change curve produced by this process can be correlated with the shape of the ejection portion of the TAC.

The analog of peak LV ejection rate (PK) and SV are defined for the scintigraphic TAC in figure 4C. Peak ejection rate was determined using the curve-fitting procedure previously described. The slope of the tangent line at each point on the ejection portion of TAC was calculated by differentiation and the largest such slope was taken as a measure of PK (in counts/sec). SV (in counts) was taken to be the difference in counts between TTO and TTC. The ratio of PK/SV (in sec\(^{-1}\)) was again determined for each study for comparison with the EMF measurements of this ratio.

Finally, in order to relate fluctuations in systolic timing (if present) to fluctuations in cardiac cycle length, a beat-length distribution function was created in each study from the R-R timing information in each scintigraphic record. Each such distribution is a plot of beat length (on the abscissa) against number of beats/10-msec interval (on the ordinate). Each of these distributions was Gaussian-like and symmetric about the mean beat length. The full width of each distribution function at its half-maximum height (FWHM) was taken as a measure of beat-length fluctuations (in msec) for that baboon during the study.

Statistical analyses were performed by means of the paired t test or linear correlation.

Results

Systolic time intervals determined from the EMF and scintigraphic methods are compared in table 1. No significant differences (p > 0.1) were observed in
**Table 1. Systolic Timing* (msec)**

<table>
<thead>
<tr>
<th>Study</th>
<th>SCINTI</th>
<th>EMF</th>
<th>SCINTI</th>
<th>EMF</th>
<th>SCINTI</th>
<th>EMF</th>
<th>SCINTI</th>
<th>EMF</th>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>75</td>
<td>93</td>
<td>145</td>
<td>143 (3)</td>
<td>305</td>
<td>303 (5)</td>
<td>230</td>
<td>208 (10)</td>
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<tr>
<td>2</td>
<td>95</td>
<td>107 (12)</td>
<td>165</td>
<td>167 (14)</td>
<td>295</td>
<td>330 (17)</td>
<td>200</td>
<td>253 (21)</td>
</tr>
<tr>
<td>3</td>
<td>95</td>
<td>106 (5)</td>
<td>165</td>
<td>158 (6)</td>
<td>325</td>
<td>334 (22)</td>
<td>230</td>
<td>228 (23)</td>
</tr>
<tr>
<td>4</td>
<td>85</td>
<td>108 (3)</td>
<td>165</td>
<td>172 (6)</td>
<td>305</td>
<td>335 (5)</td>
<td>220</td>
<td>227 (6)</td>
</tr>
<tr>
<td>5</td>
<td>105</td>
<td>109 (8)</td>
<td>165</td>
<td>177 (7)</td>
<td>355</td>
<td>348 (12)</td>
<td>250</td>
<td>238 (14)</td>
</tr>
<tr>
<td>Average</td>
<td>91</td>
<td>105</td>
<td>165</td>
<td>164</td>
<td>317</td>
<td>330</td>
<td>226</td>
<td>225</td>
</tr>
</tbody>
</table>

*p < 0.02 NS NS NS NS

*Time is measured in all cases from the R-S transition. Each EMF entry is the 10-beat mean of the designated parameter. Values are given in milliseconds; so is given in parentheses.

†p value from paired t test; NS = not significant (p > 0.1).

Abbreviations: TTO = time to onset of aortic flow (onset of ventricular ejection); TTP = time to peak aortic flow (maximum left ventricular ejection rate); TTC = time to cessation of aortic flow (minimum left ventricular volume); LVET = duration of aortic flow (left ventricular ejection time); SCINTI = scintigraphic; EMF = electromagnetic flowmeter.

The time to peak ejection (TTP), time to cessation of ejection (TTC) or in the duration of ejection (LVET). A small but significant difference (average ~ 15 msec, p < 0.02) was noted in the time to onset of ejection (TTO).

The ratio of PK/SV determined scintigraphically is compared (table 2) with the two values obtained for this ratio from the EMF data: first, from the composite EMF flow profile obtained by R-wave alignment and pointwise, 10-beat averaging, and, second, by calculating the 10-beat mean of PK and of SV for the same 10 beats and forming the ratio PK/SV.

No significant difference (p > 0.05) was observed between the scintigraphic PK/SV ratio and the ratio obtained from the composite EMF profile. No significant difference was noted between the composite EMF ratio and the EMF ratio, PK/SV. A small, systematic difference was observed between the scintigraphic ratio and the EMF ratio, PK/SV (average ~6%; p < 0.05).

**Table 2. Peak Flow/Stroke Volume (sec⁻¹)**

<table>
<thead>
<tr>
<th>Study</th>
<th>SCINTI PK/SV</th>
<th>EMF PK/SV</th>
<th>PK/SV*</th>
<th>PK/SV†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>8.9</td>
<td>9.2</td>
<td>9.7 (1.4)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>8.5</td>
<td>8.6</td>
<td>8.0 (2.1)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>8.7</td>
<td>9.1</td>
<td>9.2 (2.5)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>7.3</td>
<td>7.2</td>
<td>7.2 (0.8)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>7.4</td>
<td>7.9</td>
<td>7.9 (1.2)</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>8.2</td>
<td>8.4</td>
<td>8.6</td>
<td></td>
</tr>
</tbody>
</table>

*p < 0.05 NS NS NS

* Determined from 10-beat composite EMF profile obtained by R-wave alignment followed by pointwise averaging.
† Determined from 10 individual flow profiles:

(PK₁ + PK₂ . . .) / (SV₁ + SV₂ . . .). Values in parentheses indicate standard deviation of ratio.

The shape of each scintigraphic TAC (fig. 4C) during the ejection phase was compared with the shape of each corresponding EMF volume-change curve (fig. 4B) over the range of points common to both curves. For these points the scintigraphic TAC was plotted (on the ordinate) against the EMF volume-change curve (on the abscissa) over the ejection interval. The R-wave marker preceding each curve was set to zero time on the respective coordinate axis. Linear correlation was then performed on these data. The resulting correlation coefficients averaged 0.95 (range 0.90-0.99) for the five studies (table 3). Correlation analysis yields a measure of curve shape similarity that is independent of absolute calibration of either curve. The similarity in curve shape implied by these coefficients is shown in figure 5 by the direct overlay comparison of a scintigraphic TAC with its corresponding volume-change curve. For this comparison, the R-wave marker preceding each curve was set to zero time and the curves were allowed to superimpose where they would. No temporal scaling of either curve was performed. In this figure, however, the scintigraphic SV was scaled to the EMF SV, because the scintigraphic curve is not volume calibrated or background corrected.

An ancillary finding is also portrayed in figure 5. Inspection of the scintigraphic TAC during early systole appears to indicate a reduction in LV volume without concomitant aortic flow (measured by EMF). The magnitude of the apparent volume reduction shown in the figure was the largest observed in any of the studies (~30% of SV), but was detectable at

**Table 3. Curve Shape Comparison*†**

<table>
<thead>
<tr>
<th>Study</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.97</td>
<td>0.91</td>
<td>0.90</td>
<td>0.98</td>
<td>0.99</td>
<td>0.95</td>
</tr>
</tbody>
</table>

*Comparison of integrated composite EMF profile ("volume-change curve") with ejection portion of scintigraphic time-activity curve.
†Linear correlation coefficient.
reduced amplitude in three of the four remaining studies (\(\sim 15\%\) of SV). The effect was not detected in one baboon. This apparent volume reduction could not be eliminated by changes in the size or location of the LV ROI. The effect was present for ROIs greatly exceeding the apparent size of the ventricle at end-diastole and for ROIs that lay wholly inside the end-systolic ventricular projection. The effect, moreover, was detectable when the ROI only partially overlay the left ventricle, e.g., over half of the ventricle containing the ventricular apex. An “explanation” for this effect, consistent with these observations, is given below.

Mean heart rate for the five studies was 102 beats/min (range 90–133 beats/min). The average absolute variation in beat length (measured by FWHM) was 34 msec (range 20–70 msec). The relative beat-length variation (FWHM/mean cycle length) averaged 5.5% (range 3.2–10.4%). This relative variation is approximately half that observed in resting human patients with typical resting heart rates, but is comparable\(^*\) to that observed in patients with the same elevated resting heart rate (6.9% of mean cycle length).

**Discussion**

At present, a variety of imaging and nonimaging devices\(^2\).\(^4\).\(^5\) can produce LV TACs of high temporal resolution using gated equilibrium methods. If, however, these curves are to be interpreted as reflecting LV volume variations, a specific functional relationship between external LV count rate and LV volume must be assumed. Consideration of the physical processes involved in detecting radiation from the left ventricle under equilibrium conditions suggests that, to a first approximation, this relationship should have the form:

\[
R(t) = K \cdot V(t) + B
\]  

(1)

where \(R(t)\) is the time-averaged, instantaneous external count rate at time \(t\) after the R wave, and where \(V(t)\) is the time-averaged, instantaneous value of LV volume at the same moment. The quantity \(K\) and the quantity \(B\) (the LV “background”) are presumed constant in a given subject.

If equation (1) does, in fact, describe the relationship between external LV count rate and LV volume, then several consequences of this linear expression should be experimentally demonstrable: 1) the timing of events in \(R(t)\) should be the same as in \(V(t)\); 2) the shape of \(R(t)\) should be identical to the shape of \(V(t)\) over any prescribed finite time interval; and 3) certain rate-related parameters determined from \(R(t)\) should possess the same numerical value as when determined from \(V(t)\). In the present study, each of these hypothesized relationships can be directly examined during the systolic portion of the cardiac cycle.

**Systolic Timing**

No experimentally discernible differences could be detected between the scintigraphic and EMF estimates of the TTP, TTC, or duration of flow (table 1). The small difference (average \(\sim 15\) msec) in TTO is comparable to the effective temporal resolution of both methods (\(\sim 10\) msec), and is also comparable to the magnitude of potential sources of error in determining TTO. Among these are the nonlinear effect of smoothing the TAC, the location of the EMF flow probe and observer bias. The source of this systematic difference cannot, therefore, be unambiguously attributed to either method. Thus, substantial agreement appears to exist between the methods in the timing of selected systolic events. This result is in accord with the hypothesized linear relationship expressed in equation (1).

**Curve Shape**

Pairwise comparison of each scintigraphic TAC with the corresponding EMF volume-change curve
yielded linear correlation coefficients of 0.90 or greater for the five studies. The relative standard error of the slopes and intercepts of the regression relations obtained for the five studies averaged ±7% for both parameters. We infer from these results that there is a similarity in curve shape between R(t) and V(t) during the entire ejection interval. This result, therefore, is also in accord with the linear relationship between R(t) and V(t) expressed in equation (1).

Peak Flow/Stroke Volume

The ratio of PK/SV is predicted to possess the same numerical value (in sec⁻¹) when computed from either R(t) or V(t). The values of this ratio, determined from each TAC and corresponding composite EMF profile, are tabulated in the first two columns of table 2. The average difference between these paired measurements was about 2% (NS). It appears, therefore, that when the EMF profiles are manipulated in exactly the same manner as the scintigraphic data (R-wave alignment followed by pointwise averaging), the relationship between SV and the rate parameter, PK, is similar for both methods. This result is also in accord with the hypothesized relationships expressed in equation (1).

The ratio of PK/SV determined from each composite EMF profile is compared with the beat-by-beat EMF estimate of this ratio (PK/SV) in the second and third columns of table 3. The average difference between these two EMF determinations was about 2% (NS). This result, though obtained only from EMF measurements, has an important bearing on the capacity of the scintigraphic method to accurately reproduce LV volume variations in the presence of small fluctuations in the timing of systolic events. Such fluctuations, in concert with fluctuations in the timing of diastolic events, cumulatively give rise to the beat-by-beat changes in cardiac cycle length observed in the baboon (and in man). If such fluctuations are present, it is not difficult to show that the ratio of PK/SV determined from the composite EMF profile will be systematically lower than that obtained by the beat-by-beat averaging method (PK/SV). The magnitude of this difference depends on the shape of each profile in the vicinity of PK and on the magnitude of the fluctuations in TTP with respect to the R wave. As noted, however, no significant difference could be detected in the ratio of PK/SV determined by these two averaging methods. We conclude, therefore, that the R-wave alignment, pointwise averaging method, itself the central feature of the scintigraphic method, is not unduly sensitive to small fluctuations in the timing of systolic events. ("Small," in this context, means on the order of the standard deviations of the EMF systolic times tabulated in table 1.) By this same reasoning, the small but significant difference between the scintigraphic PK/SV ratio and the EMF ratio, PK/SV, cannot be ascribed to timing fluctuations because such fluctuations do not distort the EMF ratios.

The results obtained in each of the three preceding comparisons suggest, therefore, 1) that within experimental error, the presumed linear relationship between external LV count rate and LV volume (equation (1)) does, in fact, exist in the baboon during the ejection interval, and 2) that under the experimental conditions, the scintigraphic technique appears to measure selected systolic parameters, including those related to rate of volume change, with an accuracy comparable to that of the EMF.

Some caution must be exercised, however, in extrapolating these conclusions to man. The mean heart rate for the five studies averaged 102 beats/min, a value substantially higher than that encountered in resting adult humans. At such elevated rates it might be expected that the absolute magnitude of fluctuations in the timing of systolic events would be small. This expectation does, in fact, appear to be confirmed by the small variations noted in the direct EMF estimates of these times (table 1) and by the generally small absolute width of the beat-length distribution functions obtained in each baboon. It is possible, therefore, that in resting human adults with lower heart rates and potentially greater fluctuations in systolic timing, some distortion of the TAC might occur. In this light, the present study sets only a lower limit on the degree to which the scintigraphic method can tolerate timing fluctuations during the ejection period.

A second potential disparity may also exist as a result of the substantial difference in absolute LV size between man and baboon. In the baboon, the dimensions of the left ventricle and the change in these dimensions during the ejection interval are small compared with the half-value layer of 140 keV photons in tissue-like material. Under these conditions the detection efficiency for activity in the left ventricle is nearly identical throughout the ventricle at every moment. In man, however, ventricular dimensions and their changes constitute a larger fraction of the half-value layer. Thus, in man the possibility exists that the detection efficiency for LV activity may be neither uniform throughout the ventricular volume nor constant in time. If so, equation (1) would no longer rigorously obtain, and a more complex relationship between external count rate and LV volume would have to be assumed. While the potential magnitude of this effect is difficult to estimate in man, phantom studies have suggested that nonlinearities in detection efficiency constitute a relatively minor perturbation of the nearly ideal detection conditions in the baboon.

In contrast to these potential concerns, one difference between R(t) and V(t), directly observed in the present study, may also be demonstrable in man. TACs obtained in four of the five baboons appeared to show a reduction in LV volume during early systole without concomitant aortic flow: A change in R(t) was observed without an apparent corresponding change in V(t), violating equation (1).

The information available in the present study does not permit the source of this disparity to be unambiguously identified. However, a similar (but smaller) apparent reduction in LV volume during the prejection period has also been noted, in both man and
animals with competent valves, by other investigators using entirely different measurement methods.\textsuperscript{19-12} The explanation for this effect advanced by these investigators also appears applicable in the present case: a transient change in the shape of the sealed LV cavity during the preejection period due to bulging of the mitral valve plane upwards into the atrium. Displacement of the mitral valve plane is, in turn, attributed to the rapid increase in LV pressure during the preejection period. If such bulging occurs in the baboon, a slight translation of the LV blood toward the atrium, presumably with a corresponding displacement of the atrial blood, would reduce the activity and thus the count rate within the fixed ROI. This effect, moreover, would be observed for large or small ROIs or for ROIs that only partially overlie the LV. This “explanation” is therefore consistent with the experimental observation that the apparent volume reduction could not be eliminated by altering the size or location of the LV ROI. If this reasoning is correct, some ambiguity may also exist in interpreting LV TACs during the preejection period in man.

Summary and Conclusion

The quantitative accuracy of gated equilibrium scintigraphy (or counting) in the measurement of LV function is ultimately determined by the validity of the assumptions upon which the method rests. In the present investigation two of these assumptions were examined: 1) that a linear relationship exists between external LV count rate and LV volume (including the presumption of a time-independent background), and 2) that superimposition of scintigraphic data from many cardiac cycles, each with slightly different systolic timing, does not distort the TAC in relation to “true” LV volume variations. These assumptions are essentially correct, within experimental error, in the baboon during ventricular ejection.

These results, however, cannot be rigorously used to imply the behavior of the scintigraphic method during diastole in the baboon. Nor can these results, without some qualification, be directly extended to the measurement of systolic function in man. Despite these limitations, however, the present study is entirely consistent with recent indirect and non-simultaneous comparative studies in man.\textsuperscript{4, 13-16} In these investigations, generally favorable agreement has been noted between results obtained by the scintigraphic procedure (using the assumptions examined here) and other comparison methods. The present study supports these findings and further suggests the potential accuracy of the method in the measurement of rate-related phenomena during systole.

Acknowledgments

The authors express their gratitude to William H. Schuette, B.S.E.E., and to Mr. Richard Terrill for their invaluable technical contributions to this work. The authors also thank Luella Bentz for preparing the manuscript.

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_Circulation_. 1979;60:312-319
doi: 10.1161/01.CIR.60.2.312

_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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