Cardiac Functional Imaging with a Multi-Element Camera

Bobbie Miller and Nikolaus Schad

Scintillation Technologies Corporation, Maryville, Tennessee and University of Siena, Siena, Germany

Cardiac functional imaging (CFI) is a technique used to study the heart chambers as they eject blood into the lung (right ventricle) and the systemic circulation (left ventricle) as well as during the ventricular filling period. CFI provides an extremely accurate method to study the heart's function regionally. Changes during heart contractions (systole) and relaxations (diastole) are visualized in the CFI images.

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In cardiac functional imaging (CFI), particular emphasis is placed on the vascular perfusion territories of the coronary arteries. Digital imaging allows pixel analysis of the heart's function. In coronary stenosis, most significant abnormal changes occur at the beginning of contraction (ejection) and relaxation (filling). If the patient is at rest, these abnormal events may be extremely brief (up to 0.2 sec). Only a high-speed gamma camera, which precisely locates the short lasting event with a high enough count number (data), can provide accurate CFI images. Thus, the combination of a powerful high count rate instrument with a fast sophisticated computer program, provides the clinician with the maximum diagnostic information about the heart's function (*1*).

MATERIALS AND METHODS

A standard first pass angiogram is acquired on a multicrystal gamma camera. Eight hundred gated frames are accumulated in this technique at 25 frames per sec for a resting study. Following the rest study, 800 frames are acquired at stress at 40 frames per sec (a higher framing rate is required due to increased heart rate). Each frame corresponds to a time interval of 25 or 40 msec. These data are transferred via an interface from the multicrystal gamma camera to a high speed computer for CFI processing.

A representative cycle (repcycle) is created from this data by adding 6 to 9 heart cycles together; the cycles are selected from the left ventricle time-activity curve during the washout phase of the cardiac cycle. A left ventricular border is determined from this data by processing a spatial gradient

image. This image reflects count changes in four directions in the end-diastolic repcycle image. Background is semiautomatically determined using a lung perfusion mask and measurements around the anterior left ventricular border. After subtraction of background, functional images are generated.

RESULTS

Images generated by the Schad-Murray software (2) are divided into the following types: regional ejection fraction images, regional ejection rate images, rapid filling images, and sequential rate images.

Normal rate images (ejection rate) present regional temporal activity gradients (changes) in the form of symmetric bands of equal range of value along the longitudinal axis of the ventricle. Maximum volume change is represented by yellow. A 14-color number scale is used, yellow being the highest activity, dark green representing the least activity (Fig. 1). The activity gradient is crescent-shaped and lies immediately inside the chamber. Variations in the represented color, interruption, or loss of part of the normally peripheral crescent-shaped high-rate band of ejection, are very sensitive indications of segmental ventricular dysfunction. Left ventricular segments in functional images are divided into the anterior wall, including the entire left anterior descending (LAD) territories, and the inferior wall, including the left circumflex coronary artery (LCX) and the right coronary artery (RCA) territories.

Rapid filling images show the heart's initial filling patterns and its disturbances and are further analyzed in the sequential images.

Sequential imaging, using the Schad-Murray approach, is the latest refinement of the first pass technique. Clinical studies using this technique show that the first 200 millisec of the heart's contraction provide important information about the heart's function, not seen in standard first pass imaging covering the entire contraction. Sequential imaging demonstrates that the first part of systole shows ischemic changes of the heart that are missed in other noninvasive studies of the heart, and sequential imaging frequently shows this without the need to stress the patient.

The information derived from sequential imaging is important to the clinician because the onset of retarded contraction and the extent of ischemic areas (low ejection) provide information about the functional severity of coronary disease.
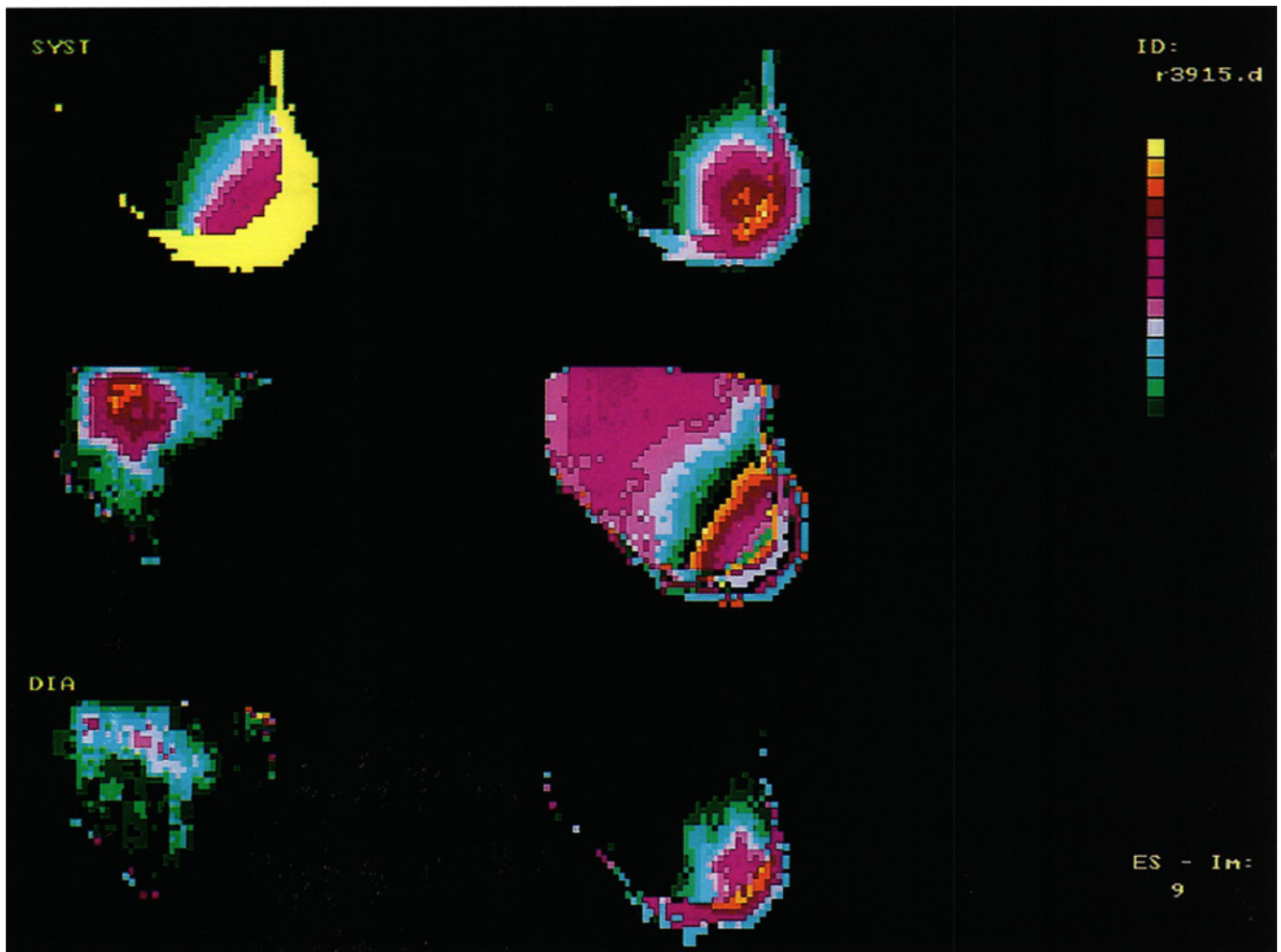
FIG. 1. (Top Row) Ejection fraction image (left): systolic image with perimeter of end-diastolic image. Colors indicate the concentration of radioactivity within the ventricle. The yellow band demonstrates the degree of contractibility within the ventricle. Regional ejection rate (right): A pixel by pixel contribution of pump efficiency. It is a decrease image, showing the mapping of all regions where activity decreases during ventricular contraction and degree of contraction. (Middle Row) Corresponding r.e. rate (left): this image visualizes all the regions where activity increases during systole—aorta and eventually left atrium. Mean time transit image (right): an image describing transit time of average blood cell for every pixel during systole. Normally during systole shortest times are near the ventricular wall, decreasing to the valve area, and being slowest in the aorta. (Bottom Row) Decrease rapid filling (left): defines rate of decrease of blood in heart during diastole. Normally there will be a decrease of blood in left atrium and aorta during diastole. Increase rapid filling (right): defines the rate of increase of blood in heart during diastole (ventricular rapid filling). Normally there is an increase in the ventricle during diastole.

In sequential imaging, six sequential systolic ejection rate images are computed using a least square linear fit (Figs. 2 and 3). Computation always begins with the end-diastolic image. In a resting study, a framing rate of 25 frames per second (fps) is used. Images are constructed at intervals of 40 msec, beginning at 80 msec and ending with 280 msec. In the instance where a stress study is performed, a framing rate of 40 fps is used. Stress sequential images are constructed at 25 msec intervals, beginning at 50 msec and ending with 175 msec.

The algorithm adopted for a least square linear fit generates two parametric images, one showing regional rates of linear decrease and the other showing regional rates of linear increase. Positive values result from one of the two images, depending on a decrease or an increase of blood volume in certain regions during the selected cardiac phase. During ventricular contraction, the blood volume routinely de-

creases in all pixels through the left ventricle as measured by the gamma camera, whereas blood volume tends to increase in the ascending segment of the aorta during the same time interval. Thus, the decrease image shows pixel values decreasing in the area of ejection flow of the left ventricle, while the clearing image shows pixels values increasing during filling into the ascending aorta.

By always adding one frame to the sequence, recomputing the ejection rate image, and comparing the resulting decrease image with the previous one, one can easily detect the additional ejected volumes and from which wall segments they depart. Thus, ventricular emptying can be sequentially analyzed.

Reduced ejection rate from a given segment is characterized by an initial lack of any ejection at the ventricular periphery. During later systole, ejection may start from this segment but will present lower rates than those from other
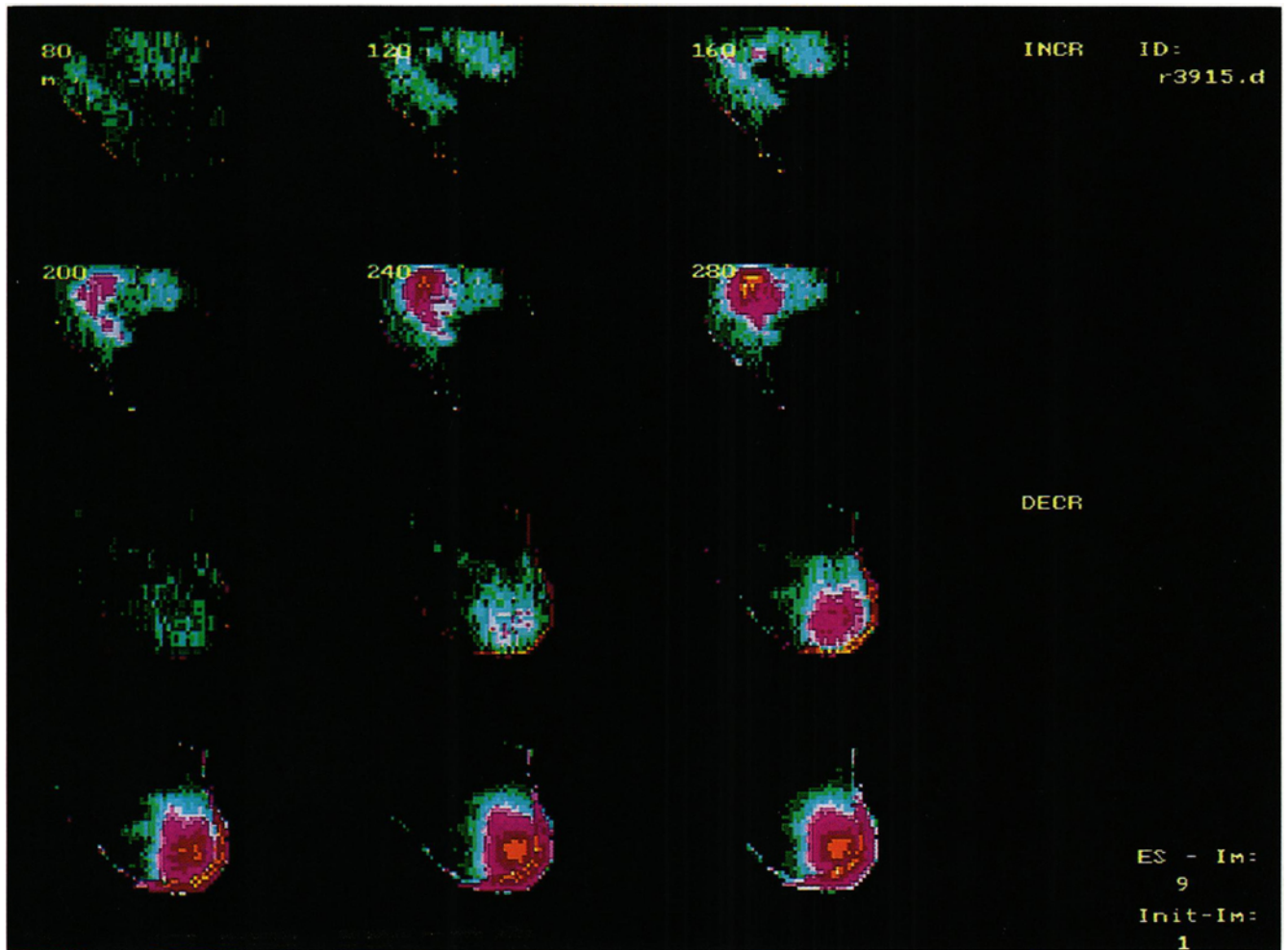
FIG. 2. (Top set of 6 images) Increase images: when top left image (diastole) is entered, initial systolic ventricular rates (decrease of blood) are computed as well as corresponding rates of increases. Latter show filling of the aorta, eventually also left atrium, if there is any reflux from the ventricle and some paradoxical ventricular outward shifting of blood (increase) or outward wall motion, particularly in severe ischemia, infarcted regions, or aneurysms. Time interval covered is from 80 msec to 280 msec. (Bottom set of 6 images) Decrease images: when top left image is entered, images which define rate of decrease of blood in heart during systole are shown. Images show first few sec of initial ejection of left ventricle and very subtle changes can be seen in first images.

regions. Finally, the high rate bands, normally seen toward the end of ejection, may be interrupted and substituted by lower values. Loss of part of the normally crescent-shaped high-rate (yellow) band at the periphery of the left ventricle, and substitution by higher central rates, is a very sensitive sign of retarded or reduced function. (1)

A study of 127 patients by Dr. Gary Murray, showed a 86% specificity and >90% sensitivity overall in detecting coronary artery disease (3). Similarly, in a study conducted by Dr. Nikolaus Schad, encompassing 43 patients, a specificity of 90%, as well as a sensitivity of 90%, was achieved (4).

DISCUSSION

As stated earlier, the most important criterion for a successful first-pass study is a gamma camera that has the ability to acquire very high counts in a very short time interval. The older and current multi-crystal gamma cameras are a modification on the general characteristics of a single-crystal in-

strument. Using a series of small individual crystals in a matrix, scientists are able to significantly increase this instrument's ability to detect a large number of counts over a very short time interval. Thus, the camera can handle very high count rates, approximately 450,000 cps, without significant dead-time losses (2).

A new version of the multi-crystal gamma camera is the multi-element gamma camera, which uses a scintillating material other than sodium iodide.

The advantages of the multi-crystal camera over the single-crystal camera are that the former can handle a higher count rate, that the thicker crystal (1.5 inch) is significantly more sensitive for higher energy photons, and it is able to accurately image dynamically, moving organs such as the heart. Temporal or dynamic resolution is the ability to discern movement by utilizing counts over time. A study published by Nickel and Schad describes the multi-crystal camera's superior temporal resolution over that of single-crystal instruments as follows (2).
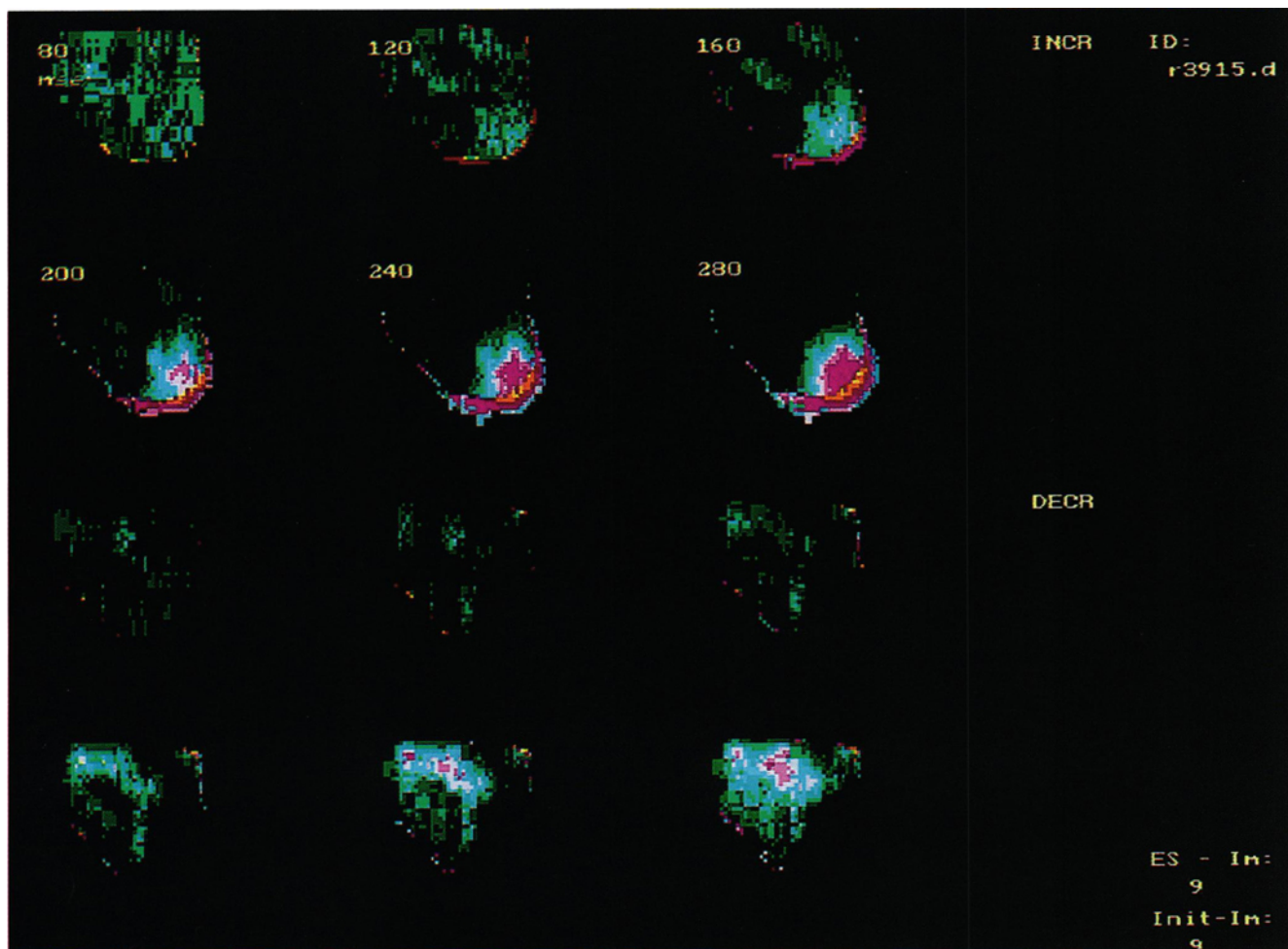
FIG. 3. (Top set of 6 images) Increase images: when systole is entered, initial diastole filling rates (increase) are computed as well as decrease images. Increase images show early filling of diastole which can detect very subtle changes that can be missed in systole. (Bottom set of 6 images) Decrease images: When systole is entered, the emptying rates of the aorta, eventually left atrium, and some paradoxical ventricular inward shifting of blood or wall motion can be seen in images.

The question has arisen whether or not one can detect motions of the heart border which are smaller than the static/spatial resolution of the camera. The answer is positive and can be demonstrated by experiment: one can measure scintigrams of the edge of a flood source *before* and *after* a movement of 3 and 5 mm perpendicular to the edge. If one makes lines of the 50% level (relative to maximum density), which corresponds to the edge, the motion of the edge can be seen even if it is only 3 mm. This, however, depends on the count rate. If the maximum count density (counts per crystal) is only 50 instead of 500, fluctuations are too excessive to resolve the motion. In this way, one can define the minimum detectable motion of an edge as the dynamic resolution.

The multi-crystal camera is used primarily to perform functional imaging of the heart. The clinical advantage of this technique is its technical simplicity coupled with the ability to study the heart in multiple projections. Another important advantage is a brief data collection time (25–30 sec) due to the camera's high count rate capabilities.

CONCLUSION

Cardiac functional imaging presents a very reliable, noninvasive means of evaluating the coronary arteries in both normal and abnormal patients. Sequential imaging information is especially helpful to the clinician because the onset of retarded contraction and the extent of ischemic areas provide information about the functional severity of coronary disease.

Another article has discussed the assumption that early changes in the cardiac pattern may indeed hold promise for better interpretation and diagnosis (5). We agree that vital information, which may hold the secret to very early detection of cardiac disease, is present in one cycle of a heartbeat. We just need to unlock the information by dissecting the cycle data into a workable recognition pattern.

The Schad-Murray software program is an avenue that can help unlock the heart's basic data for analysis. It is very cost effective, which is necessary in this era of cost containment. It can help to better evaluate potential cardiac problems.

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