

ELECTROCARDIOGRAPHY, CINEANGIOGRAPHY AND
MYOCARDIAL DISPERSION STUDIES IN THE
PATIENT WITH CHEST PAIN:
A DESCRIPTIVE STUDY

by

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ABSTRACT

The purpose of the study was to compare findings of electrocardiograms, arteriograms, and myocardial dispersion studies in patients with chest pain. Studies from 182 patients were reviewed and compared.

Findings from the anterior surface indicated close relationships between the abnormal dispersion study and abnormal electrocardiographic and arteriographic findings. Examination of results from the inferior surface revealed a disparity of information from the different parameters indicating poor evaluative tests for this surface. Dispersion study data from the posterior portion of the myocardium seemed to follow arteriographic predictions, but results of perfusion studies as compared with electrocardiograms were equivocal.

The radioisotopic findings substantiated the assumption that the patient may have normal or at least viable myocardium in the face of arteriographic and/or electrocardiographic abnormalities. Radioisotopic evaluation of the myocardium has been shown to impart valuable information about the integrity of the capillary bed that cannot be implied from the electrocardiogram or cineangiogram.

CHAPTER 1

INTRODUCTION

The diagnosis, management, and prognosis of the patient with heart disease has undergone great change in the last thirty years. Beginning with the conceptualization of coronary care units and continuing with the use of sophisticated monitoring devices, a whole new approach to heart disease has developed. New advances in medical and surgical management have produced such gratifying results that the term "heart attack" does not hold the dismal connotation it once did.

The statistics of death due to atherosclerosis, however, are still terrifying to us as a nation of prime genetic and cultural candidates for myocardial infarction. This has resulted in reassessment of medical treatment for the acute phase of the disease and the development of revascularization techniques which can stave off the immediate effects of arterial stenosis. However, the institution of these procedures relies upon prompt, specific, and reliable diagnostic information. Specifics of pathology must be recognized in order to apply the specifics of today's refined treatments. Clinical assessment, electrocardiography, and cineangiography are now

joined by myocardial radioisotopic scanning in the diagnosis of atherosclerotic heart disease.

Chest Pain

The clinical assessment of chest pain has long been a thorn in the side of the diagnostician, and the wide range of possibilities for its propagation is narrowed only by extensive and timely screening procedures. It is generally the presenting problem in the patient with coronary arterial disease, but is rarely used as a diagnostic determination in its isolated form.

Electrocardiography

Electrocardiography is a time-honored tool for diagnosis, but experience has illuminated its weaknesses. Technical errors in attainment and evaluation of the EKG may add to the misinterpretation of its rather gross representation of pathology. Previous infarctions, conduction defects and subendocardial or subepicardial injuries may make reliable diagnosis impossible from the tracing alone (Willerson et al. 1975). Laboratory values of enzymes are added to the information gained from the EKG, but their significance is only relative to the more blatant pathologies. Because of their nonspecificity, cardiac enzyme abnormalities may be affected by intramuscular injections, liver, brain, or pulmonary pathology, or hemolysis of the specimen.

Coronary Arteriography

Coronary arteriography has been used in the last twenty years to document lesions of major coronary arteries as well as to give insight into the contractile capabilities of the ventricles.

Improvement of techniques and instrumentation has yielded this invasive procedure relatively mortality free (.1%) and has greatly lowered morbidity in the hands of an adept cardiologist (Hurst 1974: 377-386). The indications for coronary arteriography have been discussed at length and are being broadened by advances in cardiovascular surgery. The need for the procedure lies in direct proportion to how well the clinician will be able to apply its information to the recovery or maintenance of the patient (Baltaxe 1973: 126-131; Grossman 1974: 4-6; Mendel 1968: 2-4). Coronary arteriography has come to the foreground as an efficient diagnostic tool, though it does represent only arterial and gross functional pathology. Therefore, integrity of the arterial bed at the cellular level still remains a matter of informed speculation.

Myocardial Scanning

Knowledge of cellular pathology is not only a matter of interest to the cardiologist in his management of the acute or chronic cardiac patient, but determination of muscle perfusion is of great importance to the

surgeon who may assess the patient for revascularization. Determination of the actual resting myocardial blood flow to areas fed by compromised coronary arteries is extremely important in evaluating the viability of that tissue. Bypass grafting procedures to areas distal to occlusions are fruitless if decreased blood flow has resulted in large areas of severely damaged myocardium. The need for insight into cellular pathology has culminated in an intensive study, ongoing for the last fifteen years, into myocardial radioisotopic scanning.

Radioisotope scanning is the visualization of masses or organs as they are illuminated by radioactive tracers (Sevelius 1965: 102-117). Refinement of techniques and research into its cardiovascular applicability has been an area of combined study by the nuclear medicine physician and the cardiologist. Medicine is presently on the threshold of clinical acceptance of myocardial scanning as an important diagnostic tool.

Statement of the Problem

What are the relationships between the results of myocardial scanning, coronary arteriography and electrocardiography in the patient with chest pain?

Significance of the Problem

The use of myocardial scanning has been proposed as a more precise diagnostic tool in the process of

evaluation of heart disease. Whether the information gleaned from myocardial scanning is accurate and applicable or not must be assessed through correlation of its results with presently used diagnostic tools. Ultimately, how useful the information has been to the cardiovascular surgeon must be assessed. Medicine is currently involved in the search for a tool that will give it detailed information on which to base a more accurate treatment.

Patients who underwent this diagnostic workup were selected primarily for their presentation of chest pain to the clinician. The nurse's observation and intervention of chest pain is important in the diagnosis of heart disease. Accordingly, her role in teaching and preparation of the patient during and after his series of tests is dependent on her understanding of the separate and combined significance of the procedures.

Nursing as a profession must involve itself with medical research, not only for the enhancement of its clinical application, but for the promotion of nursing knowledge as a whole.

Purpose of the Study

The purpose of the study is to assess the results of myocardial isotopic scanning in patients with chest pain who have also undergone coronary arteriography and electrocardiography and to report on the relationships

between these procedures. Examination of the relationships between these diagnostic tools is prompted by the following questions:

1. How does the information from the dispersion studies compare with what is already known about the myocardium from electrocardiography and cineangiography?
2. Does it clarify or substantiate the findings of the older parameters?
3. If the scan is not in agreement with information from the electrocardiogram or cineangiogram, is it a valuable and reliable source of information about the cellular integrity of the myocardium?

Theoretical Framework

Coronary arterial occlusive disease as a result of lipid deposition is historically variable from person to person. Subintimal accumulation of cholesterol and cholesterol salts and their subsequent calcification, in addition to fibrotic and dynamically induced changes in the vessel walls usually occurs over a period of many years. This results in the progressive narrowing of arterial lumen by thickening of the vessel walls. Accumulation of these intimal plaques eventually leads to luminal invasion, where platelet aggregation increases the size of the obstructive lesion (Hurst 1974: 996-1000).

The area of arterial occlusion is dependent on anatomical size and configuration, but is generally not predictable. What we know of the outcome of arterial occlusions in the three main branches is unfortunately quite predictable, however. Though embarrassed or absent blood supply to the myocardium must result in muscle damage to a greater or lesser degree, all three vessels do not carry the same import in terms of functional significance of the area perfused. Isolated occlusion of the right coronary artery holds the best long term survival rate, while similar disease of the left anterior descending or the circumflex share a much poorer prognosis (Webster, Moberly, and Rincon 1974). The most lethal single arterial occlusions have been found in the main trunk of the left coronary artery, topped only by triple vessel disease or the combination of the right and the left main trunk being occluded (Helfant, Kemp, and Garland 1970; Webster et al. 1974).

The salvation of the myocardium that has the misfortune of being fed by a severely occluded arterial tree is the spread of collateral vessels. The outgrowth of collaterals seems only to occur in disease states where myocardial oxygen demand exceeds arterial blood supply (Hood 1971). Thus, stenotic lesions of the coronary arteries may not produce injury to the proportion that might seem imminent because of collateral arterial

complement to the affected area. Though good collateralization may not make a difference in the gross clinical picture of the injury (as measured by stress testing), it is assumed that its presence helps to maintain part of the muscle's functional integrity (Knoebel et al. 1972).

Distal to arterial occlusive lesions, arteriolar dilatation occurs in response to tissue oxygen deficit (Guyton 1974: 361). Collateralization does improve arterial supply, however, and this provides a degree of dilatory reserve to the distal vasculature (Knoebel and Rasmussen 1974). If cellular hypoxia is not ameliorated by changes in arteriolar tone, aerobic metabolism and its efficient production of energy is terminated. Glycolysis continues as the only energy-producing function of the cell, as the oxidative processes of the citric acid cycle are defunct without the contribution of oxygen to the mitochondria. Though the rate of glucose uptake is augmented, energy made available through anaerobic glycolysis is only 20 percent of that derived from oxidative phosphorylation (Fritz 1975). Decreased delivery of glucose, free fatty acids, amino acids, and ketones for energy production is noted with hypoperfusion of any degree. Cellular metabolic products, such as potassium, hydrogen, and lysosomal enzymes are not removed and their presence eventually depresses metabolic and functional processes (Amsterdam 1973).

The resultant functional defects have been studied not only in the light of negative inotropism caused by cellular acidosis itself, but also as to how acidosis can displace calcium from its binding site on troponin, again decreasing contractility. Whether the acidosis is caused by lactate production or increased hydrogen ion concentration, the decline of inotropism is initially a means of conservation of energy stores in the ischemic myocardium. With continuation of the hypoperfused state, however, the benefits of low metabolism are traversed and cellular dysfunction deteriorates to rigor (Katz 1973, Marchetti and Taccordi 1967: 36-37). It has been stated that hemodynamic impairment is directly related to muscle mass involvement. Therefore, when 20-25 percent of the left ventricular muscle mass is involved, the normal myocardium cannot continue to compensate, resulting in increased end diastolic pressure and decreased cardiac output (Amsterdam 1973).

Clinically, the first problem to be dealt with by the physician and the nurse is usually the classical symptom of angina. Though this process is not completely understood, it is felt that the cellular acidosis, in addition to accumulation of histamine and kinins in the underperfused area, stimulates localized nerve fibers. Impulses carried through these fibers travel through the sympathetic system to the second, third, fourth and fifth

thoracic spinal nerves (Guyton 1971: 584, Rushmer 1970: 261). Pain is thus referred not only to the anterior chest, but also may radiate to the base of the neck, the shoulders, and to the arms. The assessment of chest pain is dependent on so many variables that consistent diagnosis of true angina may be quite elusive. Therefore, electrocardiography and arteriography are depended upon for confirmation of the clinical picture. Though there are rare instances of myocardial infarction in the presence of normal coronary arteries, the great majority of myocardial pathology can be ascertained by these parameters (Brest et al. 1974, Friesinger and Smith 1972).

When physiologic damage occurs in the myocardial cell, electrical potentials of the cellular membranes are reversed. The proportion to which this occurs is dependent on the degree of injury in that particular area. Alteration in electrical potentials is recorded by the electrocardiogram and serves as a gross statement of pathology (Goldman 1970: 144-145). Interpretation of the discrete QRS and ST segment changes by the cardiologist is added to the information accumulated in assessment and blood work.

Visualization of the coronary arterial tree by angiographic examination should be present down to a lumen of 100-200 micrometers. With this degree of opacification, occlusive disease should be apparent if

it obstructs more than ten percent of a vessel larger than one millimeter (Hurst 1974: 380). This information is invaluable to the physicians who are dealing with the medical and surgical management of the patient (Baltaxe 1973: 10-41). Keeping this in physiological perspective, it is known that as a coronary artery becomes increasingly occluded, the portion distal to the occlusion becomes increasingly dilated, as are the collaterals feeding the area, due to cellular hypoxia. Therefore, the reserve capacity of the artery to dilate in response to increased metabolic work is diminished. A 60 percent occlusive lesion of a major coronary artery is thought to decrease the myocardial reserve capabilities by 50 percent. The significance of an 80 percent occlusion or more is therefore inductively representative of severe myocardial embarrassment (Grossman 1974: 4-6).

Limitations

1. The collateral patterns were not assessed by the scans, as 99m Technecium-labelled Human Albumin Microspheres or Macroaggregates of Albumin were used for both injection, and computerization was not available.

2. Anterior, right anterior oblique (30°), left anterior oblique (30°), and left lateral views were taken of all patients, rather than lesser degrees.

3. Possibility of observer misinterpretation cannot be excluded.

4. Technical problems associated with mechanical, photographic, and positional influences may not provide optimal conditions.

Assumptions

Information from the charts was felt to be reliable in all instances for the following reasons:

1. Nurse's notes and the doctor's history and physical or progress notes correlated as to the type of pain experienced.

2. EKGs were interpreted by two cardiologists and disparities were settled by adding a third opinion. All EKGs of the admission during which the myocardial scanning took place were reviewed.

3. Cineangiography reports by the radiologist and the cardiologist who did the catheterization were consolidated.

4. The myocardial dispersion studies were interpreted by two nuclear medicine physicians and their joint opinions appeared on the report.

Definitions

Angina Pectoris: Subjective pain that is located in the anterior chest and may be radiated to the

epigastrium, shoulders, arms, neck, or back in the patient with heart disease.

Electrocardiography: The recording of electrical potentials of the heart as interpreted by a cardiologist.

Coronary Cinearteriography: The visualization of the coronary arterial tree by injection of contrast materials into the left and right coronary arteries and captured by video tape filming.

Myocardial Dispersion Studies: Intravenous, intraarterial or intracoronary injection of a radio-nucleide that either microembolizes the capillary system or is taken up by the myocardial cell.

CHAPTER 2

REVIEW OF THE LITERATURE

The volumes written on the clinical, electrocardiographic, and cineangiographic diagnosis of heart disease will not allow a worthwhile summary in this discussion. I have, therefore, dealt only with the literature evolving around the most recent diagnostic tool, myocardial dispersion studies.

The definition of nuclear medicine is broad as stated in the introduction, but cardiovascular nuclear medicine in itself covers a wide range of diagnostic procedures, each bringing further understanding of heart disease to light. Chronological development of cardiovascular nuclear medicine is discussed as it leads to the technique of albumin particulate microembolization.

All tracers used in nuclear medicine contain radioactive elements that have unstable nuclei, which, in their search for stability, emit energized particles or energy (Thompson 1973: 299). The scintillation camera records this radioactivity on an oscilloscope and photographs the image to produce the isotope study (Strauss, Pitt, and James 1974: 9-10). Selection of the radioisotope to be used is dependent on what is to be visualized, the invasiveness

of the administration procedure, and what facilities are available for the study (Cannon 1975).

The use of radionuclides in the imaging of the myocardium was introduced as early as 1952 by Yates in his dog experiments with ^{32}P . The potential of the procedure was recognized by Carr and was applied to myocardial study in man in 1962, using ^{86}Rb , which is taken up by the myocardial cell as a potassium analog. Its distribution is a function of capillary blood flow and the normal active transport process of the cell. Diminished blood flow therefore decreases cellular uptake of the radioisotope (Cannon 1975). This concept was built upon in two years when Carr and later others (Collier et al. 1968; Himes, Worth, and Smith 1965; McGeehan, Rodriguez-Antinez, and Lewis 1968) used ^{131}Cs for visualization of infarctions as deficits in uptake.

A parallel to myocardial scanning had been initiated in 1958 that must be mentioned as it relates to the growth of cardiovascular nuclear medicine as a whole. Radioisotope tracers were being used for visualization of the cardiac blood pool. This information was compared to the radiograph of the cardiac silhouette in the diagnosis of pericardial effusion (Strauss et al. 1974: 108). This diagnostic technique is felt to be the most widely used heart-related radioisotope study today. Not only

pericardial effusions may be visualized, but new developments in engineering allow measurement of muscle dysfunction and ejection fractions (Ashburn et al. 1971, Strauss and Pitt 1975). With the cardiac blood pool supplying information about the muscle hemodynamics and the perfusion study giving insight into the capillary integrity of the myocardium, the cardiologist has a detailed understanding of the patient's pathology.

Myocardial scanning is based upon the premise that distribution of the tracer in the muscle is proportional to the blood flow in that area. Functionally, there are three types of tracers that have been used. Intravenous injection of radionucleides, such as ^{43}K or ^{131}I s are selectively taken up by the myocardium. Second are the diffusible indicators that are injected intravenously or intracoronary and measured as they make their quick transit through the capillary bed. Biodegradable particles are the third type of radionucleides used, and these are also injected intracoronary or into the arterial side of the heart. These do not pass the capillary filter and remain in the myocardium for a longer time, allowing leisurely visualization (Strauss et al. 1974: 164-165).

Generally, the first group of scanning agents mentioned includes isotopic potassium, cesium, rubidium, thallium, ammonia, and oleic acid. These agents are

incorporated into the normal muscle, revealing areas of diminished perfusion as low isotope uptake on the scan (Bonte, Grahm, and Moore 1973; Botti, MacIntyre, and Pritchard 1973; Termini et al. 1974). ^{43}K has been the most frequently used radioisotope, as 70 percent of it is cleared from the coronary arterial blood at each passage. It does, therefore, require time-dependent scanning. Most of the studies using this tracer have been involved in stress-testing in search of the exercise-ischemic heart (Strauss et al. 1973, Zaret et al. 1973a). Evaluation of the pre- and post-bypass surgical patient has used this method also. It has been proven beneficial, especially because of its non-invasiveness, if the proper time-imaging techniques are available (Cannon 1975, Zaret et al. 1973b, 1974).

The second group brings new terminology into this discussion. These agents are taken up selectively by the freshly infarcted area to show a "hot spot" of injury on the backdrop of normally functioning myocardium (Zaret, Pitt, and Ross 1972). The isotopic forms of gallium, stannous pyrophosphate, tetracycline, chlormerodrin, and mercury hydroxyflurosciens have been used (Strauss et al. 1974: 150). Gallium localizes in any area of inflammatory reaction (Kramer et al. 1974), while pyrophosphate is attracted to the calcium in mitochondria of irreversibly damaged myocardial cells (Willerson et al. 1975). The

mercurial agents are felt to interact with the denatured proteins of infarcted tissue (Zaret et al. 1972). Initial attempts to use tetracycline were hindered by its instability, but stabilization of the ^{99m}Tc -labelled tetracycline provided its use as an intact sequestered radionuclide. Its presence in the infarct may be seen for around seven days (Holman et al. 1974, Strauss et al. 1974: 226-229).

From insight gained in human lung perfusion scanning, evaluation of the same technique for micro-embolization of the myocardium was begun. Injection of 10-60 micron albumin particles into the arterial circulation of the heart results in their temporary lodging in a precapillary or capillary vessel. Macroaggregates of Albumin [MAA] labelled with ^{131}I or ^{99m}Tc were the first to be used, but their wide variation of particle size was a disadvantage. Human Albumin Microspheres [HAM] were found to be of more uniform size, and have come into popular use, though both radionuclides are still used. As these particulates travel through the arterial tree, their distribution is felt to be representative of blood flow to that area. This information must be integrated with the mass containing the particles, accomplished to a degree by picturing many different views of the isotopic perfusion (Ashburn et al. 1971). The albumin particles are eventually metabolized after phagocytosis at the capillary level (Wagner et al. 1969).

For each muscle fiber in the heart, there is a corresponding capillary or about 4,000 per mm^2 cross-sectional area. By control of the number of injected particles, microembolization does not impair myocardial function (Weller et al. 1972). By modification of labeling techniques, MAA and HAM particles have been reduced in number. Preparation and dosage vary, as does the carrier. A saline solution initially used was replaced by a contrast medium to assure catheter placement upon injection by some investigators (Strauss et al. 1974: 213).

The permeation of the tracer in the patent left coronary artery covers the majority of the anterior and posterior left ventricle and all of the base and lateral surface. The particulate perfusion in the right coronary artery is minimal in the anterior surface of the right ventricle prior to the take-off of the posterior descending branch. From this bifurcation, however, there is intense accumulation of the albumin radioisotope (Jansen, Judkins, and Grames 1972). Observation of radioactivity from the right and left coronary injections may be further understood by the administration of a vasodilating agent (Gould et al. 1974).

By the advent of the 70s, the importance and application of scanning the myocardium was already recognized as indicated above. Endo et al. (1970) and Ashburn et al. (1971) used MAA labeled with both the ^{131}I and $^{99\text{m}}\text{Tc}$ for their

first human studies and found their results to be diagnostic of expected disease. Endo and associates were satisfied that their scanning could "clarify the severity, site, and range of ischemia," though their population was small. Using a larger group, Ashburn and associates found seven normal myocardial scans (of 29 studied) which correlated with normal to insignificant occlusion (less than 50%) on angiography. Abnormal perfusion was noted in all cases of 75 percent occlusion or more. Both studies revealed a wide variance in capillary perfusion distal to similar obstructive lesions, pointing out the inability to surmise muscle involvement on the basis of arterial occlusive disease (Ashburn et al. 1971, Endo et al. 1970).

Even in these initial studies, complications were negligible, and no ST segment changes were noted. It was felt that the rare instances of ectopy and transient EKG changes were seen in only the worst intrinsic pathologic states. Total time of cardiac catheterization is extended by five minutes, and the scanning procedure takes no more than half an hour (Ashburn et al. 1971; Jansen, Grames, and Judkins 1973; Weller et al. 1972).

In Jansen et al.'s study (1973), the refinements of computer science augment the relevance of the data. By using two indicators, ^{99m}Tc MAA in the left coronary and ^{131}I MAA in the right, color coding for each provided

not only specificity of dispersion, but perception of collateralization from one artery to the other. Of the 400 patients studied, 48 percent of the units had normal perfusion in the face of normal (less than 60% occlusion) arteries. Of those with a critical stenosis (more than 60% occlusion), 18 percent had normal perfusion. The group with normal arteries and abnormal perfusion (3% of arterial units studied) were listed as flow defects or thought to have had incomplete injections. Patients with arteries affected by critical stenosis who had abnormal perfusion totalled 9 percent of the units. Normal perfusion distal to complete occlusion was seen in 11 percent of the arterial units, as were those with complete occlusion and abnormal perfusion. Collateral patterns were studied as mentioned and yielded a frequent pattern of complete occlusion of the right coronary with collateral perfusion to the posterior descending and posterior lateral branches from the septal branches of the left anterior descending artery. Augmented perfusion to the right ventricular wall (which is normally minimally perfused) was repeatedly seen in complete or critical occlusion of the right coronary artery. The use of myocardial scanning in this study further substantiates the opinions of previous investigators that it is an important evaluative tool when coupled with other diagnostic procedures.

CHAPTER 3

METHODOLOGY

In an attempt to provide descriptive information that will be clinically applicable four parameters of the patient's diagnostic workup were entertained and compared. These were: the clinical assessment of chest pain, the electrocardiogram, the coronary arteriogram, and the myocardial scan or dispersion study.

Research Design

This is a descriptive study seeking the relationships between EKG's, arteriography, and myocardial scans in patients with chest pain. Charts on all patients listed as having myocardial scans were the source of information recorded on the tool. Chest pain information was taken from the nurse's notes, the doctor's history and physical, and the progress notes. EKG reports were combined to record one interpretation. Cineangiography reports by the cardiologist and radiologist provided information for that portion of the tool.

The Tool

The researcher-designed tool allowed concise collection and tabulation of the data. A copy of the tool is

found in the Appendix. The tool was divided into four parts of data collection: chest pain, EKG's, cineangiography, and myocardial scans. These will be discussed individually.

Chest Pain

Though different types of classification of angina have been noted in the literature, their application did not suit this discussion. Heart disease was not known to be the initiating factor of chest pain in all the patients of this study. Therefore, nurse's notes and doctor's admission and progress notes were monitored for reference to chest pain and the description of it placed into one of three categories: (1) resting angina, (2) exertional angina, and (3) atypical angina.

Electrocardiogram

The basis for EKG interpretation goes back to the electrical changes in the cell caused by hypoperfusion. During cellular depolarization, when normal reversal of electrical forces should result in negativity outside the cell and positivity inside the cell, pathology causes the opposite to occur. The EKG recognizes not only a positive deflection from the area of injured muscle, but due to poor potentiation of impulse through this area, sees a prolonged deflection that merges into the repolarization phase (Sodi

Pallares 1956: 69-101). Myocardium that is infarcted is electrically dead to the electrocardiogram, and if the infarct is transmural, allows the electrode oriented to the area to record activity on the wall opposite to it (Schamroth 1974: 61-81). Q waves, elevated ST segments, and inverted T waves are the more obvious signs of myocardial pathology. Minor deviations of these parameters may be interpreted as hallmarks of heart disease by the experienced electrocardiographer.

Though recorded separately, the data from the EKGs grouped injury and ischemia together, and infarct and aneurysm were combined for data analysis. Pericarditis and hypertrophy were recognized separately, but were listed under mechanical defects.

Coronary Arteriography

The Judkins technique using the right femoral artery allowed injection of the coronary arteries in most cases. Video tape filming of the procedure for review and good resolution of the film aided in proper diagnosis of arterial disease. Occlusion was designated as significant if 75 percent or more of the lumen was compromised. Included in this group were those with complete occlusions. If aneurysm was noted on the ventriculogram, it was listed separately. Valvular lesions were also listed separately.

Myocardial Scans

A Serle Radiographics Gamma Camera was used throughout the study. The resolution of this camera was two centimeters, so it was necessary to inject the rather high dose of six millicuries of the radionuclide (^{99m}Tc HAM or MAA) into each side, giving approximately a 60,000 particulate distribution to the right and left alike. The reports of the scans were divided into four parts: (1) normal perfusion, (2) obscure defect, (3) abnormal perfusion, and (4) one injection (listed under the artery injected).

Data Collection

Charts were reviewed of patients who had diagnostic workup between January 30, 1973 and October 1, 1975. Their EKG's, coronary arteriograms, and myocardial dispersion studies were collected and reported. The history, physical, and nurses' notes provided information about chest pain. (Each test was individually reviewed by the author.)

Population and Sample

Names of patients who underwent myocardial dispersion studies were collected from the Nuclear Medicine Department of St. Mary's Hospital and Health Center, Tucson, Arizona. All those patients who had EKG's, cine-angiography, and the scanning procedure were studied.

Those patients who had an incomplete injection of the tracer were eliminated from the study.

Proposed Analysis of the Data

Patients were separated into groups showing normal anterior scan and abnormal anterior scan, normal inferior scan and abnormal inferior scan, and normal posterior scan and abnormal posterior scan. The percentage of patients in each group who also showed selected electrocardiographic and arteriographic variables in the associated areas was found. The percentage of occurrence of each variable associated with the dispersion study will be compared to results of other studies.

CHAPTER 4

CHARACTERISTICS OF THE SAMPLE

The population was composed of 188 men and women who were patients at St. Mary's Hospital and Health Center between January 1, 1973, and October 1, 1975. Six patients were eliminated from the study due to incomplete injection of the radioisotope, leaving a total of 182 patients. Their age range was from 23 to 80, with a mean age of 53. Each patient had presented himself to the cardiologist with a history and/or symptoms suggestive of heart disease. Each patient had one or more electrocardiograms, and each patient underwent coronary arteriography and a myocardial dispersion study. Patient information was collected on the researcher-designed tool and classified according to type of pain and electrocardiographic, cineangiographic, and radioisotopic scan findings. The number and percentages of each of the variables are presented in Table 1.

Table 1. Information According to Findings of Electrocardiograms, Arteriograms, and Myocardial Dispersion Studies in Patient Charts

CHEST PAIN

Resting 32% N = 61
 Exertional 44% N = 82
 Atypical 21% N = 39

EKG	anterior	anteriolateral	inferior	posterior
Infarct	13.3% N=25	1.1% N=2	13.8% N=26	3.7% N=7
Aneurysm	1.6% N=3	0 N=0	0 N=0	0 N=0
Injury	2.7% N=5	1.1% N=2	1.1% N=2	0 N=0
Ischemia	1.6% N=3	0 N=0	8.0% N=15	1.1% N=2
Hypertrophy 8.0% N=15				
No Pathology 39.9% N=75				
Subendocardial 13.8% N=26				

MYOCARDIAL SCAN (area fed by)	LAD	Right	Circumflex
Normal Perfusion	68.1% N=128	71.8% N=135	74.5% N=140
Abnormal Perfusion	23.4% N=44	20.2% N=38	17.0% N=32
Obscure Defect	3.2% N=6	1.1% N=2	1.1% N=2
No Injection	eliminated N=5	eliminated N=8	eliminated N=6

CINEANGIOGRAPHY	LAD	Right	Circumflex
Complete Occlusion	11.2% N=21	15.4% N=29	6.4% N=12
Over 80%	27.1% N=51	13.8% N=26	14.4% N=27
Under 80%	11.7% N=22	11.2% N=21	9.0% N=17
Aneurysm 5.9%			
No Pathology	46.8% N=88	55.9% N=105	67.6% N=127
Dilated Mitral Annulus or Mitral Prolapse 14.9% N=28			

CHAPTER 5

PRESENTATION AND ANALYSIS OF DATA

Diagnostic information from the electrocardiogram and arteriogram has in the past provided valuable information about the heart which has guided the physician in his treatment of the patient. The advent of myocardial scanning has been proposed as a method for gaining more specific information about the myocardium at the microvascular level. To determine how this information agreed with previous findings of the electrocardiogram and arteriogram, percentages of these variables in the presence of scan reports were obtained.

Table 2 presents the percentages of patients with chest pain at rest, exertional chest pain, and atypical chest pain who had normal or abnormal myocardial dispersion studies.

Table 2. Reports of Pain Associated With Findings of the Myocardial Scan

	<u>Normal Scan</u>			<u>Abnormal Scan</u>		
	Lad %	Right %	Circ %	Lad %	Right %	Circ %
Pain at Rest	62.3	60.7	67.2	34.4	31.1	26.2
Pain on Exertion	68.3	82.9	79.3	24.4	13.5	15.9
Atypical Pain	87.2	76.9	87.2	7.7	20.5	7.7

Examination of the percentages of chest pain at rest showed surprisingly high percentages of patients to be associated with normal myocardial dispersion studies. A major part of this percentage included patients who were resuscitated before or upon admission to the emergency room and were arbitrarily put in this classification because of their poor condition. These arrests were frequently due to arrhythmias in the acute stage of infarction or even ischemia, before the total picture of muscle damage could be realized by scan. Therefore, the severity of the situation may not have dictated the severity of the disease present.

Many patients with chest pain on exertion proved to have normal myocardial scans. Interestingly, a very high number of patients had normal inferior scans in the face of exertional pain, whereas fewer showed the same findings in relation to the anterior surface. High percentages of patients with atypical pain showed no myocardial scan abnormality.

Tables 3, 4, and 5 present the percentage of patients who had electrocardiographic and arteriographic findings associated with either a normal or an abnormal myocardial scan of the anterior, inferior, and posterior surfaces.

The information from Table 3 demonstrates anticipated outcomes to a certain extent. There were a few patients who had normal anterior scans after having an

Table 3. Percentages of Patients With Anterior Myocardial Scanning Normality or Abnormality Who Display Associated EKG or Cineangiographic Variables

	Normal Anterior Dispersion Study %	Abnormal Anterior Dispersion Study %
<u>EKG</u>		
Anterior MI	6.3	38.6
Anterior Ischemia	12.5	6.8
Normal	50.0	11.4
<u>CINE</u>		
Total LAD	3.5	38.6
Over 80%	25.0	36.4
Under 80%	14.1	2.3
Normal	57.8	22.7

KEY:

EKG = electrocardiogram
 MI = myocardial infarction
 CINE = cineangiography
 LAD = left anterior descending artery
 Over 80% = over 80% occlusion of LAD
 Under 80% = under 80% occlusion of LAD

Table 4. Percentages of Patients With Inferior Myocardial Scanning Normality or Abnormality Who Display Associated EKG or Cineangiographic Variables

	Normal Inferior Dispersion Study %	Abnormal Inferior Dispersion Study %
<u>EKG</u>		
Inferior MI	8.1	42.1
Inferior Ischemia	9.6	2.6
Normal	8.9	18.4
<u>CINE</u>		
Total Right	8.9	44.7
Over 80%	13.3	23.7
Under 80%	11.1	13.2
Normal	65.9	18.4

KEY:

EKG = electrocardiogram

MI = myocardial infarction

CINE = cineangiography

RIGHT = right coronary artery

Over 80% = over 80% occlusion of Right

Under 80% = under 80% occlusion of Right

Table 5. Percentages of Patients With Posterior Myocardial Scanning Normality or Abnormality Who Display Associated EKG or Cineangiographic Variables

	Normal Posterior Dispersion Study %	Abnormal Posterior Dispersion Study %
<u>EKG</u>		
Posterior MI	0.7	9.4
Normal	48.6	9.4
<u>CINE</u>		
Total Circ	2.1	25.0
Over 80%	12.9	25.0
Under 80%	6.4	18.8
Normal	79.3	31.3

KEY:

EKG = electrocardiogram

MI = myocardial infarction

CINE = cineangiography

CIRC = circumflex coronary artery

Over 80% = over 80% occlusion of circumflex

Under 80% = under 80% occlusion of circumflex

anterior infarction. It is noteworthy that normal anterior scans did not show higher normal electrocardiographic or arteriographic percentages.

The data in Table 4 reveals rather low percentages of patients with anticipated arteriogram and electrocardiogram results both in the normal and abnormal aspects of the myocardial scan. Though 65 percent of patients with normal inferior scans had no coronary arterial disease only 8.9 percent had normal electrocardiograms. Of patients with abnormal inferior dispersion studies, 42.1 percent had inferior infarcts by electrocardiogram, but a high 18 percent had no electrocardiographic abnormality at all. The angiograms showed consistent relation between normal vessels and normal scans, abnormal vessels and abnormal scans.

Table 5 demonstrates percentages of patients with normal posterior scans to be small in respect to electrocardiographic or arteriographic pathology. Of patients with abnormal posterior scans, only 9.4 percent had associated posterior infarcts, a surprisingly small number, since there were also 9.4 percent who had normal electrocardiograms in this group. A corresponding picture is seen in the angiographic reports where more patients had normal circumflex arteries than totally occluded arteries in the face of an abnormal posterior scan.

CHAPTER 6

INTERPRETATION AND DISCUSSION

The high percentage of patients displaying chest pain at rest with normal myocardial scans has been postulated to be due to inclusion of patients who experienced cardiac arrest. Another reason for the prevalence of pain at rest with normal scans may be that the patient with cardiomyopathy or valvular disease may have no localized perfusion defects but still have a dilated, decompensated heart. The dispersion study recognized size and dilation, but these comments were not included in this study.

The high number of patients with exertional chest pain who had normal scans supports the theoretical basis of stress testing. If pain is indeed associated with exercise only, the assumption that perfusion defects are present only at this time and then return to normal seems valid. That at least 68 percent of these patients had normal myocardium upon scanning (at rest) points out their potential benefit from bypass graft surgery.

There were many patients with atypical pain who had no abnormality seen on the dispersion study. This group of patients included 29 people who had either dilated mitral annulus or leaflet prolapse and 16 who had other valvular pathologies.

All of these statistics seem to point out the need for improving our historical and subjective assessment of chest pain. Certainly the arbitrary classification of this study could be improved upon. As previously stated in this discussion, nurses are deeply involved in the on-going assessment of chest pain. How the nurse perceives and treats the pain had great bearing on the doctor's perception and treatment of the patient. The current trend toward broadening of physical assessment skills has emphasized the benefits of specific information that the nurse may contribute. Improving physical assessment skills and improving interrogative skills will aid our understanding of the patient with chest pain.

There were a few patients who displayed a total left anterior descending occlusion and an anterior infarction yet had normal anterior perfusion. However, half of the people who had normal scans showed no arteriographic or electrocardiographic abnormalities. It seems that there should be more than 50 percent of the normal scans associated with normal arteriograms and electrocardiograms, yet weighing against this percentage are the valvular pathologies and ischemia patterns. Normal myocardium is expected in these cases, yet the statistical weight of these abnormalities counts against a totally normal picture. The presence of normal dispersion studies in the face of

electrocardiographic and angiographic abnormalities is the foundation of invasive therapy. In this study 25 percent of all normal anterior myocardial scans were shown to have over 80 percent occlusion of the left anterior descending artery, making these patients optimal bypass graft candidates.

Of the patients with abnormal anterior scans, it was interesting to note that only 38.6 percent had had a confirmed infarct by electrocardiogram. Perhaps disconcerting was the fact that a few showed only anterior ischemia or no electrocardiographic abnormality at all. It may be assumed that subendocardial or intramural infarct were not recognized by the gross precordial evaluation of the anterior myocardium on electrocardiogram. This cannot be the full explanation of unexpected abnormal scans, however, because cineangiographic findings of occlusion were not widespread either. The technical acuity of the equipment was not such as to allow resolution of quite small areas, so the possibility that the perfusion studies were misinterpreted cannot be excluded. The use of photographic readout of the scans may also tend to decrease ability to assess small areas of abnormal perfusion. Nonetheless, perfusion defects of the anterior surface may be present in hypertrophy or dilatation, which may or may not have electrocardiographic or arteriographic counterparts.

Patients with normal inferior myocardial scans had both a low percentage of electrocardiographic abnormality and also a surprisingly low rate of normality. Again, because there were abnormal variables that did not necessarily denote myocardial damage, the percentage of normality in relation to all abnormalities may be disproportionately small. Arteriographic findings in the patient with a normal inferior scan seemed to follow an expected low incidence of occlusive disease.

The group with an abnormal inferior dispersion study showed a higher infarction rate in addition to an increase in the absence of abnormalities on the electrocardiogram. The percentage of people with ischemia was comfortably low, but these three pieces of information seemingly do not coincide with each other. Looking at arteriographic findings, total right occlusions are prevalent, but normal right coronary arteries account for almost one-fifth of all the arteriograms done on people with abnormal inferior scans.

The possibility that disparities could be due to mechanical or evaluative error cannot be discounted. Perhaps the limitations of positioning could account for ambiguity of the inferior surface. Electrocardiographic lead placement certainly is suboptimal for the evaluation of the inferior myocardium, as leads 2, 3, and avF are far

removed from the area. Taking all these points into consideration, it must be inferred that our understanding of the inferior portion of the heart, while generally correct, may be quite limited.

The circumflex system feeding the lateral and posterior portions of myocardium would seem to be the most difficult to assess. However, patients with normal posterior scans showed the expected normal electrocardiograms and arteriograms. There does seem to be a problem in appreciating the abnormal posterior surface on the dispersion study and the electrocardiogram, however. There were as many posterior infarcts as normal electrocardiograms, and even more normal circumflex arteries than abnormal in the presence of an abnormal scan. These differing results seem to reflect the difficulty in close assessment of the posterior surface. Again, electrocardiographic lead placement is less than optimal for assessment of this area. Positioning in the left lateral posterior position has become routine for the dispersion studies since this study was completed.

The information from this study is compared to that from Ashburn and associates (1971). Their normal myocardial scans were found to be associated with normal arteries or less than 50 percent occlusive disease. The findings of this study showed that in patients with normal

myocardial scans, each area demonstrated a corresponding normal arterial bed much more than half of the time. In contradiction to Ashburn et al.'s (1971) finding that high grade lesions were never associated with normal scans, this study found fairly significant numbers of severe occlusive lesions to be associated with normal dispersion studies.

The information from the study of Jansen et al. (1973) seems to correlate with the results of this study. Their study assessed each arterial system as one of all possible systems in all patients, whereas this study assessed the percentages of patients with a certain scan report (anterior, inferior, or posterior) who displayed other variables of the same area. Jansen et al. had a small group of patients with normal arteries and abnormal perfusion, as was seen in this study. They surmised incomplete injection to be partially responsible, while this study eliminated any scans that were felt to have had incomplete injections. Cardiomyopathy was assumed to have resulted in most of the others, as was discussed previously in this study.

Evaluation of occlusive lesions showed 18 percent high grade to 11 percent complete occlusions in the analysis of individual arteries in the Jansen et al. (1973) study as they related to normal perfusion by scan. Reference back to Tables 3, 4, and 5 will demonstrate similar

percentages as broken up into the three arterial systems. The benefit of information regarding collateral patterns was not available to us.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

Education and preparation of the patient who is to have this battery of cardiovascular testing may not only affect his comfort during the procedures, but may influence his acceptance of the medical or surgical treatment that is proposed from the results of the test. It is, therefore, the nurse's responsibility to understand the implications of the findings.

The importance of radioisotopic evaluation of the myocardium must be assessed as it is used in the diagnosis workup of each individual patient. Generally, this study has shown that it can impart valuable information about integrity of the myocardial capillary bed that cannot and must not be implied from the electrocardiogram or cineangiogram. Just as high grade occlusions may be associated with normal perfusion, so may normal electrocardiograms be associated with abnormal perfusion. The findings have also substantiated the assumption that the patient with angina may have normal or at least viable myocardium. Whatever the case, the information from myocardial dispersion studies supplies valuable information to the

cardiologist or the surgeon to enhance his treatment of the patient.

The following recommendations are made for further study:

1. Investigate the effects of different positioning for assessment of the inferior myocardium, both electrocardiographically and in the nuclear medicine department.

2. Study underperfused areas of myocardium that has been revascularized, seeking the limitations of the benefit of surgery.

APPENDIX

PATIENT DATA SHEET

PATIENT # _____ NAME _____ HOSPITAL # _____ ADMISSION DATE _____

CHEST PAIN

Resting _____
 Exertional _____
 Atypical _____

<u>EKG</u>	anterior	anteriolateral	inferior	posterior
Infarct				
Aneurysm				
Injury				
Ischemia				
Hypertrophy				
No Pathology				
Subendocardial				

<u>MYOCARDIAL SCAN</u> (area fed by)	LAD	Right	Circumflex
Normal Perfusion			
Abnormal Perfusion			
Obscure Defect			
No Injection			

<u>CINEANGIOGRAPHY</u>	LAD	Right	Circumflex
Complete Occlusion			
Over 80%			
Under 80%			
Aneurysm			
No Pathology			
Dilated Mitral Annulus or Mitral Prolapse			

SELECTED BIBLIOGRAPHY

- Amsterdam, Ezra. "Function of the Hypoxic Myocardium" American Journal of Cardiology, Vol. 32, September 20, 1973, pp. 461-471.
- Ashburn, William, Eugene Braunwald, Allan Simon, Kirk Peterson, and James Gault. "Myocardial Perfusion Imaging With Radioactive-Labeled Particles Injected Directly Into the Coronary Circulation of Patients With Coronary Artery Disease," Circulation, Vol. 44, November 1971, pp. 851-865.
- Baltaxe, Harold. Coronary Angiography. 11th Edition. Thomas, 1973, pp. 24-36.
- Berman, Daniel, Antone Salel, Gerald De Nordo, and Dean Mason. "Noninvasive Detection of Regional Myocardial Ischemia Using Rubidium-81 and the Scintillation Camera," Circulation, Vol. 52, October 1975, pp. 619-625.
- Bonte, Frederick, Kenneth Grahm, and John Moore. "Experimental Myocardial Imaging With ¹³¹I-Labeled Oleic Acid," Radiology, Vol. 108, July 1973, pp. 195-196.
- Botti, Robert, William MacIntyre, and Walter Pritchard. "Identification of Ischemic Area of Left Ventricle by Visualization of K Myocardial Deposition," Circulation, Vol. 47, March 1973, pp. 486-492.
- Brest, Albert, Leslie Wiener, Hratch Kasparian, Peter Duca, and James Rafter. "Myocardial Infarction Without Obstructive Coronary Artery Disease," American Heart Journal, Vol. 88, No. 2, August 1974, pp. 219-224.
- Cannon, Paul. "Radioisotopic Studies of the Regional Myocardial Circulation," Circulation, Vol. 51, June 1975, pp. 955-963.
- Garr, Edward. "The Image of the Heart," New England Journal of Medicine, Vol. 288, No. 16, April 19, 1973, pp. 846-848.
- Collier, R. E., J. L. Matson, I. W. Tomme, and J. W. Hyland. "Correlation of Myocardial Photoscanning and Coronary Angiography in Angina Pectoris," Radiology, Vol. 91, August 1968, pp. 310-314.

- Endo, Masahiro, Toshiro Yamazaki, Sozi Konno, Hiroo Hiratsuka, Tomio Akimoti, Tsuguhito Tanaka, and Shirizu Sakakihara. "The Direct Diagnosis of Human Myocardial Ischemia Using ^{131}I -MAA Via the Selective Coronary Catheter," American Heart Journal, Vol. 80, No. 4, October 1970, pp. 498-506.
- Friesinger, Gottlieb, and Raphael Smith. "Correlation of Electrocardiographic Studies and Arteriographic Findings With Angina Pectoris," Circulation, Vol. 46, December 1972, pp. 1173-1184.
- Fritz, S. Delbert. "Energy Metabolism in Shock," Heart and Lung, Vol. 4, No. 4, July-August 1975, pp. 615-618.
- Goldman, Mervin. Principles of Clinical Electrocardiography. 7th Edition. Lange Medical Publications, 1970.
- Gould, Lance, David Allen, Ward Kennedy, and Karl Hammerstein. "Dual Isotope Myocardial Imaging," American Journal of Cardiology, 1974, pp. 380-389.
- Grossman, William. Cardiac Catheterization and Angiography. 2nd Edition. Lea and Febiger, 1974, pp. 4-6.
- Guyton, Arthur. Textbook of Medical Physiology. 4th Edition. W. B. Saunders, 1971, pp. 359-366.
- Harper, Paul, Jeffery Schwartz, Robert Beck, Katherine Lathrop, Nicholas Lembores, Helen Krizek, Ignacio Gloria, Robert Dinwoodie, M. B. McLaughlin, Violet Stark, Carlos Beckerman, Paul Hoffer, Alexander Gottschalk, Leon Resnekov, Jafar Al Sodie, Alvaro Mazorga, and Harold Brooks. "Clinical Myocardial Imaging With Nitrogen-13 Ammonia," Radiology, Vol. 108, September 1973, pp. 613-617.
- Helfant, Richard, Howey Kemp, and Richard Garland. "Coronary Atherosclerosis, Coronary Collaterals, and Their Relation to Cardiac Function," Annals of Internal Medicine, Vol. 73, No. 2, August 1970, pp. 189-193.
- Himes, George, Leonard Worth, and Robert Smith. "Cesium-131 Uptake and Distribution in the Human Heart: An Analysis of Cardiac Scans in 104 Patients," Journal of American Osteopathic Association, Vol. 64, February 1965, pp. 575-590.

- Holman, Leonard, Michael Lesch, Franklin Zweiman, John Ternte, Bernard Lown, and Richard Gorlin. "Detection and Sizing of Acute Myocardial Infarcts With ^{99m}Tc (Sn) Tetracycline," New England Journal of Medicine, Vol. 291, No. 4, July 25, 1974, pp. 159-163.
- Hood, William. "Pathophysiology of Ischemic Heart Disease," Progress in Cardiovascular Diseases, Vol. 14, No. 3 November 1971, pp. 297-320.
- Hurst, J. Willis. The Heart. 3rd Edition. McGraw-Hill, 1974, pp. 996-1000.
- Jansen, Carl, George Grames, and Melvin Judkins. "Myocardial Perfusion Color Scintigraphy with MAA," Radiology, Vol. 109, November 1973, pp. 369-380.
- Jansen, Carl, Melvin Judkins, and George Grames. "Scintigraphy of Myocardial Perfusion With Radioactive Macroaggregated Albumin," U. S. Atomic Energy Commission. Proceedings of a Symposium of American College of Physicians. December 1972, pp. 573-578.
- Katz, Arnold. "Effects of Ischemia on the Contractile Processes of Heart Muscle," American Journal of Cardiology, Vol. 32, September 20, 1973, pp. 456-460.
- Knoebel, Suzanne, Paul McHenry, John Phillips, and Ferrel Pauletto. "Coronary Collateral Circulation and Myocardial Blood Flow Reserve," Circulation, Vol. 46, July 1972, pp. 84-94.
- Knoebel, Suzanne, and Susan Rasmussen. "Myocardial Blood Flow: Newer Clinical Considerations," Heart and Lung, Vol. 3, No. 1, January-February 1974, pp. 78-83.
- Kramer, Robert, Robert Goldstein, John Hirshfield, William Roberts, Gerald Johnston, and Stephen Epstein. "Accumulation of Gallium-67 in Regions of Acute Myocardial Infarction," American Journal of Cardiology, Vol. 33, June 1974, pp. 861-867.
- Marchetti, Germano, and Bertram Taccordi. Coronary Circulation and Energetics of the Myocardium. Basel, Switzerland: S. Karger A. G., 1967.

- McGeehan, John, Antonio Rodriguez-Antinez, and Royston Lewis. "Cesium 131 Photoscan," Journal of American Medical Association, Vol. 204, May 13, 1968, pp. 123-127.
- Mendel, Daniel. A Practice of Cardiac Catheterization. Blackwell, 1968, pp. 2-4.
- Ritchie, James, Glen Hamilton, David Allen, J. Ward Kennedy, and Karl Hammermeister. "Myocardial Imaging With Indium 113m and Technetium 99m-Macroaggregated Albumin," American Journal of Cardiology, Vol. 35, March 1975, pp. 380-386.
- Rushmer, Robert. Cardiovascular Dynamics. 2nd Edition. W. B. Saunders, 1970.
- Schamroth, Leo. "The Electrocardiographic Diagnosis of Acute Myocardial Infarction." In Textbook of Coronary Care. Compiled by Laurence Meltzer and Arend Dunning. Charles Press, 1972, pp. 61-81.
- Sevelius, Gunnar. Radioisotopes and Circulation. Little, Brown and Company, 1965, pp. 112-114.
- Sodi Pallares, Demetrio. New Bases of Electrocardiography. 2nd Edition. C. V. Mosby Company, 1956, pp. 5-62.
- Strauss, William, and Bertram Pitt. "Cardiovascular Nuclear Medicine: Its Role in Patients With Coronary Heart Disease," Applied Radiology, January-February 1975, pp. 57-78.
- Strauss, William, Bertram Pitt, and Everett James. Cardiovascular Nuclear Medicine. C. V. Mosby Company, 1974.
- Strauss, William, Barry Zaret, Neil Martin, Harry Wells, and M. D. Flamm. "Noninvasive Evaluation of Regional Myocardial Perfusion With Potassium 43," Radiology, Vol. 108, July 1973, pp. 85-90.
- Termini, Benedict, Leonard Schleris, Robert Singleton, Joseph McLaughlin, and Malcolm Cooper. "Myocardial Scanning in Patients Undergoing Coronary Bypass Surgery," Archives of Surgery, Vol. 109, November 1974, pp. 648-651.
- Thompson, Thomas. Primer of Clinical Radiology. Little, Brown and Company, 1973, pp. 299-328.

- Wagner, H. M., B. A. Rhodes, Y. Sosaki, and J. P. Regan. "Studies of the Circulation With Radioactive Microspheres," Investigative Radiology, Vol. 4, November/December 1969, pp. 374-386.
- Webster, I. S., C. Moberly, and G. Rincon. "Natural History of Severe Proximal Coronary Artery Disease as Documented by Coronary Cinenagiography," American Journal of Cardiology, Vol. 32, No. 2, February 1974, pp. 195-200.
- Weller, Daniel, Henry Wellman, Robert Adolf, Robert Cannal, and Onja Kim. "Myocardial Perfusion Scintigraphy After Intra-Coronary Injection of ^{99m}Tc -Labeled Human Albumin Microspheres," Circulation, Vol. 46, November 1972, pp. 963-975.
- Willerson, James, Robert Parkey, Frederick Bonte, Steven Meyer, James Atkins, and Ernest Stakley. "Technetium Stannous Pyrophosphate Myocardial Scintigrams in Patients With Chest Pain of Varying Etiology," Circulation, Vol. 51, June 1975, pp. 1046-1052.
- Zaret, Barry, Bertram Pitt, and Richard Ross. "Determination of the Site, Extent, and Significance of Regional Ventricular Dysfunction During Acute Myocardial Infarction," Circulation, Vol. 45, February 1972, pp. 441-456.
- Zaret, Barry, William Strauss, Neil Martin, Harry Wills, and M. D. Flamm. "Noninvasive Regional Myocardial Perfusion With Radioactive Potassium," New England Journal of Medicine, Vol. 288, No. 16, April 19, 1973a, pp. 809-812.
- Zaret, Barry, William Strauss, Neil Martin, Harry Wills, M. D. Flamm, Ronald McGowan, and Robert Stenson. "Potassium-43 Myocardial Perfusion Scanning for the Noninvasive Evaluation of Patients With False-Positive Exercise Tests," Circulation, Vol. 48, December 1973b, pp. 1234-1241.
- Zaret, Barry, William Strauss, Neil Martin, Harry Wills, M. D. Flamm, and Ronald McGowan. "Rest and Exercise Potassium-43 Myocardial Perfusion Imaging for the Noninvasive Evaluation of Aorto-coronary Bypass Surgery," Circulation, Vol. 49, April 1974, pp. 688-695.

