A COMPARISON OF THE MASON-LIKAR AND CLINICAL STANDARD 12-LEAD ECG FOR EXERCISE-INDUCED ST-SEGMENT SHIFTS IN MALES AT HIGH RISK FOR CAD

by

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(ABSTRACT)

This study sought to examine the exercise-induced ST-segment shifts, J_0 and J_{60}, attributable to ECG lead configuration, specifically to evaluate if ischemic changes are modified as a function of using the Mason-Likar lead system. Males (N=30) referred for diagnostic testing underwent a symptom-limited graded exercise test (SLGXT). ST-segment shifts, J_0 and J_{60}, measured as the difference from baseline to recovery minute one, were not significantly different in responses measured from two simultaneous complexes for lead V_5. In frontal lead II, differences were found in the ST-segment response at baseline vs. recovery minute one. All ST-segment shifts were computed as the difference between J_x obtained at resting baseline vs. the J_x obtained at the exercise measurement in the same posture. ST-segment shifts, J_0 and J_{60}, measured at peak-exercise vs. recovery minute one using the Mason-Likar lead system, revealed a significant difference according to the measurement recorded in both leads V_5 and II ($p<.05$). Comparisons of frequencies for clinically abnormal ST-segment shifts

according to ECG lead configuration at recovery minute one when measured from peak-exercise using Mason-Likar were significant in only lead II ($p<.05$). Observation of the data suggest that the Mason-Likar lead system may affect the interpretation of ischemic ST-segment shifts in lead II. However, these results do not invalidate the interpretation of ischemic ST-segment shifts in lead V_5 using the Mason-Likar lead system.

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Chapter 1

INTRODUCTION

Electrodes have been placed in a variety of ways for ECG monitoring of exercise tests. The goal of each is to maximize sensitivity and minimize baseline artifact. The standard 12-lead ECG lead placement with electrodes placed on the wrists and ankles cannot be used during exercise testing due to artifact produced by motion and muscle contraction, therefore, several other lead systems have been developed to minimize these artifacts.

The most common lead system used is the Mason-Likar, developed in 1966 for recording of multiple-lead ECG's during exercise (Kleiner, Nelson, & Boland, 1978). This system is a modification of the standard 12-lead ECG electrode placement whereby the arm electrodes are placed in the infraclavicular fossae just medial to the border of the deltoid muscle and just below the lower edge of the clavicle. The left leg electrode is placed in the anterior axillary line, midway between the rib margin and the iliac spine. Standard positions are used for the chest leads V_1 to V_6. The different 12-lead ECG lead systems are illustrated in Figure 5 in the Figures section.

STATEMENT OF THE PROBLEM

The modification of the standard electrode placement has gained wide acceptance in clinical testing both for the resting and exercise ECG (Froelicher & Myers, 1993). The original Mason and Likar study (1966) reported no differences in electrocardiographic configuration when compared to the standard-lead placement for supine resting measures, which allowed the Mason-Likar placement to gain wide-acceptance in clinical practice. However, recent studies suggest that the Mason-Likar placement may cause amplitude changes and axis shifts when compared to the standard placement in the supine resting position (Gamble, McManus, Jensen, & Froelicher, 1984). These ECG changes present important implications since the appearance of new or diagnostic Q waves or axis shifts affecting the QRS complex or T waves could be, reason to misinterpret a patients clinical status. A pre-exercise ECG tracing is very important for detecting future changes as well, which may not be possible with the Mason-Likar lead placement (Gamble et al., 1984). Because it is clinically important to obtain an accurate pre-exercise ECG, the modified placement should not be used since this could lead to diagnostic changes. Current research suggests much of the confusion regarding distortion of the pre-exercise ECG has been due to misplacement of the limb electrodes medially on the torso and by obtaining the ECG in the standing position (Gamble et al., 1984). The most recent published clinical exercise standards (1990), by the American Heart Association, acknowledge this electrode placement and lead selection issue

(Fletcher, Froelicher, Hartley, Haskell, & Pollock, 1990). The AHA recommends that the resting 12-lead recording arm and leg electrodes should be moved to the wrists and ankles, with the patient in the supine position to establish a pre-exercise baseline ECG.

In a study by Rautaharju, the Mason-Likar placement for the supine resting ECG caused the ST slope to flatten in aVL and increase in II, III, and aVF when compared to the standard placement (Rautaharju, Prineas, Crow, Seale, & Furberg, 1980). The ST changes are of particular importance to exercise ECG interpretation. The results of this study and others, however, are only valid for resting supine pre-exercise ECG's. There have been no studies investigating the changes in resting supine post-exercise ECG's using the standard electrode placement as opposed to the traditional Mason-Likar placement used for post-exercise ECG's.

Few studies have evaluated the relative yield or diagnostic sensitivity of different electrode placements for exercise-induced ST-segment shifts (Froelicher & Myers, 1993). Studies show that using other leads in addition to V_5 will increase the sensitivity; however, the specificity is generally decreased in other leads (Froelicher & Myers, 1993). In the study by Rautaharju et al., it was suggested that the reduction of the ST slope and T wave amplitude in aVL could lead to an excessive finding of "ischemic" responses to a stress test in this lead, and the opposite phenomenon could be expected to take place in leads III and aVF.

According to Froelicher and Myers, (1993) approximately 85% of all patients with abnormal ST responses, evidenced such changes in the supine position at 4 to 5 minutes into recovery. This finding suggests the importance of accurate representation of ST segment responses in the recovery or post-exercise phase. Because dramatic changes can be seen on the pre-exercise ECG when comparing the standard lead placement to the Mason-Likar, it follows that these changes could also be seen on the post-exercise ECG.

Using the standard lead placement for post-exercise tracings could have important implications for the interpretation of a patient's test. The rightward axis shift and amplitude changes caused by the Mason-Likar placement in the post-exercise phase will not be evident when using the standard lead placement. Thus, one may speculate that the number of "ischemic" responses found in aVL will be reduced and even more important a greater number of patient's with "ischemic" responses in leads II, III and aVF can be identified and treated appropriately (Rautaharju et al., 1980).

The various studies on different lead systems have evaluated exclusively the pre-exercise ECG. Conversely, none of the studies have investigated the possibility of changes occuring in the post-exercise ECG using the standard lead placement. Although the changes produced by the different electrode placements are merely artifacts, they could be very misleading. These changes are obvious in the pre-exercise ECG's and potentially could be more pronounced in exercise and recovery.

PURPOSE OF THE STUDY

The purpose of this study is to compare specific ECG indicators of exercise-induced ischemia using the Mason-Likar and standard lead systems in both pre-exercise and post-exercise ECG recordings. It is specifically designed to examine the ST segment measures, R-wave amplitudes, and axis shifts in the supine position before and after a submaximal bout of exercise while comparing the Mason-Likar electrode placement to the standard wrist and ankle electrode placement. Also to be examined are the axis shifts induced by postural changes from the supine to standing positions in the pre-exercise ECG. This protocol will allow for comparisons in the pre-exercise and post-exercise ECG using different electrode placements, as well as different postural changes, which may affect the diagnosis of ischemic responses.

SIGNIFICANCE OF THE STUDY

The significance of this study would be to technically improve the clinical performance of exercise test technology with the use of the standard electrode placement for pre-exercise and post-exercise ECG recordings. This study investigates simple inexpensive modifications in measurement that could improve assessment of ishemic ST segment changes induced by exercise.

Of importance to exercise ECG interpretation are the ST segment waveform changes: these changes have important implications during the post-exercise period and will affect the visual interpretation of the ECG. This investigation will allow the ECG to be evaluated using the standard lead system immediately post-exercise which could offer the key characteristic of the ECG waveform needed for analysis of ischemia.

RESEARCH HYPOTHESIS:

The following null hypotheses were developed:

1. Ho: There is no difference in the ST-segment shifts (J_0, J_{60}) for simultaneously recorded Mason-Likar and Standard ECG lead systems at recovery minute one in leads II and V_5.

2. Ho: There is no difference in the ST-segment shifts for peak-exercise vs. recovery minute one recorded using the Mason-Likar ECG lead system in leads II and V_5.

3. Ho: There is no difference in the number of clinically abnormal ST-segment shifts in the Mason-Likar system vs. the Standard ECG lead system at recovery minute one in leads II and V_5.

DELIMITATIONS

The following delimitations will be incorporated into the study by the investigator.

1. The subject population is delimited to male patients who are diagnosed as high risk for CAD, in accordance with ACSM criteria, and males with a diagnosis of CAD.

2. The evaluation of ECG measures in this study will be delimited to the Mason-Likar and Standard ECG lead systems.

3. This investigation will be delimited to ten electrodes for the Mason-Likar system and five electrodes for the standard lead system for examinination of leads II and V_5.

4. Only visually analyzed ECG responses were examined.

5. Due to the lead configuration used, the V_5 placement will consist of two trimmed electrodes adjacent to one another for comparison between the Mason-Likar and standard electrode placements.

LIMITATIONS

The investigatory acknowledged the following limitations:

1. Due to the specific population evaluated in this study, the results are limited to high risk males for CAD and males with a history of CAD.

2. Due to the lead configuration used, 12-lead ECG measures for both the Mason-Likar system and standard lead system will not be possible for all ECG measures obtained.

3. Due to the lead configuration used, two different stress

testing systems will be used for comparison between the Mason-Likar and standard electrode placements.

4. Due to the inability of the observer to choose "clean" complexes which coincide with the same heart rate in both leads II and V_5, the observer is forced to choose adjacent complexes with a similar configuration which may not be in the same time interval.

5. Due to the inability of the observer to detect small changes in ST segment deviation (< .05 mV), the results are limited to the nearest accuracy as the measurement tool allows (.05 mV).

BASIC ASSUMPTIONS

The following assumptions were made at the onset of this invesigation:

1. The Mason-Likar placement causes amplitude changes and axis shifts when compared to standard placement, which could lead to misinterpretation of ischemic ST changes.

2. Leads II and V_5 will be adequate leads for examining exercise-induced J-point depression.

3. None of the subjects would be taking drugs that would affect the J-point during the 24 hours prior to the exercise test.

4. The electrocardiogram visual analysis will be measured to the nearest accuracy by trained observers.

5. There is no variability between the two different stress

testing machines in electrocardiogram measurements which will affect interpretation of ischemic ST responses.

6. There is no variability between the two different V_5 electrode placements which will affect interpretation of ischemic ST responses.

DEFINITIONS - (Froelicher & Myers, 1993)

Sensitivity: the percentage of total times a test produces abnormal results when diseased subjects were tested.

Specificity: the percentage of total times a test produces normal results when non-diseased subjects were tested.

isoelectric line: the inscription on the ECG complex between the end of the p wave and the beginning of the Q wave; used as a reference for ST and PR segment slopes.

ST-level(J_0): the junction between the end of the QRS complex and the beginning of the ST-segment.

ST-segment depression: a horizontal or downsloping negative shift of the ST-segment depression on the ECG with reference to the isoelectric line, usually within the time of 60 or 80 msec after the J-point.

ST-level(J_{60}): the difference in amplitude in millimeters between the level of ST-segment at 60 milliseconds and the isoelectric line.

<u>Lead V5:</u> precordial, unipolar lead positioned at the level of the fifth intercostal space in the left anterior axillary line.

<u>Lead II:</u> torso-mounted limb lead where the positive electrode is below the left pectoral muscle and the negative below the right clavicle.

Chapter II

REVIEW OF LITERATURE

The first recordings of the electrocardiogram after exercise were made in 1908 by Einthoven, the founder of electrocardiography (Simoons & Block, 1981). A new system was introduced in 1966 by Mason and Likar which allowed recordings of multiple-lead ECGs during exercise possible (Froelicher & Myers, 1993). This system is a modification of the Standard ECG electrode placement which mostly eliminates motion and muscle contraction artifact and allows monitoring of all 12 leads during exercise. The original Mason and Likar study (1966) reported no differences in electrocardiographic configuration when compared to the standard-lead placement for supine resting measures, which allowed the Mason-Likar placement to gain wide-acceptance in clinical practice for the resting, exercise and recovery ECG (Froelicher & Myers, 1993). Since the advent of the Mason and Likar lead system, many other lead systems have been developed in attempt to discover the optimal lead system for exercise electrocardiography, however, basic questions such as selection of leads and interpretation of changes still remain unanswered (Simoons & Block, 1981).

Despite having gained clinical acceptance, recent literature evaluating electrode placements has implicated the

Mason-Likar lead placement as a source of distortion in the pre-exercise ECG. Much of the confusion regarding distortion of the pre-exercise ECG has been due to misplacement of the limb electrodes medially on the torso and by obtaining the ECG in the standing position (Gamble, McManus, Jensen, & Froelicher, 1984). The most recent published clinical exercise standards, by the American Heart Association (AHA), acknowledge this electrode placement and lead selection issue (Fletcher, Froelicher, Hartley, Haskell, & Pollock, 1990). The AHA recommends that the resting 12-lead recording arm and leg electrodes should be moved to the wrists and ankles, with the patient in the supine position to establish a pre-exercise baseline ECG.

In order to identify possible limitations caused by the Mason-Likar placement, this review evaluates the Mason-Likar and standard 12-lead ECG systems for clinical exercise stress testing. This review focuses on the variety of ways electrodes have been placed for ECG monitoring of exercise tests, including both the Mason-Likar and Standard placements, and their diagnostic accuracy in clinical practice for the resting, exercise and recovery ECG. Furthermore, standards of ECG lead system interpretation will be discussed with respect to measurement issues and populations tested. The significance of this study would be to technically improve the clinical performance of exercise test technology with the use of the standard electrode placement for pre-exercise and post-exercise ECG recordings. Because "diagnostic changes" may be seen when using the Mason-Likar placement in the pre-exercise ECG, these same changes may be evident in the post-exercise ECG, which could lead to misinterpretation of a patient's clinical status. The literature analysis did not reveal any studies evaluating different lead systems in the recovery ECG, therefore, the clinical importance of this study is supported.

LEAD SYSTEMS

Electrodes have been placed in a variety of ways for monitoring of exercise tests. The four major exercise electrocardiographic lead systems are the bipolar, the Mason-Likar 12-lead, a simulation of Wilson's central terminal, and the three-dimensional (orthogonal or nonorthogonal systems) (Froelicher & Myers, 1993). Because many different lead systems have been developed for exercise electrocardiography since Mason and Likar, comparisons of these systems becomes difficult when analyzing the ST segment response to exercise. Each of these systems yields different ECG waveforms needed for analysis of ischemia and debate continues over the optimal lead system and optimal criteria for exercise electrocardiography.

Bipolar lead systems have been used because of the relatively short time required for placement, the relative freedom from motion artifact, and the ease with which noise problems can be located (Froelicher & Myers, 1993). Figure 7, in the Figures section, illustrates the electrode placements for most of the bipolar lead systems. The usual positive reference is an electrode placed the same as the positive reference for V_5. The negative reference for V_5 is Wilson's central terminal, which consists in connecting the limb electrodes -- right arm (RA), left arm (LA), and left leg (LL). The only other notable bipolar lead system is the roving bipolar lead. In this system, beginning with a CC5 placement, the electrodes are moved around to obtain the maximal R-wave with a small S-wave (Froelicher & Myers, 1993).

Several three-dimensional or vectorcardiographic lead systems can be used during exercise. The Frank lead system, which represents the electrical activity of the heart orthogonally in three derived signals, is the most popular lead system because of the relative ease of placement of only seven electrodes required. The Vectocardiographic (VCG) approach makes it possible to evaluate the spatial changes of the ST-segment vector. When using both the 12-lead and Frank systems, several electrodes can be shared. The V_4 and V_6 are I and A, LF can also be F, and using this configuration 14 electrodes can be used to obtain both systems (Froelicher & Myers, 1993).

Each of the lead systems is designed to maximize sensitivity and minimize baseline artifact. Artifact produced by motion and muscle contraction during exercise precludes the use of electrodes on arms and legs and thus prevents the use of the standard 12-lead ECG. As mentioned previously, modifications have been developed to minimize these artifacts. Many leaders in the field of electrocardiography argue over the necessity of recording all leads during exercise. Blackburn and Katigbak (1964) showed that the monitoring of V_5 alone will detect 89% of all "positive" exercise results (Kleiner, Nelson, & Boland, 1978). However, according to Kleiner, (1978) as many as 10% to 30% of abnormal exercise tests may be positive in leads other than V_5, which makes the recording of additional leads necessary for maximum sensitivity. Froelicher and Myers (1993) state that as a minimal approach, it is advisable to record three leads: a V_5 type of lead, an anterior V_2 type of lead, and an inferior lead such as aVF; or Frank X, Y, and Z leads may be used. It is also advisable to record a second three-lead grouping consisting of V_4, V_5, and V_6. Abnormalities may be seen as borderline in V_5, whereas they will be clearly abnormal in V_4 or V_6 (Froelicher & Myers, 1993).

MASON-LIKAR AND STANDARD ELECTRODE PLACEMENTS

In 1966, Mason and Likar introduced a new system for recording of multiple-lead ECGs during exercise (Kleiner et al., 1978). As mentioned previously, this system is a modification of the Standard ECG electrode placement which mostly eliminates motion and muscle contraction artifact and allows monitoring of all 12 leads during exercise. The limb electrodes are moved centrally off the extremities, the right and left arm electrodes are moved to the infraclavicular fossae just medial to the border of the deltoid muscle and just below the lower edge of the clavicle. The position of the left leg electrode is less critical but is found to be best placed in the anterior axillarly line halfway between the costal margin and the left iliac crest. The precordial leads are placed in their standard positions (Kleiner et al., 1978).

Mason and Likar reported no differences in their modified placement when compared to the standard limb placement. However, others have found that the Mason-Likar placement causes amplitude changes and axis shifts when compared to the standard placement (Gamble, McManus, Jensen, & Froelicher, 1984). Since this could lead to diagnostic changes, the modified exercise electrode placement is not recommended for recording the resting ECG (Froelicher & Myers, 1993). Although the Mason-Likar placement may misrepresent a patient's clinical status, the Mason-Likar "modified ECG" has become the standard in exercise monitoring by which other systems are compared (Kleiner et al., 1978).

THE RESTING ECG

Clinical Importance

The preexercise ECG is very important clinically because it can be compared to previous tracings to evaluate any changes which may have occurred, and to use it as a baseline

ECG for testing (Froelicher & Myers, 1993). Kleiner et al., (1978) first observed that baseline exercise ECG's using the Mason-Likar modification occasionally differ considerably from standard 12-lead tracings on the same patient. In a study of 75 consecutive patients scheduled to undergo exercise testing for clinical reasons, simultaneous "standard" and "modified" ECG's were performed. Fifty of the initial 75 patients had a rightward axis shift of 30 degrees or more on the modified baseline exercise ECG when compared with the axis on the standard 12-lead tracing. The average rightward axis shift in these fifty patients was 45 degrees, but it frequently exceeded 60 degrees.

Other studies have confirmed the presence of these changes. Rautaharju et al., (1980) observed that pre-exercise ECG's using the Mason-Likar modification produced a 16 degree axis shift towards a more vertical position. The subjects in this study were healthy adult males and produced less of an axis shift when compared to the more high-risk subjects in Kleiner's study. Comparisons between high-risk and low risk populations for heart disease yield different ECG interpretations when comparing lead systems and will be discussed later in this review. In a study by Gamble et al., (1984) 104 male patients with stable coronary heart disease were studied. There were important differences between the standard 12-lead ECG and the ECG's gathered with the pre-exercise test modification. When compared to the standard electrode placement, the modified placement showed an average of 26 degrees of deviation to the right.

In the study by Kleiner et al., (1978) 11 of the 75 patients had a rightward axis shift on their modified ECG that resulted in Q waves and T wave inversion in aVL, without prior history or electrocardiographic evidence of myocardial infarction. Seventeen of their patients had diagnostic criteria for an old inferior infarction, and seven (41 percent) of them had these criteria erased by the rightward axis shift on the modified placement. In the patients with diagnostic criteria for anterior infarction, there was no change with the modified placement.

It is evident that the modified placement results in a more vertical and rightward shift of the QRS frontal plane angle. More alarming is that this shift results in profound amplitude and waveform changes, such as an increase of the R wave amplitude in leads II, III and aVF and a decrease in leads I and aVL (Rautaharju et al., 1984). The s wave amplitude increases in leads II and aVF and decreases in lead III. The P and T wave amplitude changes correspond to shifts similar to those observed for the R wave (Rautaharju et al., 1984).

Of clinical importance is what these shifts do to the visual interpretation of the ECG. The results from the study by Froelicher and Myers (1984) show similar results using the 104 patients with stable coronary artery disease. In five patients the ECG diagnosis of old inferior infarct was lost. In addition, seven patients lost significant Q-waves in III alone. There were instances of Q-waves gained. Eight patients had no Q-waves in aVL; one had a new Q in III, one with a new Q in II, one with a new Q in V_6; and one patient gained an inferior infarct diagnosis. These changes can be very misleading and warrants the importance of recording a standard 12-lead ECG prior to exercise testing to see if there are any important serial changes such as those that would suggest a recent myocardial infarction.

ST-Segment Changes

The most important diagnostic tool for detecting disease is the ST-segment waveform changes. Concomitant to the T amplitude changes which were mentioned earlier, there are significant ST segment waveform changes. The ST slope values show an increase in inferior leads II, III and aVF and a decrease in aVL (Rautaharju et al., 1980). The waveform changes in the chest leads are less important although statistically significant (Rautaharju et al., 1980).

Postural Changes

Postural differences further complicate the pre-exercise ECG recording. Froelicher and Myers (1993) suggest that much of the confusion regarding distortion of the pre-exercise ECG has been attributable to misplacement of limb electrodes medially on the torso as well as by obtaining the ECG in the standing position. Shapiro et al., (1976) studied the differences between Frank lead vectocardiograms in 59 adult male patients with suspected coronary artery disease. They observed that QRS spatial and R wave amplitudes in Z were significantly higher and R amplitudes in lead Y lower for sitting than for supine positions. Based on these observations, they concluded that the pre-exercise ECG should be obtained standing as well with the patient in the same position as that maintained during exercise (Froelicher & Myers, 1993).

Other studies have also shown differences between ECG's taken supine versus sitting or standing. Sigler (1938) studied 100 patients and found a left axis shift for abnormal tracings and a right axis shift for normal tracings (Froelicher & Myers, 1993). Gamble et al., (1984) demonstrated in their study of 104 male patients with stable coronary artery disease that the most significant differences were found in the standing modified electrode placement, which is consistent with Sigler's report. They also showed four patients who lost the diagnosis of old inferior infarcts, as well as the loss of one anterior infarct diagnosis. Furthermore, five patients had Q waves in lead III disappear. Most significant was the gain of an inferior infarct diagnosis in seven patients when standing. There were also two patients that had changes producing ST or T wave shifts, three patients who gained a Q wave in lead III alone, and one patient where a Q in aVL was gained.

No clear patterns emerged in either the Gamble or the Sigler study as to why some patients shift their electrical axis one way with the standing modified placement and other patients shift in the opposite direction. Although, the axis shift helps to explain why some patients gain an inferior infarct while others lose this pattern.

Implications of Findings

These studies strongly suggest that the Mason-Likar modified electrode placement can misrepresent a patient's clinical status in the pre-exercise ECG in both the supine and standing positions. They suggest that the axis shifts and amplitude changes produced by the modified placement will lead to diagnostic changes which will effect the visual interpretation of the ECG, thus recommending that the modified exercise electrode placement should not be used for routine electrocardiography prior to exercise.

THE EXERCISE ECG

Clinical Importance

Because of the extra effort and cost involved in recording the resting ECG using the standard electrode placement, the modification of the standard placement has gained wide acceptance in clinical practice both for the resting and exercise ECG (Rautaharju et al., 1980). Mason and Likar in 1966 made it possible to record all 12 leads during exercise with their modified placement, and evidence suggests that this practice increases both the sensitivity and the safety of the test (Kleiner et al., 1978). Since the development of the Mason-Likar "modified" electrode placement, the medical electronics industry has made 12 leads the standard available in all machines today (Froelicher & Myers, 1993). However, as mentioned previously, controversy still exist as to whether it is necessary to monitor all 12 leads during exercise (Miller, Desser, & Lawson, 1987). Froelicher and Myers (1983) state that in patients with normal resting ECGs, a V_5 or similar bipolar lead along the long axis of the heart is usually adequate. However, in patients with ECG evidence of myocardial damage or with a history suggestive of coronary spasm, they recommend additional leads.

The optimal ECG lead system for exercise monitoring in the detection of ischemic heart disease has not been determined (Miller et al., 1987). Several studies suggest however that monitoring leads V_4 through V_6 will detect an overwhelming majority of ischemic responses. Furthermore, ischemic ST-segment changes rarely occur in leads I and/or aVL and ST segment changes observed in the inferior leads are almost always accompanied by changes in leads V_4 and/or V_5 (Miller et al., 1987). Miranda and associates evaluated 178 males who had undergone both exercise testing and coronary angiography to evaluate the diagnostic value of ST-segment depression occurring in the inferior leads. Lead V_5 had a better sensitivity (65%) and specificity (84%) than that of lead II (sensitivity and specificity 71% and 44% respectively) at a single cut point, indicating that isolated ST-segment depression in lead II is unreliable (Froelicher & Myers, 1993).

ST-Segment Changes

The degree of exercise-induced ST depression is influence by numerous factors and can also be influenced by R-wave amplitude (Hollenberg, Mateo, Massie, Wisneski, & Gertz, 1985). According to Hollenberg et al., (1985) it is clinically important to establish whether patients with large R-wave voltage will develop increased ST-segment depression during exercise only as a function of gain or amplification. In this study, correction for the amount of ST-segment depression for the magnitude of the R-wave voltage was essential to estimate more accurately the degree of ischemia and the severity of the disease. As mentioned previously, R-wave amplitude in the inferior leads is increased when using the Mason-Likar placement.

In a study by Hakki et al., (1984) the concept of adjusting for low-amplitude R-waves was also supported (Hollenberg et al., 1985). In a group of patients similar in the extent of coronary artery disease, only 8% of patients with an RV_5 amplitude less than 11mm had a positive exercise test response, compared with 49% of patients with an RV_5 amplitude greater than 11mm. The results indicated that test accuracy could have been improved if a "gain factor" correction had been applied to patients with a low R-wave amplitude in V_5.

The previous studies indicate that the R-wave amplitude can greatly influence the magnitude of exercise-induced ST-segment depression and must be taken into account to accurately interpret the exercise electrocardiogram. Clearly, opinions still differ on basic questions such as selection of leads and interpretation of changes in the electrocardiogram during exercise. However, several investigators have tried to answer these questions, as evidenced by quantitative analysis of the whole body surface potential during exercise (Simoons & Block, 1981). In a study of 25 men with known coronary artery disease, body surface maps showed abnormal repolarization patterns that were not present in the standard 12-lead electrocardiogram. A horizontal or downsloping S-T segment depression was present in only 15 of the 25 patients, however, 21 patients had abnormal negative precordial potentials greater than 90 millivolts 60 milliseconds after the QRS complex when using body surface mapping. To a lesser degree, such negative values were also present in three normal subjects.

Further support that more abnormal patterns can be identified using the surface maps than when compared to the modified 12-lead system is demonstrated by Fox and colleagues (Fox, Selwyn, & Shillingford, 1978). In a study of 100 patients undergoing angiography for evaluation of chest pain, the sensitivity of a 16-lead precordial mapping technique (96%) for diagnosing coronary artery disease was better than the modified 12-leads (80%), using 0.1 mV horizontal ST-segment depression as being abnormal. The improved sensitivity was attributed to the improved recognition of patients with single vessel disease.

Despite some improved sensitivity, Froelicher and Myers (1993) do not recommend body-surface mapping, suggesting that it is "oversimplistic" to consider ST-segment mapping data as having the ability to directly quantitate ischemic myocardium. Furthermore, they state that identification of discrete ischemic zones unique to a given arterial lesion is still difficult and the added cost of specialized recorders and more electrodes leave mapping as a research tool without much clinical applicability.

Implications Of Findings

Since the ultimate goal of electrocardiographic monitoring during exercise is to be able to identify critical dysrhythmic or "ischemic" responses, available evidence suggests that the Mason-Likar modified electrode placement may not be the ultimate tool. Other alternatives or lead systems must be sought to fully evaluate changes which may be indicative of coronary artery disease. Simoons and Block (1981) recommends the recording of precordial and whole body surface maps both during and after exercise in a large series of patients, with the normal range of measurements from the QRS complex and the S-T segment defined for each position. Furthermore, sex, age, body dimensions and heart rate during exercise must be considered as well as the type of test protocol that is used. However, the results of a study such as this one would have limited value because both precordial mapping and computer analysis already yield sensitivity levels of 80 to 90 percent at a specificity of 90 to 95 % (Simoons and Block, 1981). The improvement in sensitivity in the electrocardiogram with the addition of precordial mapping or computer processing approximates the improvement found by nuclear imaging techniques. However, as mentioned earlier by Froelicher and Myers, (1993) the extra cost and effort does not make precordial mapping feasible and may not always yield the most accurate results. A more simple alternative which could lead to some improvement in the sensitivity of the exercise test is the monitoring of the post-exercise ECG using the standard lead placement. The axis shifts and amplitude changes will not be evident when using the standard lead placement, which may lead to a better assessment of a patient's clinical condition.

THE RECOVERY ECG

Clinical Importance

The clinical application of post-exercise electrocardiography was not introduced until almost 30 years following the first recordings of the electrocardiogram in 1908 by Einthoven (Simoons & Block, 1981). It is evident that the sensitivity of the exercise test is highest when the interpretation is based on all electrocardiographic recordings during and after exercise (Sketch, Nair, Esterbrooks, & Mohiuddin, 1978). The post-exercise ECG changes are important when diagnosing patients with an ischemic response during exercise. Furthermore, not all ischemic responses will be observed during exercise and may become evident only during recovery.

ST-Segment Changes

According to Froelicher and Myers (1993), approximately 85% of all patients with abnormal ST responses during exercise, evidence such changes in the supine position at 4 to 5 minutes into recovery as well. This finding suggests the importance of accurate representation of ST segment responses in the recovery or post-exercise phase. Because dramatic changes can be seen on the pre-exercise ECG when comparing the standard lead placement to the Mason-Likar, the post-exercise ECG could reveal possibly greater changes, especially when accompanied by an ischemic response. Froelicher and Myers

(1993) state that an abnormal response occurring only in the recovery period is not unusual.

The sensitivity of standard ST segment depression criteria at peak exercise is not reliable, thus additional diagnostic information has been sought from the time course and magnitude of ST segment depression during the post-exercise recovery phase (Okin, Ameisen, & Klingfield, 1989). Test accuracy has reportedly been improved in several ways, such as the time course of ischemic ST segment responses into recovery, as well as complex algorithms that depend on the magnitude, slope, and duration of ST segment depression in exercise and recovery. Furthermore, adjustment of the magnitude of exercise-induced ST segment depression for the change in heart rate during exercise has been reported to improve test performance (Okin et al., 1989). Okin et al., (1989) also showed that heart rate-adjusted ST-segment criteria during exercise as well as recovery can enhance the accuracy of the exercise electrocardiogram for the identification of coronary artery disease. Many different techniques have been used to try and improve the clinical performance of exercise test technology, however, none of the studies have evaluated the effect of using the standard electrode placement in recovery.

There is much support for the recording of recovery ECGs. The incidence of abnormal exercise tests only during exercise is small and these usually reflect a false-positive response (Sketch et al., 1978). Froelicher and Myers (1993), recommend that if maximal sensitivity is to be achieved with an exercise test, patients should be supine during the post-exercise period. Recent data from their laboratory indicates that having the patient lie down may enhance ST-segment abnormalities in recovery. If any exercise-induced ischemic responses do arise they can be identified in leads II, aVF, and V_3 to V_6 in virtually all patients (Sketch et al., 1978), confirming the classic study of Blackburn et al., (1964).

<u>Implications Of Findings</u>

Using the standard lead placement for post-exercise tracings could have important implications for the interpretation of a patient's test. The rightward axis shift and amplitude changes caused by the Mason-Likar placement in the post-exercise phase will not be evident when using the standard lead placement. Thus, one may speculate that the number of "ischemic" responses found in I and aVL will be reduced and even more important a greater number of patient's with "ischemic" responses in leads II, III and aVF can be identified and treated appropriately (Rautaharju, et al., 1980). Furthermore, with a normalization of the R-wave amplitude using the standard placement in the recovery ECG, the increase in the R-wave amplitude observed in the inferior leads using Mason-Likar will be eliminated. Because R-wave amplitude can greatly influence the magnitude of ST depression, the number of false-positives in the inferior leads could be reduced. Furthermore, eventhough more waveform changes may be evidenced in the recovery ECG using the standard placement when testing "high-risk" subjects, results from the precordial mapping technique indicate there is the potential to detect disease in patients who may otherwise go unnoticed when using the modified placement. Because more patients with single vessel disease can be detected using the precordial mapping technique, it may also be possible to increase the sensitivity of the test when using the standard placement in the recovery ECG.

Although the changes produced by the different electrode placements are merely artifacts, they could be very misleading. These changes are obvious in the pre-exercise ECGs and potentially could be more pronounced in exercise and recovery. This investigation will allow the ECG to be evaluated using the standard lead system immediately post-exercise which could offer the key characteristic of the ECG waveform needed for analysis of ischemia.

STANDARDS OF ECG INTERPRETATION

To more accurately report ECG findings in uniform, clearly defined terms, the Minnesota Code (MC) has been widely used for visual coding of ECG data (Rautaharju, Broste, Prineas, Eifler, Crow, & Furberg, 1986). The MC is useful in electrocardiography visual interpretation for identifying ECG abnormalities which may effect interpretation of a patient's test. The ST-segment analysis with exercise testing is not reliable in patients with resting electrocardiographic abnormalities due to bundle branch block, left ventricular hypertrophy, and digitalis. The MC will help to identify those abnormalities which may preclude accurate representation of a patient's test and will also provide a standardized way of measuring the different waveforms.

ECG MEASUREMENT ISSUES

It is evident that there are considerable differences between the modified and standard limb ECGs. However, it is not known how the modified electrode positions will influence the prevalence of various findings based on the Minnesota Code. Since the R amplitude decreases in leads I and aVL and increases in lead II with an average 16 degree or greater vertical shift of the frontal plane QRS axis, it is likely to influence certain Minnesota Code items related to the criteria for left ventricular hypertrophy (Rautaharju, et al., 1986). To avoid such ECG interpretation errors, the Minnesota Code will be used only with the standard ECG tracings in this study.

To improve the interpretation and technical quality of ECG tracings, a list of defined criteria, such as the Minnesota Code is necessary. Other important considerations include elimination of ECG tracings with excessive motion artifact, baseline wander > 3mm, ventricular preexcitation, ventricular pacemaker, and ventricular tachycardia. Following the exclusion of certain ECG abnormalities from a study, it is then important to have an experienced set of observers for the visual interpretation of ECG measures. Furthermore, it is important to have a standardized method of measuring the different waveforms, which the MC will help to provide. Considerable interobserver variability in the electrocardiogram has been repeatedly reported. A 10-fold interobserver difference in frequency of "abnormal" diagnoses was reported by Blackburn (1968) in a study of 38 records of asymptomatic subjects who had an exercise test performed (Caralis, Wiens, Shaw, Younis, Haueisen, Wiens, & Chaitman, 1990). Intraobserver variability is also important. The use of the same observer for ECG readings does not necessarily provide a high degree of reliability. The use of a calibrated magnifying lens does however significantly improve measurement accuracy (Caralis, et al., 1992).

The sensitivity and specificity of ECG lead systems is also of concern when interpretating the electrocardiogram. Since the 1970s numerous studies have compared the relative sensitivity of different ECG leads (Froelicher & Myers, 1993). In a study by Robertson and associates using 12-lead exercise tests in 39 patients with both abnormal exercise tests and abnormal coronary angiography, eighteen percent had an abnormal response in leads other than V_5. While most coronary lesions where identified with the corresponding lead, almost a third of the patients showed ST- segment depression in leads other than those anticipated from their angiographic anatomy (Froelicher & Myers, 1993). This finding indicates that all coronary lesions cannot be identified using standard 12-lead ECG criteria and additional tests may be needed.

Although the specificity of leads other than V_5 has not been demonstrated, it is clear that the inferior leads have more false-positive results and may require different criteria (Miranda, Kadar, Janosi, Froning, Lehmann, & Froelicher, 1991). According to Froelicher and Myers (1993), the lack of specificity in the inferior leads may be attributable to the effect of atrial repolarization, which causes depression of the ST-segment. The end of the PR segment can be seen to be depressed in a curved fashion to the same level that the ST segment begins.

Population Tested

In contrast to the previous studies, Diamond et al., (1979) studied 11 patients comparing the standard and modified lead placements and found minor variations using the two placements, which were random and did not alter the diagnostic interpretation. The reason for the discrepancy between investigations may be attributed to the population tested or the number of patients evaluated. It is evident that the more high-risk population will elicit more significant changes and the changes will become more evident when testing a larger population, such as in the Froelicher and Myers (1984) study using 104 male patients with stable coronary artery disease.

SUMMARY

The objective of this review was to examine the published findings regarding use of the Mason-Likar and standard 12-lead ECG systems for clinical exercise stress testing. To gain a clearer understanding of exercise electrocardiography, the variety of ways electrodes have been place for ECG monitoring of exercise tests was also discussed, as well as standards of ECG interpretation relating to ECG measurement issues and the population tested.

Although the Mason-Likar lead system has characteristically been thought to accurately represent a patient's clinical status, recent evidence suggests that the Mason-Likar placement may cause amplitude changes and axis shifts when compared to the standard placement in the supine resting position (Fletcher et al., 1990). This is supported by studies which reported that baseline exercise ECGs using the Mason-Likar modification can differ considerably from standard 12-lead tracings on the same patient (Kleiner et al., 1978, Rautaharju et at., 1980, and Gamble et al., 1984). It is further supported by a recommendation from the American Heart Association which suggests that the resting 12-lead recording arm and leg electrodes be moved to the wrists and ankles, with the patient in the supine position to establish a pre-exercise baseline ECG (Fletcher et al., 1990).

In support of the above notion, the amplitude changes and axis shifts observed in the pre-exercise ECG may also be evident in the post-exercise ECG. The various studies on different lead systems have evaluated exclusively the pre-exercise ECG. Conversely, none of the studies have investigated the possibility of changes occurring in the post-exercise ECG using the standard lead placement. Using the standard lead placement for post-exercise ECG tracings could have important implications for the interpretation of a patient's test. The rightward axis shift and amplitude changes caused by the Mason-Likar placement in the post-exercise phase will not be evident when using the standard lead placement. Because dramatic changes can be seen on the pre-exercise ECG when comparing the standard lead placement to the Mason-Likar, the post-exercise ECG could reveal possibly greater changes, especially when accompanied by an ischemic response.

Chapter III

JOURNAL MANUSCRIPT

A COMPARISON OF THE MASON-LIKAR AND CLINICAL STANDARD 12-LEAD ECG FOR FOR EXERCISE-INDUCED ST-SEGMENT SHIFTS IN MALES AT HIGH RISK FOR CAD

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A COMPARISON OF THE MASON-LIKAR AND CLINICAL STANDARD 12-LEAD ECG FOR EXERCISE-INDUCED ST-SEGMENT SHIFTS IN MALES AT HIGH RISK FOR CAD

David G. Shell

ABSTRACT

This study sought to examine the exercise-induced ST-segment shifts, J_0 and J_{60}, attributable to ECG lead configuration, specifically to evaluate if ischemic changes are modified as a function of using the Mason-Likar lead system. Males (N=30) referred for diagnostic testing underwent a symptom-limited graded exercise test (SLGXT). ST-segment shifts, J_0 and J_{60}, measured as the difference from baseline to recovery minute one, were not significantly different in responses measured from two simultaneous complexes for lead V_5. In frontal lead II, differences were found in the ST-segment response at baseline vs. recovery minute one. All ST-segment shifts were computed as the difference between J_x obtained at resting baseline vs. the J_x obtained at the exercise measurement in the same posture. ST-segment shifts, J_0 and J_{60}, measured at peak-exercise vs. recovery minute one using the Mason-Likar lead system, revealed a significant difference according to the measurement recorded in both leads V_5 and II ($p<.05$). Comparisons of frequencies for clinically abnormal ST-segment shifts according to ECG lead configuration at IPE when measured from peak-exercise using Mason-Likar were significant in only lead

II ($p<.05$). Observation of the data suggest that the Mason-Likar lead system may affect the interpretation of ischemic ST-segment shifts in lead II. However, these results do not invalidate the interpretation of ischemic ST-segment shifts in lead V_5 using the Mason-Likar lead system.

INTRODUCTION

Since a 12-lead ECG could not be obtained accurately during exercise with electrodes placed on the wrists and ankles, Mason and Likar introduced a new lead system for the recording of multiple-lead ECG's during exercise.[4] This system is a modification of the standard 12-lead ECG lead system whereby the arm electrodes are placed in the infraclavicular fossae 2 cm below the lower border of the clavicle and medial to the border of the deltoid muscle. The left leg electrode is placed in the anterior axillary line, midway between the rib margin and the iliac spine. Standard positions are used for the chest leads V_1 to V_6. In addition to providing a noise-free exercise tracing, the Mason-Likar lead system showed no differences in electrocardiographic configuration when compared to the standard 12-lead ECG.[3] However, this has been disputed by others who have found that the Mason-Likar lead system is associated with amplitude differences and axis shifts when compared to the standard lead system.[3]

Studies evaluating the differences associated with the Mason-Likar lead system in the pre-exercise ECG report the increased frequency of new or diagnostic Q waves and axis shifts affecting the QRS complex or T waves, which could be reason to minsinterpret a patient's clinical status.[4] Current research suggests much of the confusion regarding distortion of the pre-exercise ECG has been due to misplacement of the limb electrodes on the torso and by obtaining the ECG in the standing position.[4] The most recent published clinical American Heart Association (AHA) exercise standards (1990), acknowledge this electrode placement and lead selection issue.[2] The AHA recommends that the resting 12-lead recording arm and leg electrodes be placed on the wrists and ankles, with the patient in the supine position to establish a pre-exercise baseline ECG.

Because it is important clinically to obtain an accurate pre-exercise ECG, the standard 12-lead ECG system is recommended. However, the Mason-Likar lead system has gained wide acceptance in clinical testing for both the exercise and recovery ECG.[3] The various studies comparing the Mason-Likar and standard 12-lead ECG systems have evaluated exclusively the pre-exercise ECG.[4,5,7] Conversely, none of the studies have investigated the possibility of differences occurring in the recovery ECG when using the Mason-Lead system.

Approximately 85% of all patients with abnormal ST-segment responses during exercise continue to be abnormal at 4 to 5 minutes into recovery.[3] This finding underscores the importance of accurate representation of ST-segment responses during recovery. In this investigation, ST-segment shifts, ST_0 and ST_{60} (evaluated at the J-point and 60 msec following the J-point, respectively) in leads II and V_5, were measured to evaluate ECG responses simultaneously in the standard lead system (electrodes on wrists and ankles) and Mason-Likar lead system one minute into recovery. ST_0 and ST_{60} were measured prior to exercise at supine and standing, at peak-exercise (Mason-Likar only), and one minute into recovery.

The primary objective of this research was to examine if ischemic ST-segment changes are modified by the Mason-Likar lead system used during exercise testing. The second objective was to determine if ischemic ST-segment changes at peak-exercise are different from those one minute into recovery. In this study, it was not possible to simultaneously record ECG responses at peak-exercise with the standard and Mason-Likar lead systems. Therefore, recordings were made at the first minute of recovery to compare these lead systems for ischemic responses. Since ischemic ST-segment changes resolve quickly in recovery as myocardial oxygen demand declines, it was essential to examine the ST-segment shifts obtained from the different lead systems for possible differences as soon as the patient could be placed in the supine position and the standard lead system utilized.

METHODS

Subjects

Thirty male subjects, 29 to 72 years, undergoing treadmill exercise testing for diagnosis or evaluation of coronary artery disease were used in this investigation. These patients had symptoms of coronary artery disease, or two or more risk factors for coronary artery disease. Patients with resting ECG's showing bundle branch block, left ventricular hypertrophy, ST-segment elevation or depression > 1 mm, and patients on digitalis were excluded.

General Protocol and Study Design

Prior to the treadmill test, each subject had simultaneous ECG recordings taken with the "standard" and Mason-Likar ECG lead systems. Recordings for ST-segment measures, J_0 and J_{60}, in leads II and V_5 for the Mason-Likar and standard lead systems were made in the supine and standing postures using Quinton 4500 and Quinton 2000 ECG recording machines. Each ECG machine was calibrated so that a 1-mv standardization signal produced a deflection of exactly 10 mm (standardization was checked and recorded before every ECG). The paper speed for each ECG machine was standardized at 25 mm/second. The filtering mechanism useful for the recording of exercise ECG's remained off both in the pre-exercise and post-exercise recordings for each ECG machine.

The Quinton 4500 was used for the recording of the Mason-Likar lead system and the Quinton 2000 was used for the recording of the standard lead system in this study. The Quinton 2000 allowed for the placement of only 5 electrodes for the standard lead system whereby the arm and leg and the V_5 electrode placements were recorded for comparison to the Mason-Likar lead system ST-segment measures in leads II and V_5. The V_5 placement consisted of two electrodes with trimmed adhesive collars placed adjacent to one another used for comparison between the Mason-Likar and standard lead system ST-segment measures. The V_5 placement used for the Mason-Likar and standard lead systems for comparison of the ST-segment measures was alternated between the two electrodes following each test. There were no differences in electrocardiographic configuration between the two electrodes used for the V_5 placement.

Following the pre-exercise ECG comparisons between lead systems, the subject underwent a symptom-limited graded exercise test (SLGXT). During the test, heart rate, blood pressure, rating of perceived exertion, and the electrocardiogram were monitored. A peak-exercise ECG was taken using the Mason-Likar lead system within 10 seconds of the end of the test with the patient standing to avoid signal artifact. During this period, the heart rate remained elevated at the same level as peak-exercise. During the post-exercise period with the patient supine, simultaneous ECGs were recorded with the standard and Mason-Likar lead systems. Thus, direct comparisons could be made during the first minute of recovery in both leads II and V_5.

Investigators have shown that monitoring of lead V_5 alone will detect 89% of all "positive" exercise results.[5] In patients with normal electrocardiograms, precordial lead V_5 is more sensitive for detection of CAD during exercise testing than is limb lead II.[6] Lead II was chosen as the representative inferior lead because it has been shown to be the inferior lead that is the most stable for ECG recording during exercise.[6] In this study leads II and V_5 were chosen to provide a stable means of recording myocardial ischemia on the ECG.

ECG Measurement Procedure

The first measurements taken in this study were from the exercise test of 20 patients randomly chosen from a group of 30. The electrocardiograms chosen were selected to represent a sample. Each ECG response for the study was coded separately by three independent observers. The observers were graduate level exercise physiology students with technical experience in measuring exercise ECG's. The observers read only the supine, peak exercise and immediate post-exercise measurements. All observers were trained using the Minnesota Code (MC), which provided a standardized method of measuring the different waveforms.[1] The ST-segment measurements were made to the nearest .05 mV. A ten-power, hand-held magnifying lens marked in tenths of a millimeter was used to enhance measurement precision. The interobserver reliability coefficient was calculated using Pearson's product-moment correlation and was greater than 0.85 for all of the ST-segment measures. Having established reliability of measurements in this manner, ECG responses for all 30 subjects were analyzed using values for only one of the observers.

Statistics

A two-way ANOVA for repeated measures was performed in order to evaluate the effects of lead placement (V_5 or II) and lead system (Mason-Likar or standard) upon ST-segment shifts (J_0 andJ_{60}). First, the differences in the ST-segment shifts, (J_0 and J_{60} pooled), between lead systems were compared for baseline vs. one minute of recovery. Also evaluated were the differences between J-point measures, (J_0 vs. J_{60}), for baseline vs. one minute of recovery. Second, the differences in the ST-segment shifts, (J_0 and J_{60} pooled), were compared for different ECG exercise measurements, peak exercise vs. one minute of recovery, using only the Mason-Likar lead system. Also evaluated were the differences between J-point measures, (J_0 vs. J_{60}), for peak-exercise vs. one minute of recovery. Chi-square analysis was used to compare the difference in the number of clinically "abnormal" ST-segment shifts for the Mason-Likar and standard lead systems one minute into recovery.

RESULTS

Key characteristics of the ECG waveform (J_0 and J_{60}) were analyzed since these are considered the most reliable markers of myocardial ischemia. Table 1 presents demographics, health characteristics, and resting ECG measures for the group of patients utilized in this study. The sample had 50.0% of patients with hypertension and 66.6% of patients with angina symptoms. The average age was 49.8 + 10.8 years.

Insert Table 1 here

Table 2 (and Figures 1 and 2) presents the differences in the pre-exercise baseline vs. one minute of recovery ECG ST-segment shifts (J_0 and J_{60} pooled) in the Mason-Likar vs. the standard lead systems in leads V_5 and II. All ST-segment shifts were computed as the difference between J_x obtained at resting baseline vs. the J_x obtained at the peak-exercise or one minute of recovery measurement in the same posture. There were no significant differences in ST-segment shifts (J_0 and J_{60} pooled) attributable to ECG lead system in lead V_5, however, significant differences were observed between lead systems in lead II for the ST-segment shifts ($P < 0.05$). Significance was also found between the different J-point measures (J_0 vs. J_{60}) in both leads V_5 and II for baseline vs. recovery minute one. ($P < 0.05$).

Insert Table 2, Figures 1 and 2 here

Table 3 (and Figures 3 and 4) presents the differences in the peak-exercise vs. one minute of recovery ECG ST-segment shifts (J_0 and J_{60} pooled) using the Mason-Likar lead system. Significant differences were observed in ST-segment shifts according to the exercise measurement recorded (peak-exercise or one minute of recovery) during the exercise stress test in both leads V_5 and II ($P < 0.05$). Significant differences were also found between J-point measures (J_0 vs. J_{60}) in both leads V_5 and II ($P < 0.05$).

Insert Table 3, Figures 3 and 4 here

Figures 1 and 2 present the differences in the number of clinically "abnormal" ST-segment shifts between the Mason-Likar and standard lead systems at one minute of recovery in leads V_5 and II. When these shifts are compared to the "abnormal" ST-segment shifts presented in figures 3 and 4 for leads V_5 and II at peak-exercise using Mason-Likar, there are significant differences between the Mason-Likar and standard lead systems for the change in "abnormals" in lead II ($P < 0.05$). Table 4 shows the Chi-square analysis for the change in "abnormals" for peak-exercise vs. minute one of recovery.

Insert Table 4 here

DISCUSSION

Differences in the ST-segment measures (J_0 and J_{60}) have been reported in the pre-exercise ECG when using the Mason-Likar lead system.[7] The present study found that there is a significant difference in ST-segment shifts when comparing the

Mason-Likar to the standard lead system in lead II for baseline vs. one minute of recovery measurements. The significant difference between lead systems in lead II is caused primarily by J-point depression. However, because significantly more "abnormals" are present when using the Mason-Likar lead system at one minute of recovery in lead II, this could result in over diagnosis of ischemia. In addition to the differences found between lead systems for ST-segment shifts, a significant difference between ST-segment shifts (J_0 vs. J_{60}) was found in leads II and V_5 when evaluating the ischemic response from peak-exercise to one minute of recovery using the Mason-Likar lead system. The peak-exercise response is lost very rapidly and does not continue into recovery which makes prediction of the ST-segment shift differences between lead systems difficult at peak-exercise in lead V_5. Clearly, the ST-segment shifts in lead II produced by the Mason-Likar lead system may warrant caution when evaluating an ischemic response in the inferior leads due to the significant differences observed between lead systems for ST-segment shifts at one minute of recovery.

The decrease in the number of abnormal ST-segment shifts occuring from peak-exercise using Mason-Likar to one minute of recovery using the standard lead system in lead II represents a clinically important difference between lead systems for the evaluation of ST-segment shifts. Significantly less abnormal ST-segment shifts are observed at recovery minute one when using the standard lead system in lead II. Therefore, there is a trend toward more clinically abnormal ST-segment shifts when using the Mason-Likar lead system in lead II.

Exercise-induced ST-segment depression in inferior limb lead II has been shown to be a notoriously poor marker for CAD.[6] Precordial lead V_5 alone has been shown to consistently outperform lead II and the combination of leads V_5 and II, because lead II has such a high false-positive rate.[6] We can speculate that the higher false-positive rate in lead II may be a function of using the Mason-Likar lead system. The significant decrease in the number of clinical "abnormals" with the standard lead system at recovery minute one in lead II provides support for possible differences between lead systems for ST-segment shifts which may influence diagnostic interpretation. Since the ultimate goal of electrocardiographic monitoring during exercise is to identify coronary artery disease, these findings suggest that the Mason-Likar "modified" lead system may not provide the most reliable measure of ischemia for CAD detection.

SUMMARY

The differences in the exercise-induced ST-segment shifts observed between the Mason-Likar and standard lead systems suggests that ECG lead system and ECG lead selection may influence the interpretation of ischemic ST-segment responses. Observation of the data suggest that the Mason-Likar lead system may affect the interpretation of ischemic ST-segment shifts in lead II. We can speculate that interpretation may be altered in leads III and aVF as well. Lead II results do not invalidate the interpretation of ischemic ST-segment shifts in lead V_5 using the Mason-Likar lead system. We caution, however, that the Mason-Likar lead system may falsely produce evidence of ischemia during exercise and recovery in the inferior leads. Exercise-induced ST-segment depression isolated to the inferior leads may be of little value when using the Mason-Likar lead system.

These data provide a framework for further research in order to determine if the standard lead system is superior to Mason-Likar for the evaluation of ischemic ST-segment shifts. Electrode placement may affect the visual interpretation of the ECG and could have important implications when a test is borderline in its ischemic response. However, whether these changes are significant enough to alarm a cardiologist when evaluating an ischemic response in the post-exercise ECG remains to be determined.

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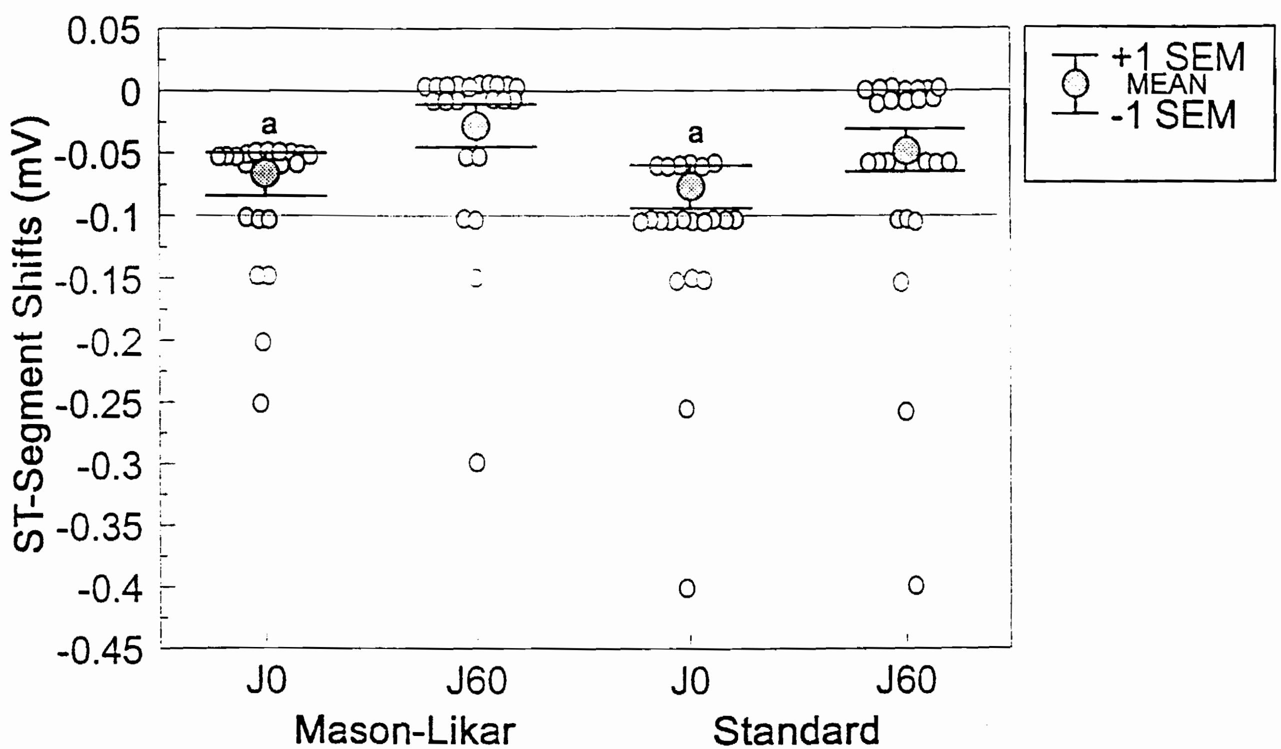

Figure 1: ST-Segment shifts in lead V5 for simultaneously recorded Mason-Likar and Standard ECG lead configurations at recovery minute one in male patients undergoing graded exercise tests.

a denotes significant main effect for differences between time of J-point measurements. See Table 2 for further explanation.

— dashed line represents threshold for clinically abnormal ST depression.

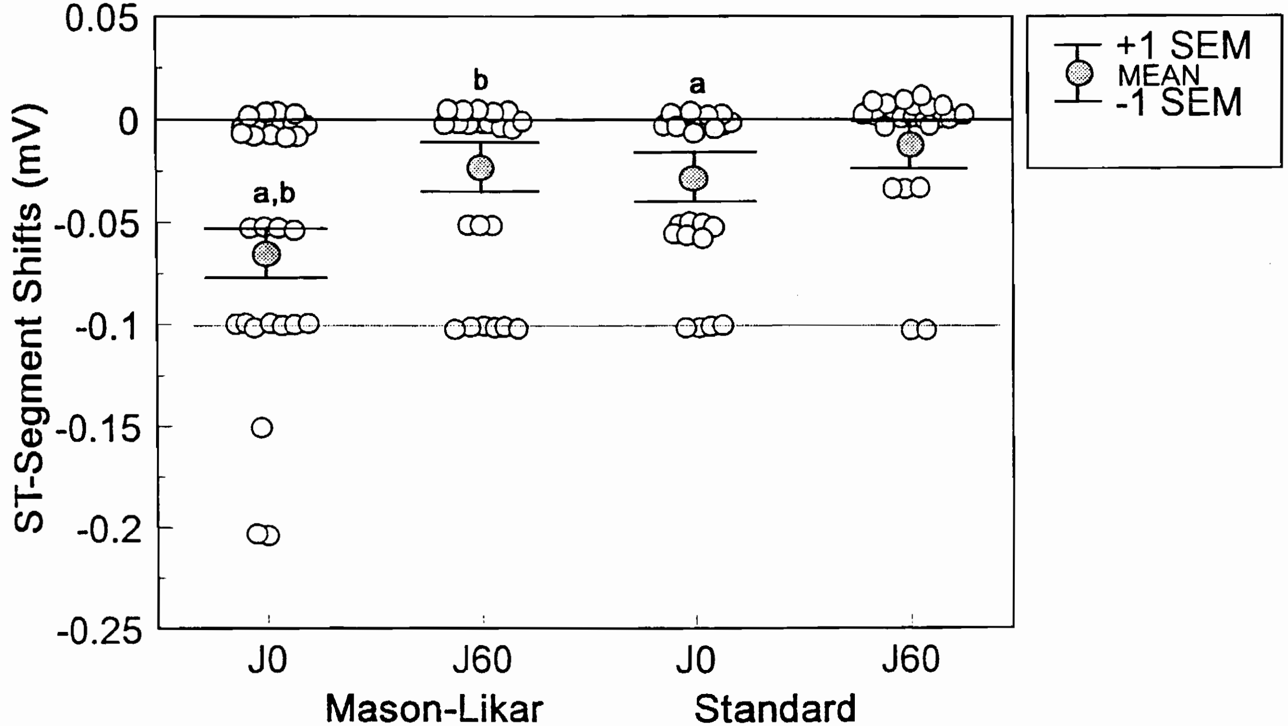

Figure 2: ST-Segment shifts in lead II for simultaneously recorded Mason-Likar and Standard ECG lead configurations at recovery minute one in male patients undergoing graded exercise tests.

[a] denotes significant main effect for differences between time of J-point measurements.

[b] denotes significant main effect for ECG lead configuration. See Table 2 for further explanation.

--- dashed line represents threshold for clinically abnormal ST depression.

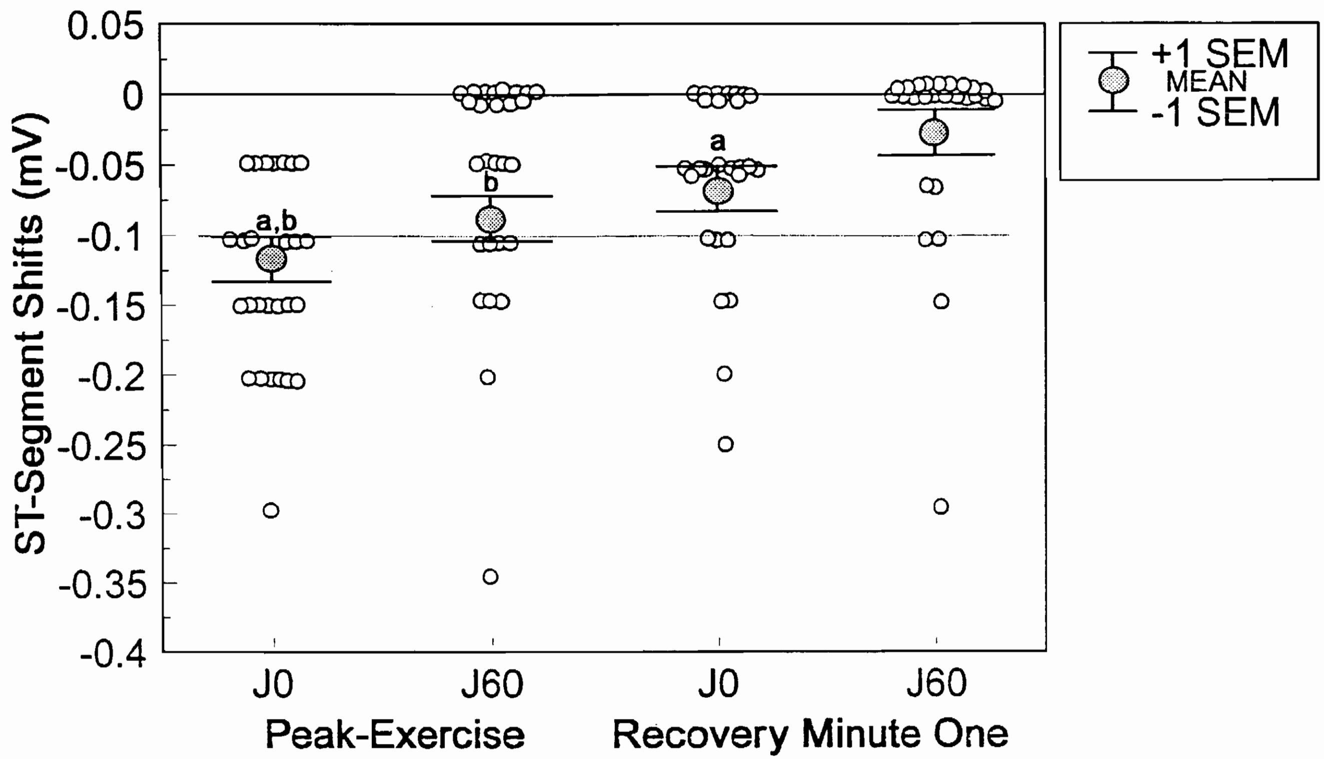

Figure 3: ST-Segment shifts in lead V5 for peak-exercise and recovery minute one recorded using the Mason-Likar ECG lead system in male patients undergoing graded exercise tests.

[a] denotes significant main effect for differences between time of J-point measurements.

[b] denotes significant main effect for ST-segment shifts recorded at peak-exercise vs. recovery minute one.

--- dashed line represents threshold for clinically abnormal ST depression. See Table 3 for further explanations.

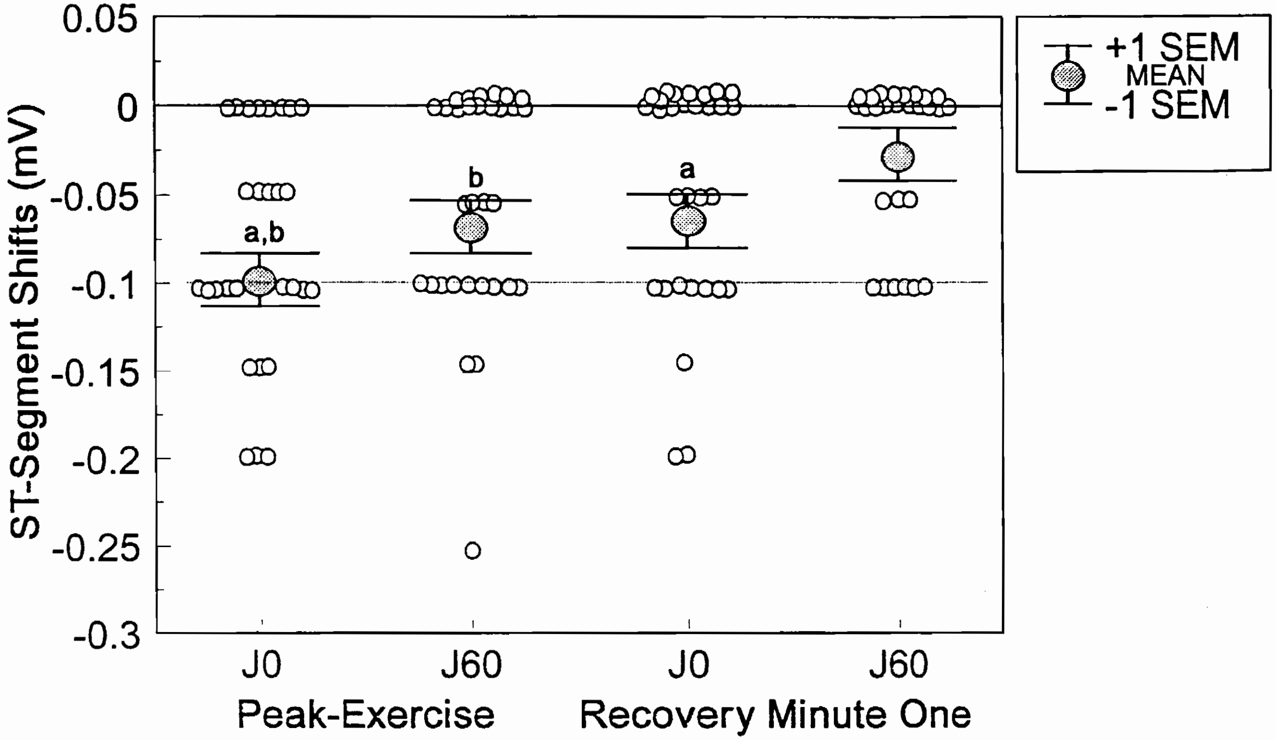

Figure 4: ST-Segment shifts in lead II for peak-exercise and recovery minute one recorded using the Mason-Likar ECG lead system in male patients undergoing graded exercise tests.

[a] denotes significant main effect for differences between time of J-point measurements.

[b] denotes significant main effect for ST-segment shifts recorded at peak-exercise vs. recovery minute one.

--- dashed line represents threshold for clinically abnormal ST depression. See Table 3 for further explanation.

Table I. Patient Characteristics	x ± SD or N	Percentage (%)
Age (yr; mean)	49.8 ± 10.8	
Height (cm)	180.2 ± 8.7	
Weight (kg)	92.7 ± 12.5	
History of MI	3	10
MI Q-waves present	3	10
Diabetes Mellitus	3	10
Tobacco use	9	30
Hypertension	15	50
Hyperlipidemia	9	30
Family History of CAD	18	60
History of Angina	20	68
Medications		
Beta Blockers	8	26
Calcium Channel Blockers	8	26
Nitrates	4	13
Antiarrhythmics	2	7
ACE Inhibitors	2	10
Resting (supine) ECG Measures		
Mason-Likar Lead System		
V_5 J_0	0.01 ± 0.07	
J_{60}	0.05 ± 0.05	
SII J_0	0.01 ± 0.05	
J_{60}	0.04 ± 0.05	
Standard Lead System		
V_5 J_0	-0.03 ± 0.05	
J_{60}	0.03 ± 0.04	
SII J_0	-0.01 ± 0.05	
J_{60}	0.02 ± 0.04	

Values presented are x ± SD or numbers and percentage of group with each characteristic. MI = myocardial infarction; CAD = coronary artery disease; V_5 = Precordial Lead V_5; SII = Frontal Lead II

Table II - Comparisons of Exercise-Induced ST-Segment Shifts According to ECG Lead System at Minute One of Recovery

		ML System		STD System		Mean	Percent
Lead	ΔST	Mean	(SE)	Mean	(SE)	Difference	Difference*
V5	ΔJ_0[a]	-0.07	(0.02)	-0.08	(0.02)	-0.01	+13
	ΔJ_{60}[a]	-0.03	(0.02)	-0.05	(0.02)	-0.02	+40
	ΔST	ML System[b]		STD System[b]			
SII	ΔJ_0[c]	-0.07	(0.01)	-0.03	(0.01)	-0.04	-133
	ΔJ_{60}[c]	-0.03	(0.01)	-0.01	(0.01)	-0.02	-200

[a] significant F ratio for main effect: time of ΔJx in lead V_5 ($F=5.65$;df=1;$p<0.05$).

[b] significant F ratio for main effect: ECG Electrode Placement in lead II ($F=4.63$;df=1;$p<0.05$).

[c] significant F ratio for main effect: time of ΔJx in lead II ($F=5.25$;df=1;$p<0.05$).

* Differences are Standard minus Mason-Likar Placements. Percent difference is expressed as percentage of standard.

Δ ST values are computed as the difference between J_x obtained at resting baseline vs. J_x obtained at immediate post-exercise in the same posture.

ML = Mason-Likar Lead System
STD = Standard Lead System
(SE) = Standard Error of the Mean
SII = Standard Frontal Lead II
V_5 = Precordial Lead V_5

Table III - Comparisons of ST-Segment Shifts at Peak-Exercise and Minute One of Recovery for Leads V5 and SII Using the Mason-Likar Lead System

Lead	ΔST	Peak-Exercise[a] Mean	(SE)	Minute One Recovery[a] Mean	(SE)	Mean Differences	Percent Difference*
V5	ΔJ_0[b]	-0.12	(0.02)	-0.06	(0.02)	-0.06	-100
	ΔJ_{60}[b]	-0.09	(0.02)	-0.03	(0.02)	-0.06	-200
	ΔST	Peak-Exercise[c]		Minute One Recovery[c]			
SII	ΔJ_0[d]	-0.10	(0.02)	-0.07	(0.02)	-0.03	-43
	ΔJ_{60}[d]	-0.07	(0.02)	-0.03	(0.02)	-0.04	-133

[a] significant F ratio for main effect: exercise measurement recorded in lead V_5 ($F=12.46; df=1; p<0.05$).
[b] significant F ratio for main effect: time of ΔJx in lead V_5 ($F=4.67; df=1; p<0.05$).
[c] significant F ratio for main effect: exercise measurement recorded in lead SII ($F=5.97; df=1; p<0.05$).
[d] significant F ratio for main effect: time of ΔJx in lead SII ($F=4.96; df=1; p<0.05$).
* Differences are immediate post-exercise minus peak-exercise measurements. Percent difference is expressed as percentage of immediate post-exercise measurement.
Δ ST values are computed as the difference between Jx obtained at resting baseline vs. Jx obtained at peak-exercise or immediate post-exercise in the same posture.
ML = Mason-Likar Lead System
STD = Standard Lead System
(SE) = Standard Error of the Mean
SII = Standard Frontal Lead II
V_5 = Precordial Lead V_5

Table IV. Chi-Square Analysis for the Change in the Number of Abnormal ST-Segment Shifts from Peak-Exercise to Minute One of Recovery According to ECG Lead System

ECG Lead	Source	Chi-Square	p
V_5	ML Peak-Exercise vs. ML Rec1	3.35	0.07
	ML Peak-Exercise vs. STD Rec1	1.36	0.24
SII	ML Peak-Exercise vs. ML Rec1	2.86	0.09
	ML Peak-Exercise vs. STD Rec 1	9.32	<0.05*

*P < 0.05
Abnormal ST depression = $\Delta J_{60} \geq 0.10$ mV
ML = Mason-Likar Lead System
STD = Standard Lead System
Rec1 = Minute one of recovery
SII = Frontal Lead II

Chapter IV

SUMMARY

Recent literature comparing the Mason-Likar to the standard electrode placement has implicated the Mason-Likar "modified" placement as a possible source of distortion in the supine resting position. However, none of the studies comparing different electrode placements have examined the possibility of distortion being produced by the Mason-Likar placement in the post-exercise ECG. The present investigation compared the Mason-Likar and standard electrode placements in both pre-exercise and post-exercise ECG recordings. It specifically examined the ST-segment shifts, J_0 and J_{60} before and after a submaximal bout of exercise. The main research question was to determine if ischemic changes are being lost with the evolution of the Mason-Likar lead system. The study was further designed to determine if ischemic changes are being lost in the early post-exercise phase of the exercise stress test. Specifically, to determine if changes observed in the early post-exercise measurements between electrode placements can be predicted to also occur at peak-exercise.

Thirty male subjects diagnosed at "high risk" for coronary artery disease (CAD), according to ACSM criteria, underwent a symptom-limited graded exercise test (SLGXT) or achieved 85% of the predicted maximum heart rate for the subject's age. ST_0 and ST_{60} were measured at base supine, base standing, peak-exercise, supine recovery at immediate post-exercise (IPE) or minute one, and minutes three and five in recovery. The measures were taken simultaneously for comparison between the electrode placements and recorded all phases except exercise. Only the Mason-Likar placement was recorded at peak-exercise, thus comparisons between electrode placements were not possible.

The present study found significant differences between electrode placements in the post-exercise ECG which could effect the interpretation of ischemic ST-segment shifts, depending on the ECG lead selected. Significant differences in the ST-segment shifts, J_0 and J_{60}, between lead systems for baseline vs. IPE in lead II suggest that the use of the standard electrode placement may be more appropriate for post-exercise ECG recordings. The difference in the ST-segment shift J_{60} in lead II when the standard is compared to the Mason-Likar lead system is -200%. Therefore, this finding suggests that there is a tendency for the Mason-Likar placement to produce more "false-positives" in lead II in post-exercise ECG measurements.

Also important was the significant difference found in ST-segment shifts, J_0 and J_{60}, in both leads II and V_5 when evaluating the ischemic response for the different ECG exercise measurements, peak-exercise vs. IPE, using the Mason-Likar lead system. The differences between measurement periods, IPE vs. peak-exercise, for ST-segment shifts in lead

V_5 are -100% and -200% for J_0 and J_{60}, respectively. This finding suggest that even though no significant differences were observed in the ST-segment shifts for baseline vs. IPE in lead V_5, significant differences could possibly be observed at peak-exercise.

To support these findings, the comparisons of the frequencies for clinically abnormal ST-segment shifts for peak-exercise using Mason-Likar vs. IPE using the standard electrode placement were also significant in lead II. The difference observed when comparing the ischemic response that is lost for IPE vs. peak-exercise using the Mason-Likar placement is -500%. This significant difference confirms the findings for the significant ST-segment shifts observed between electrode placements in lead II for baseline vs. IPE. These findings indicate that there may be a tendency toward more "false-positive" results when using the Mason-Likar electrode placement for post-exercise ECG recordings in lead II. No significant difference, however, was found for comparisons of the frequencies of clinically abnormal ST-segment shifts for peak-exercise vs. IPE using the Mason-Likar electrode placement for both exercise measurements in lead II. Also important, no significant differences were found for comparisons of the frequencies of clinically abnormal ST-segment shifts for peak-exercise vs. IPE using either the Mason-Likar or standard electrode placements at IPE in lead V_5. However, the results do suggest that there is a tendency toward more "false-negative" results in lead V_5 when using the Mason-Likar electrode placement for post-exercise ECG recordings. The differences observed between ECG electrode placements at IPE in lead V_5 were not significant, however, there is a reduction in the number of "true-positive" findings when using the Mason-Likar electrode placement.

Based on these results it is clear that the Mason-Likar placement may effect the interpretation of ischemic ST-segment shifts in lead II or in the inferior leads. However, the results are less conclusive for lead V_5, as significant ST-segment shifts may occur at peak-exercise when comparing the different electrode placements. Since the ultimate goal of electrocardiographic monitoring during exercise is to identify critical dysrhythmic or "ischemic" responses, these findings suggest that the Mason-Likar "modified" placement may not be the ultimate tool.

COMPARISONS TO OTHER STUDIES

The magnitude of change in axis, R-wave, and ST-segment shifts found in this study is similar to that seen in other studies comparing the Mason-Likar to the standard electrode placement. Although the post-exercise measures in this study cannot be compared to other studies it is possible to evaluate the supine and standing changes caused by the different electrode placements in the pre-exercise ECG. Gamble showed an average of 26 degrees of deviation to the right using the

Mason-Likar placement in the pre-exercise supine ECG when compared to the standard placement in 104 male patients with stable coronary heart disease.[3] Kleiner and co-workers compared ECG's gathered on 75 patients using the standard wrist and ankle placement to the Mason-Likar placement. Fifty of the 75 patients had a rightward axis shift of 30 degrees or more on the modified ECG compared to the standard.[4] These studies are in agreement with the mean 30 degree rightward axis shift found using the Mason-Likar placement in the present study.

The R-wave amplitude changes were also similar between studies. In the study by Gamble, the axis shift caused increased amplitudes in the R-waves in II, III, and aVf.[3] The same change occurred in the other studies as well as the present study, with an increase in the R-wave amplitude being observed in lead II with the Mason-Likar placement. No significant difference was observed for R-wave amplitude in lead V_5, which is consistent with other studies. In analyzing the measurements for standing-exercise, it was seen that mean axis measurements varied little compared to the standard, which is consistent with other studies. However, in the Gamble study, more clinical changes were observed in the standing posture, thus having the patient supine is recommended for the pre-exercise ECG when using the modified placement.[3] In the present study, clinical changes (such as loss or gain of significant Q-waves) were not observed most likely due to the healthier population used in this study.

The changes observed with the ST-segment shifts, J_0 and J_{60}, were also similar to other studies analyzing the different electrode placements in the pre-exercise ECG. The modification caused the ST slope to increase in both leads II and V_5 in the baseline ECG, which is consistent with other studies.

DISCUSSION

The present study demonstrates that the rightward axis shift and amplitude changes caused by the Mason-Likar placement in the pre-exercise ECG are also evident in the post-exercise ECG. Although the changes produced by the different electrode placements in the post-exercise ECG are merely artifacts, they could be very misleading. The significant differences found in the ST-segment shifts, J_0 and J_{60}, between electrode placements for baseline vs. IPE in lead II suggest that the use of the standard electrode placement may be more appropriate for post-exercise ECG recordings. The differences in the ST-segment shifts in lead II when the standard is compared to the Mason-Likar placement are -133% and -200% for J_0 and J_{60}, respectively. Although this finding does not invalidate the interpretation of ST-segment changes during or after exercise using the Mason-Likar placement in lead V_5, it does suggest that the Mason-Likar placement may cause distortion in lead II or in the inferior leads. More specifically, the findings for lead II suggest that the Mason-Likar placement may exaggerate the ischemic response, or produce more "false-positives" in the post-exercise ECG.

Studies comparing the Mason-Likar to the standard electrode placement suggest that the resting 12-lead recording arm and leg electrodes be moved to the wrists and ankles, with the patient in the supine position to establish a pre-exercise baseline ECG.[1] Research demonstrates that the Mason-Likar placement can lead to diagnostic changes in the pre-exercise ECG. However, post-exercise ST-segment shifts have not been studied and have important implications during the post-exercise period and will affect the visual interpretation of the ECG. In a study by Rautaharju, the Mason-Likar placement for the supine resting ECG caused the ST slope to flatten in aVL and increase in II, III, and aVF when compared to the standard placement.[7] It was suggested that the reduction of the ST slope and T wave amplitude in aVL could lead to an excessive finding of "ischemic" responses to a stress test in this lead, and the opposite phenomenon could be expected to take place in the inferior leads.[7]

The present study found the Mason-Likar "modified" placement for the supine resting ECG to cause the ST slope to increase in both leads II and V_5 when compared to the standard placement. These findings are consistent with the findings present in the study by Rautaurju for lead II. The increase in the ST slope caused by the modification was not only present in the pre-exercise ECG but persisted throughout recovery in both leads II and V_5, although it was not significant. Even though the modification caused the ST slope to increase in lead II, the modification did not obscure ischemic changes in the inferior leads as predicted by Rautaurju; conversely, the modification produced more "false-positive" findings in lead II at IPE. Furthermore, a greater number of "false-negative" findings in lead V_5 were observed using the Mason-Likar placement, although it was not significant.

The present investigation supports the idea that diagnostic changes caused by the Mason-Likar placement in the pre-exercise ECG may alter the assessment of ischemic responses found in the post-exercise ECG. Although none of the investigations have examined the possibility of changes occurring in the post-exercise using the Mason-Likar lead placement, research in this area support the possibility that it may occur.

RESEARCH IMPLICATIONS

The primary objective of this study was to evaluate if ischemia is being lost with the evolution of the Mason-Likar lead system. A secondary objective was to determine if ischemic changes are being lost in the early post-exercise phase of the exercise stress test. The differences in the exercise-induced ST-segment shifts observed between the Mason-

Likar and standard electrode placements suggest that electrode placement may influence the interpretation of ischemic ST-segment responses. Furthermore, because ischemic changes are lost from peak-exercise to IPE, a comparison of the different electrode placments at peak exercise needs to be examined to fully evaluate the magnitude of change between electrode placements. Also, lead V_5 could be examined more closely as being a possible source of distortion when evaluating ischemic ST-segment shifts at peak-exercise.

These data provide a framework for further research in order to determine if the standard electrode placement is superior to Mason-Likar for the evaluation of ischemic ST-segment responses. Electrode placement could have important implications when a test is borderline in its ischemic response and may affect the visual interpretation of the ECG. Since greater diagnostic changes are observed in heart disease patients when comparing the electrode placements, perhaps the changes observed in the post-exercise ECG may become more pronounced with a diseased population. If this were to be confirmed, the standard electrode placement may be more appropriate when evaluating ischemic ST-segment shifts, especially in the higher risk population. However, whether these changes are significant enough to alarm a cardiologist when evaluating an ischemic response in the post-exercise ECG remains to be determined.

RECOMMENDATIONS FOR FURTHER RESEARCH

In order to fully understand the significance of the ST-segment shifts observed from pre-exercise to post-exercise ECG tracings, further research is necessary. The following are suggestions for further research relating to the changes observed between the Mason-Likar and standard electrode placements, as well as the evaluation of ischemic ST-segment shifts.

1) Since research indicates that "diagnostic" changes are greater in diseased subjects rather than non-diseased subjects, it would be beneficial to repeat the present investigation using subjects diagnosed as having coronary artery disease (CAD). By comparing the magnitude of change found in diseased and non-diseased subjects, more information could be gathered regarding the possibility of distortion being caused by the Mason-Likar placement in post-exercise ECG tracings.

2) Another important question in the area of ECG changes caused by the modification is whether the ST-segment shifts observed between electrode placements at IPE are also present at peak exercise. The answer to this question could help to determine the importance of further study in the evaluation of ischemic ST-segment shifts. Therefore, it would be beneficial to evaluate the ST-segment shifts at peak exercise using the standard placement for comparison to the Mason-Likar

placement. A significant change is observed in the ST-segment shift for baseline vs. IPE in lead II when comparing the different electrode placements, which suggests that it may occur at peak exercise.

3) Another important area of investigation in order to determine the magnitude of change caused by the modification is to examine the effect of atrial repolarization in the inferior leads, which causes depression of the ST-segment. Since the inferior leads generally have more false-positive results, different criteria may be required for the evaluation of an ischemic response.

4) Furthermore, it is important to investigate the ST-segment shifts observed in a female population. By comparing the magnitude of decline found in female and male subjects, more information can be gathered regarding the possibility of changes caused by the modification. Also important is to determine whether the modification leads to more "diagnostic" changes in females, which could help to explain their unusually high number of false-positive results.

5) As a follow-up investigation, it would be beneficial to calculate the degree of exercise-induced ST depression that is influenced by R-wave amplitude in the inferior leads. In the present investigation the Mason-Likar placement caused the R-wave amplitude to increase in lead II. Therefore, the ST-segment shifts in lead II produced by the modification in this study may possibly be explained by an increase in the R-wave

amplitude. Since the inferior leads generally have more false-positive results, standardization of the R-wave amplitude may be necessary when evaluating an ischemic response.

6) Finally, because the Mason-Likar placement may lead to distortion when evaluating ischemic ST-segment shifts, a "wireless electrode" standard ECG lead sytem may be necessary for development. Thus, the electrodes could be placed on the ankles and wrists of the patient during the exercise stress test without artifact or distortion being produced by the Mason-Likar placement.

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FIGURES

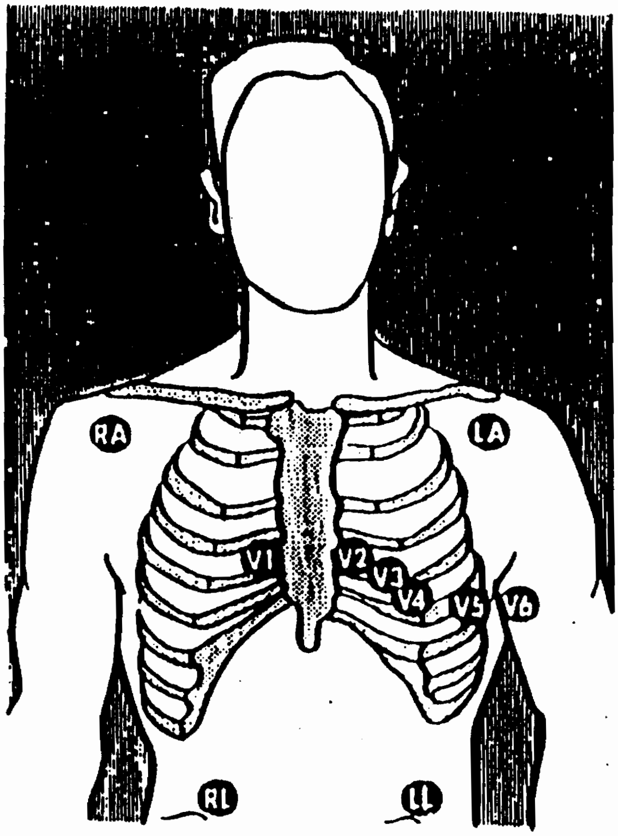
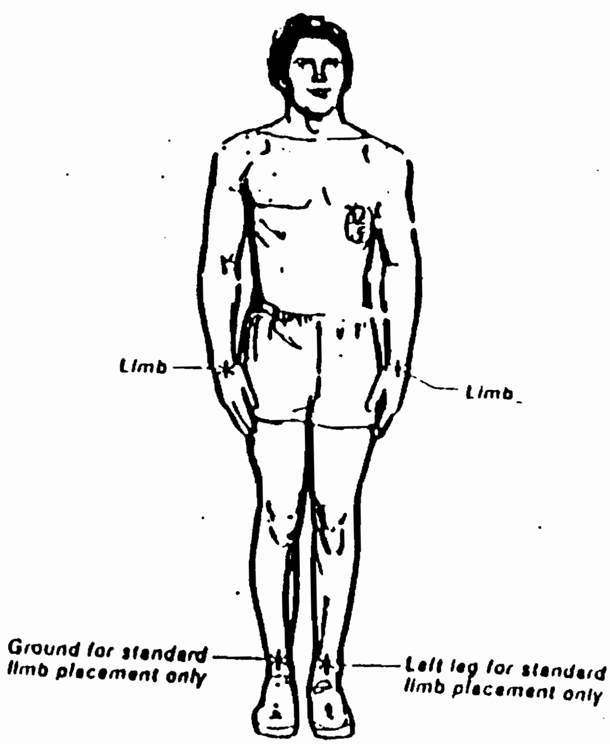


Figure 5. Mason-Likar simulated standard 12-lead ECG electrode placement for exercise testing.



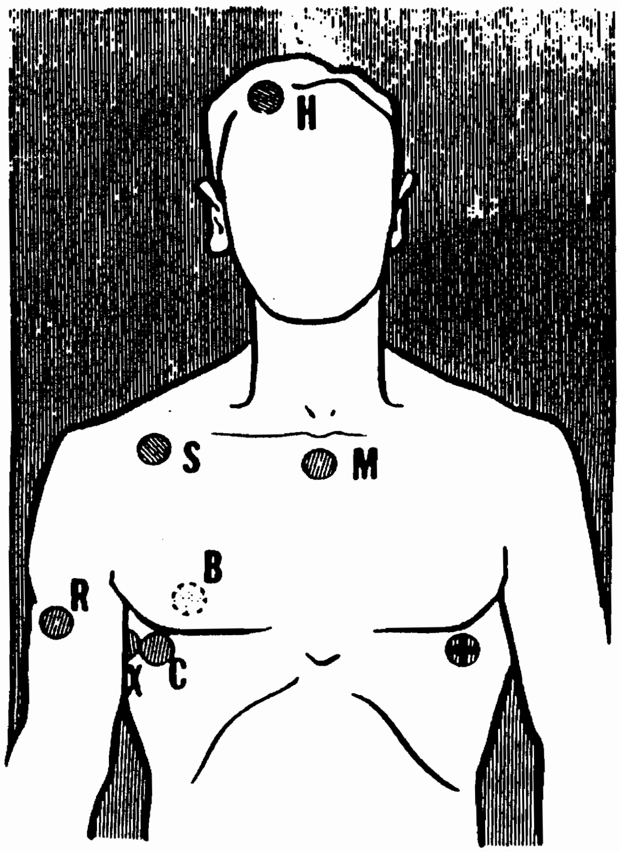
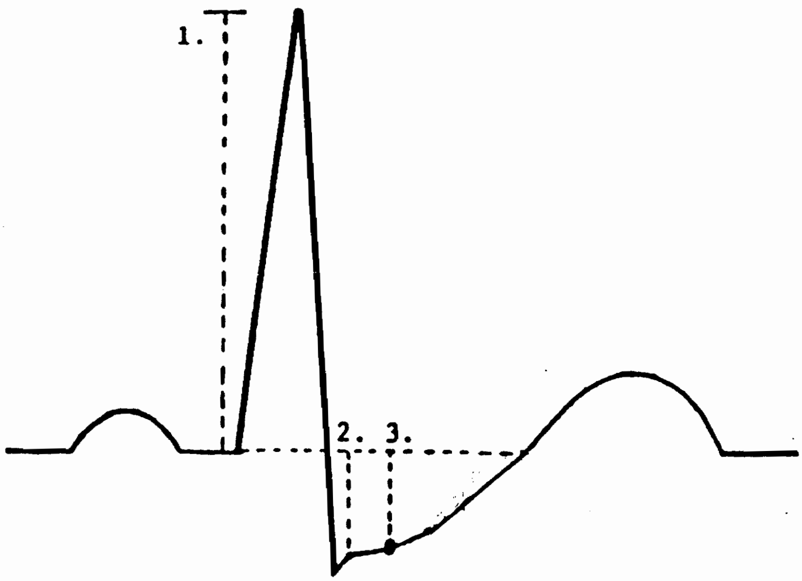


Figure 6. The common bipolar ECG leads used during exercise testing.



1. R-wave amplitude
2. J-point amplitude
3. S-T segment deviation @ 0.06 seconds

Figure 7. Method of ECG Measurement

TABLES

Table V. Inter-observer Reliablility in Leads V_5 and SII Using the Mason-Likar and Standard ECG Lead Systems.

			Observers		
ECG Lead	Measurement	Source	A vs. B	B vs. C	A vs. C
V_5	R-wave Amplitude	BL	0.996	0.997	0.996
		PE	0.988	0.994	0.996
		IPE	0.996	0.995	0.997
	ST_0	BL	0.974	0.953	0.975
		PE	0.947	0.899	0.936
		IPE	0.985	0.963	0.963
	ST_{60}	BL	0.960	0.913	0.914
		PE	0.918	0.952	0.951
		IPE	0.982	0.969	0.981
SII	R-wave Amplitude	BL	0.995	0.994	0.997
		PE	0.984	0.982	0.993
		IPE	0.990	0.998	0.995
	ST_0	BL	0.953	0.845	0.865
		PE	0.917	0.834	0.904
		IPE	0.985	0.907	0.921
	ST_{60}	BL	0.900	0.870	0.909
		PE	0.950	0.829	0.892
		IPE	0.966	0.909	0.928

*computed by Pearson Product-Moment Correlation (critical r at $p < .05$, df = 18, = .7545).
*Baseline(supine); Peak-Exercise(standing); IPE = Minute one of recovery (Supine);
BL = Baseline; PE = Peak-Exercise
SII = Frontal Lead II
V_5 = Precordial Lead V_5

Table VI. Analysis of Variance Between Measurement Periods Baseline and Minute One of Recovery for ST-Segment Shifts J_0 and J_{60} According to ECG Lead System

ECG Lead	Source	DF	Sum of Squares	Mean Square	F Ratio	p
V_5	ML vs. STD	1	0.0152	0.0152	1.72	0.19
	ΔJ_0 vs. ΔJ_{60}	1	0.0500	0.0500	5.67	0.02*
	Interactions	1	0.0047	0.0047	0.53	0.48
	Error	117	1.0374	0.0089		
	Total	119	1.0973			
SII	ML vs. STD	1	0.0200	0.0200	4.63	0.03*
	ΔJ_0 vs. ΔJ_{60}	1	0.0227	0.0227	5.25	0.02*
	Interactions	1	0.0035	0.0035	0.82	0.38
	Error	116	0.5013	0.0043		
	Total	119	0.5575			

*$P < 0.05$
ML = Mason-Likar Electrode Placement
STD = Standard Electrode Placement
SII = Frontal Lead II
V_5 = Precordial Lead V_5
See Table II for explanation of ΔJ_X values.

Table VII. Analysis of Variance Between Measurement Periods Peak Exercise and Minute One of Recovery for ST-Segment Shifts J_0 and J_{60} using the Mason-Likar Lead System

ECG Lead	Source	DF	Sum of Squares	Mean Square	F Ratio	p
V_5	PkEx vs. Rec1	1	0.0935	0.0935	12.46	<0.01*
	ΔJ_0 vs. ΔJ_{60}	1	0.0350	0.0350	4.67	0.03*
	Interactions	1	0.0010	0.0010	0.14	0.72
	Error	116	0.8704	0.0075		
	Total	119	0.9999			
SI I	PkEx vs. Rec1	1	0.0422	0.0422	5.97	0.02*
	ΔJ_0 vs. ΔJ_{60}	1	0.0350	0.0350	4.96	0.03*
	Interactions	1	0.0052	0.0052	0.07	0.79
	Error	116	0.8193	0.0071	Total	119
	Total	119	0.8970			

*$P < 0.05$
PkEx = Peak-Exercise (standing)
Rec1 = Minute One of Recovery (supine)
See Table III for explanation of ΔJ_X values.
SII = Frontal Lead II
V_5 = Precordial Lead V_5

Appendix A

METHODOLOGY

METHODOLOGY

Subjects

Thirty male subjects diagnosed at "high risk" for coronary artery disease (CAD) were used in this investigation. According to the Guidelines for Exercise Testing and Prescription (1991), individuals at high risk for CAD are those who have symptoms suggestive of possible cardiopulmonary or metabolic disease and/or two or more major coronary risk factors.[5] In order to qualify for participation in this study, individuals had to be taking the treadmill tests for clinical reasons, with informed consent and recommendation of their physician. In addition, ECG's with excessive motion artifact, baseline wander > 3 mm, bundle branch block, left ventricular hypertrophy, ventricular preexcitation, ventricular pacemaker, and ventricular tachycardia were excluded. The sample consisted of 50.0% hypertensives, 66.6% with angina symptoms, and the average age was 49.8 years. Other demographic and health status information, as well as medications, are presented in Table 1.

Insert Table 1 here

General Protocol

Prior to the treadmill test, each subject had simultaneous Mason-Likar and standard ECG supine and standing

ECG recordings using similar ECG recording machines. The measures obtained from each machine using the different electrode placements were compared prior to the onset of the study to account for any measure variance between the machines to allow for a more accurate study. The V_5 placement, which consisted of two trimmed electrodes adjacent to one another for comparison between the electrode placements, was also switched to a different machine following each test. The subject then underwent a symptom-limited graded exercise test (SLGXT) or achieved 85% of the predicted max heart rate for the subject's age. During the test, heart rate, blood pressure, RPE, and the electrocardiogram were monitored. A peak-exercise measure was taken immediately post-exercise (within 10 seconds of ending the test) using the Mason-Likar placement with the patient standing to avoid unneccessary artifact. The heart rate remained elevated, thus a peak heart-rate response was obtained. During the post-exercise period with the patient supine, the standard electrode placement was used for comparison to the Mason-Likar electrode placement at minutes one (IPE), three, and five in leads II and V_5.

ECG Measurements

The ST-segment measures ST_0 and ST_{60}, and the R-wave amplitudes in the supine and standing positions before and after a submaximal bout of exercise were measured while comparing the Mason-Likar electrode placement to the standard wrist and ankle electrode placement. Also to be examined were the axis shifts induced by the different electrode placements or by the switch from the supine to the standing position in the pre-exercise ECG. Figure 9 presents the ECG measurements analyzed in this study.

Insert Figure 9 here

ECG Measurement Procedure

The first measurements taken in this study were from the exercise test of 20 patients randomly chosen from a group of 30. The electrocardiograms chosen were selected to represent a sample. Each ECG was coded separately by three observers blinded from each others interpretation. The observers were master's level exercise physiology students with experience in reading ECG's. The observers read only the supine, peak exercise and immediate post-exercise measurements. All observers were trained in Minnesota Code (MC) procedures, which provided a standardized method of measuring the different waveforms. A ten-power, hand-held magnifying loop calibrated in tenths of a millimeter was also used to enhance measurement precision. The interobserver reliability coefficient was then calculated using Pearson's product-moment correlation and was found to be greater than .85 between observers in all phases of the measurements. Table IV presents the results for interobserver reliability.

Insert Table IV here

These findings allowed the researcher in this study, whom is also the main observer, to interpret the remaining ECG's with confidence in achieving definitive and clinically useful results. Refer to Appendix E for the raw data results obtained by the main observer for the ECG measurements used in this study. Refer to Appendix D for the measures and definitions of ECG change variables calculated from the raw data results by computer.

Statistics

A two-way ANOVA adjusted for repeated measures was performed for comparing the change in the ST-segment shifts, J_0 and J_{60}, attributable to ECG electrode placement or different ECG exercise measurements (peak-exercise vs. IPE) recorded during the exercise stress test. Also evaluated were the changes between time of J-point measures, J_0 and J_{60}. First, the change in the ST-segment shifts, J_0 and J_{60}, between electrode placements were compared for baseline vs. immediate post-exercise (IPE). Also evaluated were the changes between time of J-point measures, J_0 and J_{60}, for baseline vs. IPE. Refer to Table V for baseline vs. IPE ANOVA results.

Insert Table V here

Second, the change in the ST-segment shifts, J_0 and J_{60}, were compared for different ECG exercise measurements, peak exercise vs. immediate post-exercise (IPE) using only the Mason-Likar placement. Also evaluated were the changes between time of J-point measures, J_0 and J_{60}, for peak-exercise vs. IPE. Refer to Table VI for peak-exercise vs. IPE ANOVA results.

Insert Table VI here

The final analysis used a Chi-square to compare the change in the frequency of "abnormal" ST-segment shifts > than 1mm from peak exercise using Mason-Likar vs. IPE according to the ECG electrode placement used. Refer to Table VII for chi-square results.

Insert Table VII here

Pilot Study and Power Analysis

Prior to the collection of data, several trial runs of procedures and analysis of results were conducted to determine the most appropriate design of the study. A power analysis was also conducted to determine the appropriate number of subjects needed to increase the odds of rejecting a false null hypothesis.

The electrocardiogram (ECG) recording machines used in this study, the Quinton 2000 and 4500, were compared for differences in ECG responses prior to the onset of this study. There were no differences found in the ECG responses between recording machines. One healthy subject and one subject at high risk for coronary artery disease (CAD) were tested to determine differences between populations for ECG responses using the Mason-Likar or standard ECG lead system. Differences in ECG responses between lead systems was greater when using the patient at high risk for CAD. Therefore, the population chosen for this study were subjects at high risk for CAD. Several studies also support greater changes between lead systems for ECG responses when using high risk subjects.

Thirty subjects were used in this study. The treatments compared in this study, the Mason-Likar and standard lead system exercise-induced ECG responses, increased the difference between the means to allow for clinically significant results.

Appendix B

INFORMED CONSENT

MONTGOMERY REGIONAL HOSPITAL
CARDIOLOGY SERVICES DEPARTMENT
CONSENT FOR EXERCISE TEST

A Stress Test is a non-invasive test which evaluates the function of your heart and circulation.

Prior to the Stress Test, you will be prepared for the procedure by shaving and prepping the skin. Ten electrodes will be placed on your chest and upper abdomen. These electrode will be connected to wires which will monitor your heart. Electrocardiograms and your blood pressure will be obtained prior to the start of the test.

Once you are on the treadmill, you will be walking at a certain speed and grade. Every two to three minutes the speed and/or grade will change, making the workload harder. Your heart rate and rhythm will constantly be monitored and displayed. Your blood pressure will be checked periodically throughout the test.

During the Stress Test, a physician and/or his/her assistant will monitor your pulse, blood pressure, and electrocardiogram. During the test you can expect your heart rate and blood pressure to increase, however, there exists the possibility of certain changes occurring during the Stress Test. These may include a heart rate which is too fast or slow, abnormal blood pressure response to exercise, and in rare instances, heart attack.

Every effort will be made to minimize these problems through the preliminary examination and monitoring during the test. There is emergency medical equipment readily available should the need arise.

The information obtained from this test is confidential and will not be released without your expressed written consent. Your right of privacy will be retained if the information is used for scientific or statistical purposes.

I have read the Consent Form and any questions that I may have had have been answered to my satisfaction.

Patient Signature:________________________________ Date:____________________

Witness Signature:________________________________ Date:____________________

Physician Signature:______________________________ Date:____________________

Appendix C

ECG VISUAL ANALYSIS PLAN

ECG Visual Analysis Plan: (Based on Minnesota Code)

1. For each subject there are 10 tracings analyzed, five for the Standard placement and five for the Mason-Likar placement. The tracings selected are pre-exercise supine and standing, and post-exercise minutes one, three and five. A comparison will also be made at peak exercise and minute one in recovery using only the Mason-Likar placement.

2. A magnifying instrument will be used to enhance the visual interpretation capabilities.

3. The leads selected for ST_0, ST_{60} and R-wave analysis will be leads II and V_5. The magnifying instrument will be turned vertically for R-wave analysis.

4. The axis determination for each tracing will be calculated from the leads in which the QRS is most biphasic and will be comfirmed by the tallest R-wave which will point at 90 degrees (right angles) to the biphasic QRS.

5. Measurements will be made on ECG complexes with flat baselines and no artifact that could distort the signal.

6. Visual analysis should be made on the next to last "clean" complex in leads II and V_5 for the resting ECG. However, visual analysis for peak-exercise should be made on two consecutive complexes with a similar configuration within leads II and V_5 and the average raw signal measurement recorded.

7. The PR segment at the start of the Q-wave will define the isoelectric line from which ST segment measurements will be made.

8. The ST60 measurement will be taken 60 milliseconds after the J point (one small box and a half).

9. The ST segment deviation will be measured to the nearest accuracy as the measurement tool allows (.05 mV).

10. The measures will be recorded in millivolts (mV). Note: 1.0 mm = 0.01 mV.

11. A plus or minus sign will be used to denote direction since the measurements represent change from the isoelectric line.

12. Each of the three observers will recieve a seperate recording sheet and the average for each measurement will be calculated for the final data analysis.

13. The complexes to be measured will be marked to allow for an accurate comparison between observers.

14. A limitation of the visual analysis is that the observer is forced to choose adjacent complexes with a similar configuration which may not coincide with the same heart in both leads II and V5.

Appendix D

MEASURES AND DEFINITIONS FOR COMPUTER DATA CODING

Measures and Definitions for Computer Data Coding:

Identification Number (ID) -- Each subject was given a four-digit identification number referring to the last four digits of the subject's SSN.

Age (AGE) -- The actual age in years at the time of the initial GXT was recorded for each subject.

Weight (WT) -- The actual weight in kilograms at the time of the initial GXT was recorded for each subject.

Height (HT) -- The actual height in centimeters was recorded for each subject.

History of MI (HXMI) -- Each subject was categorized as either having a history of MI = 1 or no history of MI = 0.

MI Q-waves (MIQW) -- Each subject was categorized as either having two or more Q-waves = 1 or as having no Q-waves = 0.

Diabetes Mellitus (DM) -- Each subject was categorized as either diabetic = 1 or non-diabetic = 0.

Tobacco use (TOB) -- Each subject was categorized as a tobacco user = 1 or non-tobacco user = 0.

Hypertension (HTN) -- Each subject was categorized as either being hypertensive = 1 or non-hypertensive = 0.

Hyperlipidemia (CHOL) -- Each subject was categorized as either having high cholesterol > 200 = 1 or < 200 = 0.

Family History (FAHX) -- Each subject was categorized as having a positive family history of coronary artery disease (CAD) = 1 or no history of CAD = 0.

History of chest pain (HXCP) -- Each subject was categorized as having typical angina = 1, atypical angina = 2, or no angina = 0.

Chest pain during test (DAP) -- Each subject was categorized as having test angina = 1, test angina causing termination of test = 2, or no test angina = 0.

ST-segment abnormals (STAB) -- Each subject was categorized as either having an ST-segment shift > 1 mm = 1 or < 1 mm = 0.

Test results (TR) -- Each subject was categorized as either having positive for CAD test results = 1 or negative = 0.

ECG MEASUREMENTS -- Electrocardiographic recordings were evaluated as previously described within one-half millimeter. All tracings were evaluated using the next to last complex for resting measurements and two complexes for the peak-exercise measurement. The ECG changes were evaluated by computer using the following commands:

```
M5zsprc1 = Mrc5z1 - Msp5z
S5zsprc1 = Src5z1 - Ssp5z
M5ssprc1 = Mrc5s1 - Msp5s
S5ssprc1 = Src5s1 - Ssp5s
M2zsprc1 = Mrc2z1 - Msp2z
S2zsprc1 = Src2z1 - Ssp2z
M2ssprc1 = Mrc2s1 - Msp2s
S2ssprc1 = Src2s1 - Ssp2s
M5zsdmx  = Mmx5z  - Msd5z
```

S5zsdmx = Smx5z - Ssd5z

M5ssdmx = Mmx5s - Msd5s

S5ssdmx = Smx5s - Ssd5s

M2zsdmx = Mmx2z - Msd2z

S2zsdmx = Smx2z - Ssd2z

M2ssdmx = Mmx2s - Msd2s

S2ssdmx = Smx2s - Ssd2s,

where, M5zsprc1 represents the following: M = Mason-Likar, 5 = Lead V_5, z = ST_0, sp = supine, rc = recovery, and 1 = recovery minute one. Mrc5z1 represents the following: M = Mason-Likar, rc = recovery, 5 = Lead V_5, z = ST0, and 1 = recovery minute one. Msp5z represents the following: M = Mason-Likar, sp = supine, 5 = Lead V_5, and z = ST_0. Therefore, M5zsprc1 represents the change in lead V_5 at ST_0 recovery minute one using the Mason-Likar lead system minus the measurements recorded for lead V_5 at ST_0 at baseline supine using Mason-Likar. The other ECG changes are defined accordingly except S = Standard lead system, 2 = Lead II, sd = standing, mx = peak-exercise, and s = ST_{60}.

<u>MEDICATIONS</u> -- Each subject's file was reviewed for use of any medications. Each of the medication categories (Beta blockers, Calcium blockers, Nitrates, Digoxin, Antiarrhythmics, and ACE inhibitors) were evaluated in relation to the information obtained from the file records.

Usage of any medication in each category was recorded as presence = 1; while nonusage of any medication in each category was recorded as absence = 0.

Appendix E

RAW DATA

Mason-Likar vs. Standard Lead System at J_0 in Lead V_5

Subject	Base-Supine ML	Base-Supine STD	Base-Standing ML	Base-Standing STD	Peak-Exercise ML
1	-0.05	0.00	0.00	-0.05	-0.10
2	0.00	-0.05	0.00	-0.05	-0.05
3	0.00	0.00	0.00	-0.10	-0.10
4	-0.15	-0.10	-0.10	-0.15	-0.25
5	0.00	-0.05	0.00	-0.05	-0.15
6	0.00	-0.05	0.00	0.00	-0.30
7	0.00	-0.05	0.00	-0.05	-0.20
8	0.00	-0.10	0.00	-0.10	-0.15
9	0.00	-0.05	0.00	0.00	-0.05
10	0.05	0.00	0.05	0.00	-0.05
11	0.00	0.00	0.05	0.00	-0.20
12	0.05	0.00	0.05	0.00	-0.20
13	0.05	0.00	0.05	-0.05	-0.05
14	0.05	0.00	0.05	0.05	-0.10
15	0.00	0.00	0.00	0.00	0.05
16	0.00	0.00	0.05	0.00	-0.10
17	-0.05	-0.10	0.00	0.00	-0.05
18	0.00	-0.05	0.00	-0.10	0.00
19	0.00	0.00	0.00	0.00	-0.15
20	-0.05	-0.10	-0.05	-0.10	-0.10
21	0.05	0.00	0.05	0.00	0.00
22	0.10	0.10	0.05	0.05	-0.10
23	0.00	0.00	0.05	0.05	-0.20
24	0.00	-0.05	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00
26	0.10	0.00	0.10	0.00	0.00
27	0.00	0.00	0.00	0.00	-0.15
28	0.00	-0.05	0.00	-0.05	-0.10
29	0.05	0.00	0.05	0.05	-0.20
30	0.00	-0.10	0.00	-0.10	0.00

Mason-Likar vs. Standard Lead System at J_0 in Lead V_5

Subject	Post 1 ML	Post 1 STD	Post 3 ML	Post 3 STD	Post 5 ML	Post 5 STD
1	-0.10	-0.10	-0.10	-0.15	-0.10	-0.15
2	-0.05	-0.10	-0.05	-0.05	-0.05	-0.15
3	-0.05	-0.05	0.00	-0.10	0.00	-0.05
4	-0.40	-0.50	-0.40	-0.50	-0.30	-0.40
5	-0.15	-0.15	-0.10	-0.20	-0.05	-0.10
6	-0.20	-0.20	-0.10	-0.25	-0.10	-0.10
7	-0.10	-0.15	-0.10	-0.15	-0.05	-0.15
8	0.00	-0.15	-0.05	-0.15	-0.05	-0.10
9	-0.05	0.00	0.00	-0.15	0.00	-0.15
10	0.00	-0.05	0.00	0.00	0.00	-0.05
11	-0.05	-0.25	-0.10	-0.20	-0.10	-0.15
12	-0.05	-0.05	-0.10	-0.15	-0.05	-0.10
13	0.00	-0.10	0.00	-0.10	0.00	-0.05
14	0.00	-0.10	0.00	0.00	0.00	-0.05
15	-0.05	0.00	0.00	-0.10	-0.05	0.00
16	0.00	-0.10	0.00	0.00	0.00	0.00
17	-0.10	-0.05	0.00	-0.10	0.00	-0.05
18	0.00	-0.05	0.00	-0.05	0.00	-0.05
19	-0.10	-0.15	-0.05	0.00	0.00	0.00
20	-0.05	-0.10	-0.05	-0.10	0.00	-0.10
21	0.00	0.00	0.00	0.00	0.00	0.00
22	-0.05	-0.10	0.00	-0.05	0.00	0.00
23	-0.10	-0.10	-0.10	-0.10	-0.05	-0.05
24	0.00	0.00	0.00	0.00	0.00	-0.05
25	0.00	-0.10	0.00	-0.10	0.00	-0.10
26	0.00	-0.10	0.00	-0.10	0.00	0.00
27	-0.05	-0.10	0.00	-0.05	0.00	-0.05
28	0.00	-0.05	0.00	-0.10	0.00	0.05
29	-0.15	-0.15	-0.10	-0.10	0.00	-0.05
30	0.05	0.00	0.10	0.00	0.10	0.00

Mason-Likar vs. Standard Lead System at J_{60} in Lead V_5

Subject	Base-Supine		Base-Standing		Peak-Exercise		
	ML	STD	ML	STD	ML	ST	Ab
1	0.00	0.00	0.00	0.00	-0.05	-0.05	
2	0.10	0.05	0.10	0.00	0.10	0.00	
3	0.05	0.00	0.05	0.05	-0.05	-0.05	
4	-0.10	-0.10	-0.10	-0.10	-0.25	-0.25	+
5	0.00	0.00	0.05	0.00	-0.10	-0.10	+
6	0.00	0.00	0.00	0.00	-0.35	-0.35	+
7	0.00	0.00	0.00	0.05	-0.20	-0.20	+
8	0.05	0.00	0.05	-0.05	-0.10	-0.10	+
9	0.00	0.05	0.05	0.05	0.05	0.00	
10	0.10	0.05	0.10	0.10	0.05	0.00	
11	0.05	0.05	0.05	0.05	-0.10	-0.10	+
12	0.05	0.05	0.05	0.00	-0.05	-0.05	
13	0.05	0.05	0.05	0.05	0.05	0.00	
14	0.15	0.10	0.10	0.10	0.00	0.00	
15	0.05	0.05	0.10	0.10	0.10	0.00	
16	0.05	0.05	0.10	0.00	0.00	0.00	
17	0.05	0.00	0.00	0.00	-0.05	-0.05	
18	0.00	0.00	0.00	-0.10	0.00	0.00	
19	0.00	0.00	0.05	0.05	-0.15	-0.15	+
20	0.00	-0.05	-0.05	-0.10	-0.10	-0.05	
21	0.10	0.10	0.10	0.05	0.15	0.00	
22	0.10	0.10	0.05	0.05	-0.05	-0.05	
23	0.05	0.05	0.10	0.05	-0.15	-0.15	+
24	0.00	0.00	0.05	0.05	0.05	0.00	
25	0.10	0.05	0.15	0.05	0.15	0.00	
26	0.15	0.10	0.20	0.05	0.10	0.00	
27	0.00	0.05	0.05	0.00	0.00	0.00	
28	0.05	0.00	0.05	0.00	0.00	0.00	
29	0.10	0.05	0.15	0.10	-0.10	-0.10	+
30	0.00	-0.05	0.00	-0.05	0.10	0.00	

ST values are computed as the difference between J_{60} obtained at baseline-standing vs. J_{60} obtained at peak-exercise upright using the Mason-Likar lead system (ML). ST-segment elevation was ignored when computing ST-segment shifts from baseline.

AB represents clinically abnormal ST-segment shifts (> 1 mV) identified with a positive (+) symbol.

(SE) = Standard Error of the Mean

Average ST (SE) = -0.09 (0.02) with ML at Peak-Exercise

Mason-Likar vs. Standard Lead System at J_{60} in Lead V_5

Subject			Post 1				Post 3		Post 5	
	ST	AB	ML	STD	ST	Ab	ML	STD	ML	STD
1	-0.10	+	-0.10	-0.10	-0.10	+	-0.15	-0.20	-0.15	0.20
2	0.00		0.10	0.00	0.00		0.05	0.00	0.05	0.00
3	0.00		0.00	0.00	0.00		0.05	0.00	0.00	0.00
4	-0.30	+	-0.40	-0.50	-0.40	+	-0.45	-0.55	-0.35	-0.45
5	0.00		0.05	0.00	0.00		0.00	-0.10	0.00	-0.05
6	-0.15	+	-0.15	-0.25	-0.25	+	-0.15	-0.30	-0.10	-0.15
7	0.00		0.00	0.00	0.00		0.00	-0.05	0.00	-0.05
8	0.00		0.10	0.00	0.00		0.00	0.00	0.00	-0.05
9	0.00		0.15	0.10	0.00		0.10	0.00	0.10	0.00
10	0.00		0.10	0.00	0.00		0.05	0.05	0.05	0.05
11	-0.10	+	-0.10	-0.20	-0.15	+	-0.05	-0.15	-0.05	-0.10
12	0.00		0.00	-0.05	-0.05		-0.10	-0.10	-0.05	-0.10
13	0.00		0.05	0.05	0.00		0.00	0.00	0.00	0.00
14	0.00		0.15	0.05	0.00		0.10	0.10	0.05	0.00
15	0.00		0.15	0.15	0.00		0.05	0.05	0.05	0.05
16	0.00		0.10	0.00	0.00		0.05	0.05	0.05	0.05
17	0.00		0.05	0.05	0.00		0.00	-0.05	0.00	0.00
18	0.00		0.00	-0.05	-0.05		0.00	-0.05	0.00	-0.05
19	0.00		0.00	-0.10	-0.10	+	0.00	0.05	0.00	0.00
20	-0.05		-0.05	-0.10	-0.05		-0.05	-0.10	0.00	-0.10
21	0.00		0.15	0.15	0.00		0.05	0.05	0.00	-0.05
22	0.00		0.00	-0.05	-0.05		0.00	-0.05	0.00	0.00
23	-0.05		-0.05	-0.05	-0.05		-0.05	-0.05	0.05	-0.05
24	0.00		0.10	0.10	0.00		0.10	0.05	0.00	0.00
25	0.00		0.10	0.00	0.00		0.10	0.00	0.05	0.00
26	0.00		0.15	0.05	0.00		0.10	0.00	0.10	0.05
27	0.00		0.05	-0.05	-0.05		0.00	0.00	0.00	0.00
28	0.00		0.10	0.05	0.05		0.10	0.00	0.05	0.00
29	0.00		0.00	0.00	0.00		-0.05	0.00	0.00	-0.05
30	0.00		0.10	0.10	0.00		0.20	0.10	0.20	0.10

ST values are computed as the difference between J_{60} obtained at baseline-supine vs. J_{60} obtained at recovery minute one supine using the Mason-Likar (ML) or Standard (STD) lead system.

Average ST (SE) = -0.03 (0.02) with ML at recovery minute one
Average ST (SE) = -0.05 (0.02) with STD at recovery minute one

Mason-Likar vs. Standard Lead System at J_0 in Lead II

Subject	Base-Supine		Base-Standing		Peak-Exercise
	ML	STD	ML	STD	ML
1	0.00	0.00	0.00	0.00	0.15
2	0.00	-0.10	0.00	-0.05	-0.15
3	0.05	0.00	0.00	0.00	-0.15
4	-0.15	-0.10	-0.10	-0.10	-0.20
5	0.05	0.05	0.05	0.00	-0.10
6	0.00	-0.05	0.05	-0.05	-0.15
7	0.00	0.00	0.00	0.00	-0.20
8	0.00	0.00	0.00	0.00	-0.20
9	0.00	0.00	0.00	0.00	-0.05
10	0.10	0.10	0.10	0.10	-0.05
11	0.00	-0.05	0.05	0.00	-0.10
12	0.05	0.00	0.00	0.00	-0.10
13	0.05	0.00	0.05	0.00	-0.10
14	0.05	0.10	0.10	0.10	-0.05
15	0.00	0.00	0.00	0.00	0.00
16	0.05	-0.05	0.05	0.00	0.00
17	0.00	-0.05	-0.10	-0.05	-0.20
18	0.00	-0.05	0.00	0.05	0.00
19	0.05	0.00	0.05	0.00	-0.20
20	-0.05	0.00	-0.10	-0.05	-0.15
21	0.05	0.05	0.05	0.05	0.00
22	0.05	0.05	0.05	0.05	-0.05
23	0.00	0.05	0.10	0.05	-0.10
24	-0.05	-0.10	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00
26	0.10	0.00	0.10	0.00	0.00
27	0.00	0.00	0.00	0.00	-0.10
28	0.00	0.00	0.00	0.00	-0.10
29	0.00	0.00	0.05	0.00	-0.10
30	0.00	0.00	0.00	0.00	0.05

Mason-Likar vs. Standard Lead System at J_0 in Lead II

Subject	Post 1 ML	Post 1 STD	Post 3 ML	Post 3 STD	Post 5 ML	Post 5 STD
1	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10
2	-0.10	-0.05	-0.10	-0.10	-0.05	-0.10
3	-0.05	-0.05	0.00	-0.05	0.00	-0.05
4	-0.10	-0.05	-0.15	-0.10	-0.20	-0.10
5	-0.10	0.00	-0.05	0.00	0.00	0.00
6	-0.20	-0.10	-0.10	-0.05	-0.10	-0.05
7	-0.10	-0.10	-0.10	-0.10	-0.05	-0.05
8	-0.15	0.00	-0.10	-0.05	-0.10	0.00
9	0.00	0.00	-0.05	0.00	0.00	0.00
10	-0.05	0.00	0.00	0.00	0.00	0.05
11	-0.20	-0.10	-0.10	-0.10	-0.15	-0.10
12	0.00	-0.05	-0.10	-0.10	-0.05	0.00
13	-0.05	-0.05	-0.05	-0.05	0.00	0.00
14	-0.10	0.00	0.00	0.05	0.00	0.05
15	0.00	0.00	0.00	0.05	0.00	0.00
16	0.00	-0.10	-0.10	-0.10	0.00	0.00
17	0.00	-0.05	0.00	-0.10	0.00	-0.05
18	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	-0.10	0.00	0.00	0.00	0.00
20	-0.05	0.05	-0.05	0.00	0.00	0.00
21	0.00	0.05	0.00	0.05	0.00	0.05
22	-0.10	-0.05	0.00	0.00	0.00	0.00
23	0.00	0.00	-0.05	0.00	-0.05	-0.05
24	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	-0.05	0.00	-0.05
26	0.00	0.00	0.00	0.00	0.00	0.00
27	-0.05	-0.05	0.00	-0.05	0.00	0.00
28	0.00	0.00	0.00	-0.05	0.00	0.00
29	-0.10	-0.10	-0.10	-0.15	-0.05	-0.05
30	0.05	0.00	0.00	0.00	0.00	0.00

Mason-Likar vs. Standard Lead System at J_{60} in Lead II

Subject	Base-Supine		Base-Standing		Peak-Exercise		
	ML	STD	ML	STD	ML	ST	AB
1	0.00	0.00	0.00	0.00	-0.10	0.10	+
2	0.05	0.05	0.05	0.00	-0.10	-0.10	+
3	0.05	0.00	0.00	0.00	0.00	0.00	
4	-0.10	-0.10	-0.10	-0.10	-0.20	0.10	+
5	0.10	0.05	0.10	0.00	-0.05	-0.05	
6	0.00	0.00	0.05	0.00	-0.10	-0.10	+
7	0.00	0.00	0.00	0.05	-0.15	-0.15	+
8	0.00	0.00	0.00	0.00	-0.15	-0.15	+
9	0.00	0.00	0.00	0.00	0.05	0.00	
10	0.10	0.10	0.10	0.10	0.00	0.00	
11	0.00	0.00	0.05	0.00	-0.05	-0.05	
12	0.05	0.00	0.00	0.00	0.00	0.00	
13	0.05	0.05	0.05	0.00	-0.10	-0.10	+
14	0.05	0.10	0.10	0.10	0.00	0.00	
15	0.05	0.00	0.00	0.00	0.05	0.00	
16	0.10	0.00	0.10	0.05	0.10	0.00	
17	0.05	0.00	-0.05	0.00	-0.10	-0.05	
18	0.00	0.00	0.00	0.05	0.00	0.00	
19	0.05	0.00	0.05	0.00	-0.25	-0.20	+
20	-0.05	0.00	-0.15	-0.05	0.00	0.00	
21	0.05	0.05	0.05	0.05	0.10	0.00	
22	0.10	0.05	0.05	0.10	-0.05	-0.05	
23	0.05	0.05	0.10	0.05	-0.10	-0.10	+
24	0.00	-0.05	0.05	0.00	0.00	0.00	
25	0.10	0.05	0.10	0.05	0.10	0.00	
26	0.20	0.15	0.10	0.05	0.10	0.00	
27	0.00	0.00	0.00	0.00	-0.10	-0.10	+
28	0.05	0.05	0.05	0.05	0.00	0.00	
29	0.05	0.05	0.10	0.05	-0.10	-0.10	+
30	0.00	0.00	0.00	0.00	0.10	0.00	

Average ST (SE) = -0.07 (0.02) with ML at peak-exercise

Mason-Likar vs. Standard Lead System at J_{60} in Lead II

Subject			Post 1				Post 3		Post 5	
	ST	AB	ML	STD	ST	AB	ML	STD	ML	STD
1	-0.10	+	-0.10	-0.10	-0.10	+	-0.15	-0.10	0.15	-0.10
2	0.00		0.00	0.00	-0.05		0.00	-0.05	0.00	0.05
3	0.00		0.00	0.00	0.00		0.10	0.00	0.05	0.00
4	-0.10	+	-0.20	-0.15	-0.05		-0.15	-0.10	-0.20	-0.10
5	-0.05		-0.05	0.00	-0.05		-0.05	0.00	0.00	0.00
6	-0.10	+	-0.10	0.00	0.00		-0.10	-0.05	-0.10	-0.05
7	0.00		0.00	0.00	0.00		0.00	-0.05	0.00	0.00
8	0.00		0.00	0.00	0.00		-0.10	-0.05	-0.10	0.00
9	0.00		0.00	0.00	0.00		0.05	0.00	0.00	0.00
10	0.00		0.00	0.00	0.00		0.00	0.00	0.05	0.05
11	-0.10	+	-0.10	-0.05	-0.05		-0.10	-0.05	-0.10	-0.05
12	-0.05		-0.05	0.00	0.00		-0.05	-0.10	-0.05	0.00
13	0.00		0.05	0.00	-0.05		0.05	0.00	0.00	0.05
14	0.00		0.00	0.00	0.00		0.00	0.05	0.05	0.05
15	0.00		0.05	0.05	0.05		0.00	0.05	0.00	0.05
16	0.00		0.10	0.00	0.00		0.05	0.00	0.05	0.05
17	0.00		0.10	0.00	0.00		0.05	-0.10	0.00	0.00
18	0.00		0.00	0.00	0.00		0.00	0.00	0.00	0.00
19	0.00		0.05	0.00	0.00		0.05	0.00	0.00	0.00
20	-0.05		-0.10	0.00	0.00		-0.05	-0.05	-0.05	0.00
21	0.00		0.15	0.05	0.00		0.05	0.05	0.00	0.05
22	-0.10	+	-0.10	-0.05	-0.05		0.00	0.00	0.00	0.00
23	0.00		0.05	0.00	0.00		0.00	0.00	-0.05	-0.05
24	0.00		0.10	0.10	0.00		0.10	0.10	0.05	0.05
25	0.00		0.15	0.10	0.00		0.05	0.00	0.05	0.00
26	0.00		0.10	0.10	0.00		0.10	0.05	0.10	0.10
27	0.00		0.05	0.00	0.00		0.00	0.00	0.00	0.00
28	0.00		0.10	0.10	0.00		0.10	0.00	0.05	0.00
29	0.00		0.00	0.05	0.00		0.00	0.00	-0.05	-0.05
30	0.00		0.10	0.10	0.00		0.10	0.10	0.10	0.10

Average ST (SE) = -0.03 (0.01) with ML at recovery minute one
Average ST (SE) = -0.01 (0.01) with STD at recovery minute one

Mason-Likar vs. Standard Lead System for R-wave Amplitude in Lead V_5

Subject	Base-Supine ML	Base-Supine STD	Base-Standing ML	Base-Standing STD	Peak-Exercise ML
1	11.0	10.0	7.5	8.0	8.5
2	12.0	10.0	11.0	10.0	14.5
3	7.0	7.0	5.0	4.0	6.5
4	26.5	21.0	25.0	20.0	23.0
5	17.0	17.0	17.5	16.0	12.0
6	24.5	17.0	16.0	19.0	23.0
7	16.5	17.0	16.5	17.0	15.0
8	21.0	21.0	19.0	19.0	20.5
9	18.0	19.0	21.0	22.0	18.0
10	9.5	7.0	7.0	5.0	7.0
11	12.5	11.5	10.0	6.5	6.5
12	17.5	17.5	17.0	19.0	19.5
13	11.0	12.0	9.5	9.0	11.0
14	15.5	19.0	16.0	16.0	15.0
15	6.0	7.5	9.0	6.5	10.5
16	18.5	17.5	14.0	17.0	19.5
17	11.0	13.5	10.0	12.0	10.0
18	11.0	11.5	12.0	13.0	13.5
19	16.0	15.0	8.0	8.0	14.0
20	11.0	12.0	17.0	16.0	18.0
21	16.0	17.0	14.0	12.0	14.5
22	18.0	19.0	16.0	17.0	16.5
23	17.0	17.0	17.0	19.0	16.0
24	6.0	2.5	1.5	1.0	8.0
25	17.0	17.0	16.5	18.0	13.0
26	21.0	22.0	23.0	21.0	24.0
27	20.0	19.0	14.0	17.0	17.0
28	13.0	13.0	11.0	13.0	11.0
29	17.0	19.0	17.0	15.0	12.0
30	3.5	4.0	2.0	2.0	5.0

Mason-Likar vs. Standard Lead System for R-wave amplitude in Lead V_5

Subject	Post 1		Post 3		Post 5	
	ML	STD	ML	STD	ML	STD
1	11.0	11.5	11.0	10.0	11.0	10.0
2	14.5	15.0	14.0	14.0	14.0	15.0
3	8.0	7.0	7.0	7.0	7.0	7.0
4	24.5	19.0	28.0	17.0	28.0	15.0
5	13.5	13.0	16.0	14.0	16.0	13.0
6	23.0	19.5	22.0	22.0	22.0	22.0
7	13.5	14.0	15.0	17.0	14.5	17.0
8	22.0	21.0	22.0	24.0	23.0	24.0
9	20.0	20.5	20.0	19.0	19.0	19.0
10	10.5	7.0	9.0	8.0	9.0	8.0
11	11.0	14.0	13.0	14.0	12.0	13.5
12	20.0	23.0	20.0	20.0	21.0	18.0
13	11.5	13.5	11.0	11.0	11.0	12.0
14	16.5	18.0	15.0	19.0	17.0	17.5
15	8.0	8.0	9.0	9.0	7.0	7.0
16	17.5	19.5	20.5	20.0	20.0	21.5
17	10.0	13.0	11.0	12.0	11.0	14.0
18	11.5	12.0	11.0	13.0	11.0	12.5
19	18.0	22.0	15.0	15.0	16.0	15.0
20	10.5	11.0	10.5	11.0	10.5	10.0
21	18.0	20.0	19.0	19.0	17.5	18.0
22	18.0	19.0	19.0	19.0	19.0	19.0
23	20.0	23.0	24.0	24.0	24.0	24.0
24	8.5	8.0	9.0	8.0	7.5	8.0
25	18.5	17.5	19.5	18.0	18.0	17.5
26	19.0	20.0	25.0	22.0	26.0	23.0
27	18.0	19.5	20.5	20.0	19.0	18.0
28	14.5	15.0	17.5	15.0	14.0	13.5
29	18.0	16.0	19.0	20.0	16.0	15.0
30	8.0	7.0	6.5	8.0	7.0	8.0

Mason-Likar vs. Standard Lead System for R-wave Amplitude in Lead II

Subject	Base-Supine		Base-Standing		Peak-Exercise
	ML	STD	ML	STD	ML
1	9.5	5.0	7.5	4.0	7.0
2	14.0	13.5	11.0	7.0	12.5
3	4.5	3.0	4.0	2.0	4.0
4	15.0	7.0	13.0	5.0	11.5
5	14.0	7.0	13.5	6.0	10.5
6	17.0	8.0	12.0	5.0	12.5
7	15.0	9.5	14.0	7.5	15.0
8	22.0	13.0	20.0	12.0	22.0
9	18.0	10.5	16.0	12.0	15.0
10	12.0	7.0	10.0	6.0	10.5
11	15.0	7.0	10.0	7.0	9.0
12	13.0	7.5	12.0	8.0	13.5
13	11.5	8.5	10.0	6.0	9.0
14	14.0	10.0	14.0	10.5	12.0
15	5.0	2.0	7.0	2.5	7.0
16	15.0	8.5	14.0	9.0	14.0
17	14.0	8.5	11.0	7.0	9.0
18	11.5	9.5	10.5	8.0	11.5
19	11.0	8.0	7.0	6.0	10.0
20	14.0	7.0	18.0	10.5	18.5
21	13.0	7.0	10.5	5.5	11.0
22	16.0	12.0	16.0	11.0	15.0
23	14.0	8.5	12.0	7.0	13.0
24	5.0	1.5	1.5	1.0	4.0
25	14.0	8.0	14.0	7.0	7.0
26	15.0	10.5	17.0	11.5	12.0
27	14.5	8.0	12.5	7.0	14.5
28	12.5	7.0	10.0	7.0	12.0
29	15.0	10.0	16.0	8.5	10.0
30	2.5	1.0	2.5	1.0	7.0

Mason-Likar vs. Standard Lead System for R-wave Amplitude in Lead II

Subject	Post 1		Post 3		Post 5	
	ML	STD	ML	STD	ML	STD
1	9.0	4.5	8.0	4.0	9.0	4.0
2	11.0	11.0	11.0	11.0	11.0	11.0
3	5.0	3.0	6.0	3.0	6.0	3.0
4	14.0	6.0	17.0	7.0	15.0	6.0
5	13.0	6.5	16.0	8.0	16.0	7.0
6	16.0	8.0	15.0	8.0	16.0	6.0
7	13.5	7.5	14.0	8.5	15.0	8.0
8	24.0	12.0	23.0	12.0	24.0	12.0
9	21.0	12.0	23.0	12.0	21.0	12.0
10	10.5	7.0	12.0	7.5	11.0	8.0
11	15.0	5.0	17.0	8.0	16.0	7.0
12	16.0	8.0	17.0	9.0	17.0	10.0
13	10.5	7.0	11.5	8.0	11.0	8.0
14	14.5	10.0	18.0	12.0	17.0	10.0
15	6.5	2.5	7.0	3.5	5.0	3.0
16	16.5	10.5	16.5	10.0	16.0	10.0
17	12.0	6.5	13.5	9.0	15.0	8.5
18	10.0	7.5	11.0	8.5	11.0	7.5
19	12.0	8.0	10.0	7.0	11.0	7.0
20	14.0	7.0	13.5	7.0	14.0	8.0
21	12.0	7.5	15.0	7.5	13.0	7.0
22	18.0	13.5	19.0	14.0	19.0	13.5
23	15.5	10.0	17.5	10.0	18.0	9.5
24	5.0	2.0	6.0	2.5	5.5	1.5
25	12.0	7.0	14.0	7.0	13.5	8.0
26	14.0	11.5	17.0	11.0	17.0	11.0
27	14.0	9.0	19.0	10.0	17.0	10.0
28	16.0	9.0	16.0	8.0	13.5	8.0
29	16.0	8.0	17.0	8.0	16.0	9.0
30	8.0	5.0	6.0	4.0	6.5	4.0

Patient Characteristics

Subject	Age	WT	HT	HXMI	MIQW
1	54.4	90.9	175.3	0	0
2	50.2	90.9	177.8	0	0
3	55.6	113.6	198.1	0	0
4	70.2	90.0	172.7	0	0
5	50.6	84.1	185.4	0	0
6	54.9	109.1	193.0	0	0
7	58.1	72.7	172.7	0	0
8	51.7	87.3	180.3	0	0
9	39.1	90.9	182.9	0	0
10	38.9	95.9	175.3	0	0
11	68.5	100.0	182.9	0	0
12	51.3	80.9	185.4	0	0
13	44.3	106.4	185.4	0	0
14	47.4	90.9	177.8	1	1
15	59.9	95.0	172.7	0	0
16	29.1	97.3	180.3	0	0
17	59.3	68.2	172.7	1	1
18	48.6	104.5	190.5	1	1
19	42.1	108.2	182.9	0	0
20	72.5	86.4	177.8	0	0
21	46.5	98.6	180.3	0	0
22	53.2	90.9	175.3	0	0
23	55.6	113.4	198.1	0	0
24	47.6	110.0	185.4	0	0
25	39.1	78.2	172.7	0	0
26	32.3	78.2	182.9	0	0
27	53.8	108.2	185.4	0	0
28	33.7	88.2	180.3	0	0
29	39.6	79.5	180.3	0	0
30	52.4	74.1	177.8	0	0

WT = Weight (Kg)
HT = Height (Cm)
HXMI = History of MI (0=no;1=yes)
MIQW = MI Q-waves (0=no clinically significant Q-waves;
1=presence of 2 or more clinically significant Qs)

Patient Characteristics

Subject	DM	TOB	HTN	CHOL
1	1	1	1	0
2	0	0	0	0
3	0	0	0	1
4	0	1	1	1
5	0	1	1	0
6	0	0	1	0
7	0	0	1	0
8	0	0	0	1
9	0	0	0	1
10	0	0	0	0
11	0	0	1	0
12	0	0	1	0
13	0	0	1	0
14	0	0	1	1
15	0	0	1	0
16	0	1	0	0
17	0	0	0	1
18	1	1	1	0
19	0	0	0	1
20	0	0	1	0
21	0	0	1	0
22	0	1	0	0
23	0	0	0	0
24	0	0	1	0
25	0	0	0	0
26	0	1	1	1
27	0	1	0	0
28	0	0	0	0
29	0	0	0	0
30	1	1	0	0

DM = Diabetes Mellitus (0=no;1=yes)
TOB = Tobacco Use (0=no;1=yes)
HTN = Hypertension (<160/90=0;≥160/90 or on antihypertensive medication=1)
CHOL = Hyperlipidemia (<200=0;≥200=1)

Patient Characteristics

Subject	FAHX	HXCP	DAP	STAB	TR
1	0	1	1	1	1
2	1	2	0	1	0
3	1	0	0	0	0
4	1	1	2	1	1
5	1	1	1	1	1
6	0	1	1	1	1
7	0	2	0	1	0
8	1	2	0	1	0
9	0	2	0	0	0
10	1	2	0	0	0
11	1	1	1	1	1
12	1	1	1	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	2	0	0	0
16	0	2	0	0	0
17	1	0	0	0	0
18	1	0	0	0	0
19	0	1	0	1	0
20	0	1	0	0	0
21	1	0	0	0	0
22	1	1	0	1	0
23	1	1	0	1	0
24	0	0	0	0	0
25	0	2	0	0	0
26	1	0	0	0	0
27	1	0	1	0	0
28	1	2	0	0	0
29	1	2	0	1	0
30	0	0	1	0	0

FAHX = Family History (0=no;1=yes)
HXCP = History of Chest Pain (0=none;1=typical;2=atypical)
DAP = Chest Pain During Test (0=none;1=present;2=reason test was stopped)
STAB = Abnormal ST-segment Shifts at Peak-Exercise ($\geq$.1mV at J_{60}= 1; < .1mV at J_{60} = 0)
TR = Test Results or physician decision on clinical results of test (0=negative;1=positive or abnormal)

Patient Medications

Subject	BB	CCB	Nitrates	Antiarrythmics	ACE
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	1
4	0	0	0	1	1
5	1	0	0	0	0
6	1	0	0	0	0
7	0	1	0	0	0
8	1	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	1	1	1	0	0
12	1	1	0	0	0
13	0	1	0	1	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	0	0	1	0	0
19	0	0	0	0	0
20	0	1	0	0	0
21	0	1	0	0	0
22	0	0	0	0	0
23	0	0	0	0	0
24	1	0	1	0	0
25	0	1	0	0	0
26	1	0	1	0	0
27	1	1	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	0	0	0	0	0

0 = Presence of medication
1 = Absence of medication
BB = Beta Blockers
CCB = Calcium Channel Blockers
ACE = ACE Inhibitors

VITA

David Glen Shell was born August 4, 1970 in Roanoke, Virginia to Janet and Paul Shell. He has a younger sister, Christy, who is currently in her junior year at Virginia Tech and is majoring in Exercise Science. David graduated from William Byrd High School in 1988, and from there went to attend Virginia Tech on an athletic scholarship in track and field. At Virginia Tech, David ran cross-country and track four years and majored in Exercise Science. He obtained a B.S. degree in Exercise Science from Virginia Tech in 1992, and began courses toward his Master of Science degree in clinical exercise physiology at Virginia Tech later that same year. While a graduate student, David worked in the Virginia Tech Cardiac Rehabilitation Program. In addition, David worked in the Cardio-Pulmonary Department at Montgomery Regional Hospital as a cardiac rehabilitation educator, assisting in exercise testing and phases I, II and III cardiac rehabilitation. After obtaining his masters degree, David went to work at University Medical Center in Jacksonville, Florida where he is working with a group of cardiologists and developing a phase II program at a local YMCA.

David G. Shell