Right Precordial Leads and Lead aVR at Exercise Electrocardiography: Does It Change Test Results?

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Background: A recent study on exercise testing (ET) suggested that ST-segment changes in the right precordial leads (RPL) may increase its sensitivity substantially. However, this study looked at a highly selected population of patients who all underwent thallium-201 scintigraphy and coronary angiography. The present study evaluated the clinical utility of ST-segment changes in the RPL and lead aVR in an unselected population of patients undergoing ET.

Methods: A total of 906 consecutive patients who received ET were included in the study. ET was done using the Bruce Protocol with a 12-lead electrocardiogram (ECG) substituting V₄R and V₆R for V₁ and V₆. Leads V₁ and V₆ were selected for omission as these two leads hardly ever manifest changes in isolation. Substituting two leads would obviate the need for a more complex recording system, thus improving clinical utility.

Results: On the basis of horizontal/downsloping ST-segment depression (STD) of 1.0 mm or more (the usually accepted criterion for a positive ET), 159 (17.5%) patients had a positive ET. In those patients with a negative ET (545 patients), 4 patients (0.7%) manifested STD and 5 patients (0.9%) manifested ST-segment elevation (STE) in leads V₄R and/or V₆R, respectively. Of note, 44.7% of the positive ET group had STE in lead aVR.

Conclusion: The use of ST-segment changes in RPL during exercise stress testing does not appreciably change the test results of a standard ET. If one was to consider an additional marker, STE in aVR may be more useful, as it shows a stronger correlation with positive tests and does not require the recording of additional leads.

A.N.E. 2006;11(3):247-252

right precordial leads; exercise testing; electrocardiography

INTRODUCTION

Chest pain is a frequently presenting symptom in patients presenting to family physicians and in those seeking treatment in the emergency departments.¹ Early assessment and diagnosis using exercise tests (ET) may minimize inappropriate use of hospital beds, as admissions may be avoided if patients are found to have a normal ET. Still, those individuals who show electrocardiographic evidence of ischemia on ET need to be investigated in addition to evidence of coronary artery disease (CAD). While ET is a common diagnostic test for CAD, its sensitivity is limited. For exam-

ple, reports for the detection of single-vessel CAD range from 35% to 61% in various studies.²⁻⁶ Despite its limitations, ET remains a common non-invasive approach to evaluating patients with suspected CAD in view of its widespread availability across the globe. A recent study on ET suggested that ST-segment changes in the right precordial leads (RPL) may increase the sensitivity of the ET in identifying patients with CAD.⁷ If confirmed, the incremental diagnostic value provided by recording the RPL may be considerable. However, the above mentioned study has limitations from the point of view of patient selection. All patients enrolled underwent thallium-201 scintigraphy and coronary

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angiography. Eighty-six percent of the patients were found to have significant ($\geq 70\%$ stenosis) CAD by angiography. Evaluating a group of patients who underwent coronary angiography would give a better assessment of the sensitivity of the test. However, it does not answer the question of clinical usefulness as the population studied is quite different from the population of patients who undergo ET in usual clinical practice. The latter group of patients who undergo ET for evaluation of chest pain have a much lower probability of significant CAD (accounting for their chest pain), and thus have a much lower likelihood of having positive tests. Thus, the present study focused on whether the use of RPL in ET would significantly influence the results of the ET (positive vs negative) in an unselected population of patients who have been referred for ET in the course of evaluation for chest pain. It was felt that the present study was of utmost importance even if one assumes the findings of Michaelides et al. that ST-segment elevation/depression in the RPL is indicative of myocardial ischemia. This is due to the fact that the clinical significance of an additional abnormal criterion (i.e., RPL changes) will only have a meaningful impact if the claimed criterion is abnormal when the usually accepted criteria (i.e., ST-segment changes in the 12-lead electrocardiogram (ECG) remain normal. Also, the significance of simultaneous ST-segment changes in lead aVR during ET was reviewed, as this lead is generally ignored during the evaluation of 12-lead ECG, although recent studies have demonstrated some clinical usefulness in an acute myocardial infarction (AMI) setting.^{8,9}

METHODS

Selection of Patients

Consecutive patients who underwent ET for evaluation of episodic chest pain over a 42-month period at the Electrodiagnostic Department at the Grey Nuns Hospital were included in the study. Patients with a left bundle branch block (LBBB) on the resting ECG and those with significant STD on their resting ECG (i.e., digoxin) were not accepted for ET and thus not included in the study. The sources of patients were as follows: referred as outpatients for evaluation of chest pain; referred from the emergency room for evaluation of chest pain; from the coronary care unit/medical wards following admission with an acute coronary syndrome; follow-up

of patients already diagnosed with CAD. All ETs were performed under the supervision of a physician (general internist or cardiologist) along with an ET technician.

ET was done using the Bruce Protocol with a 12-lead ECG recorded substituting V_6R and V_4R for V_1 and V_6 . Leads V_1 and V_6 were selected for omission as these two leads rarely ever manifest significant STD in isolation. In addition, substituting two leads (as opposed to recording V_4R and V_6R in addition) would obviate the need for a more complex and cost-incurring recording system that would be required otherwise, thus improving the clinical utility. Patients underwent a symptom limited ET using an automated system (model # Q5000, Quinton Instruments Company, Bothell, WA, USA 98021-8906). The modified 12-lead ECG was recorded using the lead system described by Mason and Likar.¹⁰ A 12-lead ECG was recorded before exercise; at the end of each stage of exercise; at maximum exercise; and 1, 2, and 4 minutes after completion of the exercise. Leads V_3 , V_5 , and aVF were monitored continuously with the magnitude of STD measured 60 ms after the J-point and the ST-segment slope analyzed. Horizontal or downsloping ST depression of >0.1 mV observed in three consecutive beats was considered a positive test. The Bruce protocol was used as the preferred method wherever possible. The test was carried out to maximum effort in the absence of any of the following: (1) horizontal or downsloping ST depression in excess of 0.4 mV (test terminated before this in some instances in the presence of concomitant typical angina-type chest pain associated with horizontal or downsloping ST depression >0.1 mV); (2) fall in systolic blood pressure of > 10 mmHg accompanied by symptoms of lightheadedness; (3) sustained or frequent runs of nonsustained ventricular tachycardia; (4) as requested by the patient. The physician was present in the ET room (as is the practice in all ETs done at this institution) and made the decisions with regard to the timing of termination of the ET and provided the final interpretation of the test. Changes in leads V_4R , V_6R , and aVR during exercise were analyzed. Horizontal or downsloping STD >0.1 mV was identified as significant. In addition, ST-segment elevation (STE) of >0.1 mV was identified as significant STE.

Statistical Analysis

All data were entered into a database formulated within the Statistical Package for the Social Sciences

data management system. Continuous variables were entered as such with all discrete variables categorized to ensure that responses would fall into mutually exclusive categories. The cross-tabulation analyses between discrete variables were done using the chi-square test. Analyses on continuous variables were made using a Student's *t*-test for unpaired data.

RESULTS

During the period of study there were 906 patients ($M=563$, age: mean 57.3 ± 0.5 years SEM; $F=343$, age: mean 60.5 ± 0.6 years SEM) who received an ET at this institution for complaints of chest pain. Thus, 563 (62%) were males and 343 (38%) were females with an average age of 58.5 ± 0.4 years SEM. All demographic and clinical characteristics of the patient population are outlined in Table 1. Three hundred thirty-nine patients (37.4%) had a history of arterial hypertension. One hundred twelve patients (12.4%) had diabetes mellitus while 569 patients (62.8%) had a history of smoking. Four hundred sixty-one patients (50.9%) had a known diagnosis of dyslipidemia. Three hundred twenty-two

Table 1. Patient Demographics/Baseline Characteristics (n = 906)

	Male	Female
No. of Patients	563 (62%)	343 (38%)
Age	57.3 ± 0.5	60.5 ± 0.6
Cardiac risk factors		
Hypertension	196 (34.8%)	143 (41.7%)
Diabetes	69 (12.3%)	43 (12.5%)
Dyslipidemia	309 (54.9%)	152 (44.3%)
History of smoking	386 (68.6%)	183 (53.4%)
History of known CAD	250 (44.4%)	94 (27.4%)
Family history of CAD ^a	194 (34.4%)	128 (37.3%)
History of AMI	201 (35.7%)	78 (22.7%)
Medications at time of ET		
Beta-blocker	180 (32.0%)	66 (19.2%)
Calcium channel blocker)	62 (11.0%)	35 (10.2%)
Long acting nitrates	23 (4.1%)	26 (7.6%)
Diuretic	30 (5.3%)	38 (11.1%)
ACE inhibitor	17 (3.0%)	26 (7.6%)
Digoxin (absence of STD)	99 (17.6%)	57 (16.6%)

Mean $\pm$ SEM or the number of patients with percentages within that group (male vs female) in brackets are given.

CAD = coronary artery disease; AMI = acute myocardial infarction; ET = exercise test.

^aFamily history of CAD = first degree male with onset of disease < 55 years/first degree female with onset of disease < 65 years.

patients (35.5%) had a significant family history of CAD in first degree relatives (females < 55 years, males < 65 years), while 279 patients (30.8%) had a history of previous myocardial infarctions and 344 patients (38.0%) had a history of CAD.

Results of the ET are shown in Table 2. In our study population, the Bruce protocol was used in 871 patients (96.1%), with a modified Bruce protocol or a Low Level protocol (starting at stage II of the modified Bruce protocol) used in the rest. The duration of exercise was a mean of 492 ± 6 seconds (range 63–1080 seconds) together with a mean maximum heart rate of 144 ± 1 beats/min (range 61–211 beats/min). Of the 906 tests, 545 (60.2%) were negative, 159 (17.5%) were positive (based on horizontal or developing STD of 1.0 mm or more measured at 60 ms after the J-point), and 202 (22.3%) were considered indeterminate.

As shown in Table 3, of the patients with a positive ET, 2 (1.3%) patients had significant STD in lead V_4R and 24 patients (15.1%) had STE in lead V_4R . In lead V_6R , 2 (1.3%) patients showed significant STD, while 37 patients (23.3%) had STE. Please note, out of the 37 patients who had STE in V_6R , 23 patients had STE in V_4R as well. Out of the 2 patients who had STD in V_6R , 1 patient had STD in V_4R as well. Thus, 41 patients (25.8%) had STD or STE in either V_4R or V_6R . With respect to lead aVR, 2 patients (1.3%) had STD, while 71 patients (44.7%) showed STE.

As shown in Table 3, of the patients who had a negative ET based on the standard criteria, 3 patients (0.6%) demonstrated STD in V_4R and 4 patients (0.7%) demonstrated STE. In lead V_6R , 3 patients (0.6%) showed STD and 4 patients (0.7%) showed STE. Of those with negative ET only 4 (0.7%) patients (as opposed to 6 patients) manifested STD in leads V_4R and/or V_6R and 2 patients had STD in both V_4R and V_6R . Similarly, in those with negative ET only 5 (0.9%) patients (as opposed to 8 patients) manifested STE in leads V_4R and/or V_6R and 3 patients had STE in both V_4R and V_6R . When looking at limb lead aVR, 2 patients (0.4%) showed STD, while 23 patients (4.2%) showed STE.

DISCUSSION

ET is a necessary and important noninvasive tool for answering important clinical questions related to exercise tolerance and heart disease. The

Table 2. Results of Exercise Tests (n = 906)

	Male (n = 563)	Female (n = 343)
ET Results		
Positive	108 (19.1%)	51 (14.9%)
Negative	319 (56.6%)	226 (66.1%)
Indeterminate	137 (24.3%)	65 (19.0%)
ET Procedure		
Bruce	545 (97.0%)	326 (94.8%)
Low-level	5 (0.9%)	4 (1.2%)
Modified	6 (1.1%)	7 (2.0%)
Other	8 (1.4%)	8 (2.3%)
Duration of ET (seconds)	535 ± 8	422 ± 9
Maximal HR (beats/min)	144 ± 1	145 ± 1

Mean ± SEM or the number of patients with percentages within that group (male vs female) in brackets are given.

ET = exercise test.

electrocardiographic changes during exercise provide an indirect assessment of the adequacy of myocardial oxygen supply during periods of increased demand. Despite its limitations, ET is a popular and well-established office based procedure that is inexpensive and widely available. With such universal use and wide acceptance, it is important to examine additional parameters that may expand its use in the diagnosis of myocardial ischemia. A study by Michaelides et al. suggested that ST-segment changes in the RPL may increase the sensitivity of the ET substantially.⁷ Several other studies that used RPLs during ET reported a small improvement in the detection of right CAD.^{11,12} Thus, RPLs may increase the sensitivity of the standard ET in the detection of CAD. Michaelides et al. also suggested that recording RPL with a standard ET may enforce its sensitivity to equal that of exercise thallium-201 scintigraphy in the detection of myocardial ischemic disease.⁷ If this argument holds true, then ET with RPL may become a more cost-effective and efficient tool for evaluating the presence of CAD than the more costly nuclear imaging procedures.

However, before accepting the validity of this modified test, it is important to confirm the generalizability of this data to patients who undergo ET in day-to-day practice. In this regard, the above mentioned study has a limitation due to the fact that the data is based mostly on patients with abnormally high prevalence of angiographic CAD. Michaelides et al. study population included 86% of the patients with significant (>70% stenosis) angiographic CAD. Although the prevalence of CAD in patient populations who undergo ET in institutions may

vary (depending on the source of the patients), the incidence would generally be expected to be much lower than 86%. The present study examined the clinical utility of recording the RPL from a different perspective. The approach was selected based on the premise that for the recording of RPL to be considered useful, these leads should demonstrate positive changes when the ECG analysis based on the other leads are considered negative. Furthermore, it was felt that an accurate reflection of the clinical utility of recording RPLs can only be determined when all patients who are referred to an ET laboratory are included as opposed to a select subgroup of individuals. The present study incorporated leads V₄R and V₆R within the standard 12 leads that are recorded in the performance of an ET substituting V₄R for lead V₁ and V₆R for lead V₆. Leads V₁ and V₆ were selected for omission as these two leads hardly ever manifest ST-segment changes in isolation. It was felt that this approach would also be necessary to ensure widespread acceptance, even if the RPL recording was concluded to be useful. The recording of more than 12 leads would require complex and expensive recording systems that are generally not available in most ET laboratories.

In those patients with a negative ET based on standard criteria, the RPLs provided no significant information as only 4 patients (0.7%) manifested STD and 5 patients (0.9%) manifested ST-segment elevation (STE) in leads V₄R and/or V₆R, respectively. Thus, the utility of simultaneous recording of RPL would have led to very little change in the final conclusion of the ET even if ST-segment changes in these leads were considered a positive test.

Table 3. Correlation of Exercise Test Results with RPL and Lead aVR ST-Segment Changes (n = 906)

	Positive ET			Indeterminate ET			Negative ET		
	Male (n = 108)	Female (n = 51)	Total (n = 159)	Male (n = 137)	Female (n = 65)	Total (n = 202)	Male (n = 319)	Female (n = 226)	Total (n = 545)
V ₄ R STD	2 (1.9%)	0 (0.0%)	2 (1.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	3 (0.9%)	0 (0.0%)	3 (0.6%)
V ₄ R STE	20 (18.5%)	4 (7.8%)	24 (15.1%)	6 (4.4%)	0 (0.0%)	6 (3.0%)	4 (1.3%)	0 (0.0%)	4 (0.7%)
V ₆ R STD	1 (0.9%)	1 (2.0%)	2 (1.3%)	2 (1.5%)	1 (1.5%)	3 (1.5%)	2 (0.6%)	1 (0.4%)	3 (0.6%)
V ₆ R STE	30 (27.8%)	7 (13.7%)	37 (23.3%)	4 (2.9%)	0 (0.0%)	4 (2.0%)	4 (1.3%)	0 (0.0%)	4 (0.7%)
aVR STD	0 (0.0%)	2 (3.9%)	2 (1.3%)	2 (1.5%)	0 (0.0%)	2 (1.0%)	2 (0.6%)	0 (0.0%)	2 (0.4%)
aVR STE	58 (53.7%)	13 (25.5%)	71 (44.7%)	12 (8.8%)	4 (6.2%)	16 (7.9%)	13 (4.1%)	9 (4.0%)	23 (4.2%)

ET = exercise test.

Of those patients with a positive ET test based on standard criteria, 41 patients (25.8%) demonstrated either STE or STD in leads V₄R or V₆R. These positive changes noted in leads V₄R/V₆R would not have resulted in a change to the classification of the test results (positive vs negative). However, the concomitant significant changes noted in leads V₄R/V₆R could potentially add to the specificity and positive predictive accuracy of the ET although this remains to be proven.

Of note, concomitant STE in lead aVR manifesting in 44.7% of the patients was more closely associated with a positive ET in spite of using >0.1 mV STE as the cutoff point as opposed to >0.05 mV used in some studies. Interestingly, lead aVR is often ignored in ECG interpretation.¹³ As pointed out in the editorial by Gorgels et al.,¹³ most physicians consider lead aVR as providing reciprocal information from the left lateral side already covered by V₅, V₆, I, and aVL, and thus not useful. On the contrary, it may provide information from the basal part of the septum and the outflow tract of the right ventricle. In this regard, some studies have suggested that STE in lead aVR may reflect significant coronary lesions in the left main coronary artery and proximal left anterior descending artery (LAD) distribution.^{14,15} Also, in ET there is limited data regarding the significance of ST-segment changes in lead aVR to detect myocardial ischemia. But, Halon et al.¹⁶ showed that STE in lead aVR during ET did provide an accurate reflection of myocardial ischemia, demonstrating a sensitivity of 89% and a specificity of 44% for the detection of LAD CAD. Also, Michaelides et al.¹⁷ showed that STE in aVR with concomitant STD in lead V₅ is associated with significant stenosis of the proximal LAD artery during ET. Thus, STE in lead aVR may be an accurate reflector of left main and proximal LAD artery disease, and thus provides additional information to the standard 12-lead ET. Also, in cases of difficult placement of left precordial leads (i.e., recent left-sided thoracic surgery), lead aVR may be useful, given the frequent association of STE in lead aVR with positive ET.

The present study is limited by the fact that a positive or negative result during ET was not confirmed by a more sensitive and/or specific investigative modality. Nevertheless, when one looks at ET in day-to-day clinical practice, the majority of the negative and positive tests are not followed by a confirmatory test in the absence of additional clinical indications and/or on the basis of the magnitude

of the abnormality of the ET. The fact that 27.1% (246 of 906) of the patients were on beta-blockers at the time of the ET could also be viewed as a limitation of the study as beta-blockers may reduce the sensitivity of ETs, and thus also the ST-segment changes in the RPL. Nevertheless, the beta-blocker use was in a minority of patients and thus unlikely to have a significant impact on the results. As the goal was to examine the utility of the RPL in a group of unselected, consecutive patients referred for ETs (excluding only those whose exercise ECG would be uninterpretable based on resting changes), it was decided to include those on beta-blockers. The beta blockers were not discontinued in these patients due to valid clinical reasons: patients admitted with an acute coronary syndrome and commenced on beta-blockers with in-hospital ET to decide on the need for coronary angiography; patients with stable angina on beta-blockers where follow-up ETs done to judge efficacy of treatment.

In summary, given the results of the present study, one cannot recommend the simultaneous recording of RPL during a routine ET. Furthermore, the present study reinforces the need to pay more attention to lead aVR looking for STE during ET.

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