

CHAPTER 25

EXERCISE TOLERANCE TESTING

GENERAL INFORMATION

This chapter will provide the learner with the definition, fundamental principles, indications, contraindications, protocols and responses to exercise tolerance testing.

LIST OF TOPICS INCLUDED IN THIS CHAPTER

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CARDIAC MEDICATIONS**SUMMARY****SELF-ASSESSMENT LEARNING GUIDE****SUPPLEMENTARY READING****KEY WORDS USED IN THIS CHAPTER** (*See Glossary*)

<i>anaerobic</i>	<i>angina</i>
<i>glycosis</i>	<i>maximal</i>
<i>METS (metabolic equivalent)</i>	<i>submaximal</i>
<i>tidal volume</i>	

CERTIFICATION**LEARNING GOAL**

The learner will have a basic understanding of the fundamental principles of exercise tolerance testing and the role of a cardiology technologist.

CERTIFICATION**LEARNING OBJECTIVES**

Upon completion of this section the learner will be able to:

1. Define exercise tolerance testing.
2. State role and responsibilities of a cardiology technologist.
3. List the diagnostic and therapeutic indications for exercise tolerance testing.
4. List major contraindications to exercise tolerance testing.
5. Discuss patient preparation.
6. Describe electrode placement and motion artifact prevention.

7. State the normal cardiovascular response to exercise.
8. State the normal ECG manifestations in response to exercise.
9. State the criteria for a positive (abnormal) exercise test.

SPECIALTY LEVEL**LEARNING GOAL**

The learner will be able to further assess patients during exercise tolerance testing and define the procedure to patients.

SPECIALTY LEVEL**LEARNING OBJECTIVES**

1. Fulfil all of the objectives of the certification level.
2. List the relative contraindications for exercise tolerance testing.
3. Define Metabolic equivalents (METS).
4. Explain the purpose of maximal and submaximal exercise tolerance testing.
5. Describe the following exercise protocols:
 - (i) Bruce
 - (ii) Modified Bruce
 - (iii) Naughton
6. Discuss frequency of ECG recordings and blood pressure measurements.
7. List the various parameters to be observed prior to, during and post testing.
8. Describe in detail the symptomatic and cardiovascular response to exercise.
9. Identify the abnormal ECG manifestations and clinical reasons for terminating an exercise test.
10. Discuss false positive and false negative results.
11. Discuss immediate medical management of the following complications of exercise testing.
 - (i) ventricular tachycardia
 - (ii) ventricular fibrillation
 - (iii) supraventricular tachycardia/atrial fib/flutter

- (iv) prolonged post exercise angina
- (v) myocardial infarction

12. Describe special considerations when exercise testing in patients:

- (i) recovering from a recent myocardial infarction or open heart surgery
- (ii) with chronic obstructive pulmonary disease
- (iii) with a pacemaker
- (iv) paediatric
- (v) radionuclide imaging

INTRODUCTION

Exercise Tolerance testing is defined as the observation and recording of a patient's cardiovascular response to exercise. Exercise tolerance testing involves the monitoring of heart rate, blood pressure, electrocardiogram, as well as patient symptoms and appearances during an aerobic type of exercise, which may utilize a treadmill or, a bicycle ergometer and a complete electrocardiogram.

Diagnosis and evaluation of suspected or known cardiovascular disease is the most common application of exercise testing. Also, modified and submaximal exercise testing is used to evaluate the medical management of patients after myocardial infarction, coronary artery bypass surgery, and angioplasty, during recovery and before discharge. It is an important tool in risk stratification of persons who have sustained a recent myocardial infarct or have a positive history and risk factors to develop a cardiac problem in the future.

Exercise testing is used to determine the exercise capacity in individuals who would require an exercise prescription, such as those participating in a cardiac rehabilitation program.

Patients who have undergone valvular replacements, repair of congenital defects or a cardiac transplant are also candidates for clinical assessment.

Exercise testing may be used to evaluate pharmacological therapy such as antiarrhythmic agents, antianginal agents, and antihypertensive agents. Please Note: Information found in this chapter is to be used as a guideline only. Follow Policies, Procedures and Protocols established for your laboratory.

HISTORY

Feil and Siegel, in 1928, first recorded ST segment depression occurring simultaneously with angina while they exercised patients known to have

angina pectoris. They showed that the ST segments returned to resting values with the disappearance of symptoms and also with nitroglycerine therapy. In 1934, Wood and Wolferth suggested that exercise testing would be useful in diagnosing coronary artery disease. They also demonstrated the importance of a symptom-limited test according to the patient's capacity.

Bruce introduced the concept of calibrated protocols and aerobic principles, thus providing the ideas of quantitative assessment of disease not just a diagnosis.

In 1967, Robb and Marks verified the prognostic significance of the degree of exercise-induced ischemia.

More recent techniques have demonstrated that the rate of change of the ST segment with respect to the increase in heart rate during exercise provides a diagnostic guide to the severity of coronary disease.

The Master Step test was one of the major means of testing patients for ischemia up until the mid-sixties. It was effective and inexpensive as all that was needed was an ECG machine and a two-sided staircase. Today, treadmills and bicycle have supplanted the step test as they are more effective and allow a more reproducible graded sub maximal at 85%.

THE ROLE OF THE TECHNOLOGIST

The technologist performs the exercise test usually under the supervision of a physician. The technologist's responsibilities include:

1. Calibration and maintenance of the exercise testing equipment.
2. Explanation of the test to the patient. Demonstrate how to walk on treadmill.
3. Physical preparation of the patient.
4. Monitoring and recording the patient's electrocardiogram, blood pressure data and reporting any changes to physician.
5. Observing patients' physical condition and reporting any changes to physician.
6. Documenting all findings, medications given and any responses to medications given.

Note: Some institutions may require a patient consent form to be signed prior to the test.

Figure 25-1. Physician responsibilities during stress testing (many technologists also hold these responsibilities).

1. Evaluating the patient before the test
2. Selecting the appropriate exercise protocol
3. Monitoring the patient during the test
4. Terminating the test when the appropriate endpoint is reached
5. Interpreting the test

INDICATIONS AND CLINICAL USES OF EXERCISE TOLERANCE TESTING

The purpose of the exercise test is to determine physiological responses to controlled exercise. Clinical applications include diagnostic, therapeutic, and functional goals. The most common application of exercise tolerance testing is the diagnosis and evaluation of suspected or known cardiovascular disease. Modified and submaximal exercise testing is used to evaluate medical management of patients after myocardial infarction, coronary bypass surgery and angioplasty procedures.

Exercise tolerance testing may be used to evaluate medical therapy with certain types of drugs, such as antiarrhythmic, antianginal, and antihypertensive agents. Patients who are well controlled at rest may show abnormalities or limitations with exercise.

Functional exercise testing is used to determine exercise capacity and cardiovascular responses in patients who require an exercise prescription, such as those joining a cardiac rehabilitation program. Also, patients who have had repair of congenital defects, valvular replacement, or transplant are candidates for functional assessment. Other patients evaluated include those with diabetes, pulmonary disease, renal failure, and congestive heart failure.

CONTRAINDICATIONS TO EXERCISE TOLERANCE TESTING

Major contraindications to exercise testing include acute myocardial infarction, unstable cardiovascular status (unstable angina is probably the most important contraindication), or orthopaedic limitations. Relative contraindications include arrhythmias, moderate congestive heart failure, or severe hypertension. In some cases, a low-level exercise test may be indicated when diagnostic or therapeutic information is required and the potential benefit to the patient exceeds the risk.

Table 25-1

INDICATIONS FOR EXERCISE TESTING	CONTRAINDICATIONS FOR EXERCISE TESTING
Diagnostic Evaluation of suspected heart disease Evaluation of high risk individuals After myocardial infarction (risk stratification) After angioplasty Arrhythmia provocation Peripheral vascular disease	Major Contraindications Recent acute MI Unstable angina Uncontrolled atrial or ventricular arrhythmias Congestive heart failure Uncontrolled hypertension Severe aortic stenosis Acute myocarditis Acute pericarditis Endocarditis Third degree heart block Dissecting aneurysm Acute illness (embolus, phlebitis, GI disease)
Functional Capacity After myocardial infarction After coronary bypass After repair of valvular or congenital defect Exercise prescription Chronic pulmonary disease Chronic renal failure evaluation for insurance company	Relative Contraindications Moderate valvular disease Cardiomyopathy Complex ventricular activity Ventricular aneurysm Acute systemic disease Neuromuscular or musculoskeletal disorders that make exercise difficult Uncontrolled metabolic disorders Electrolyte abnormalities Digitalis or other drug effect Arrhythmias Moderate Congestive Heart Failure Severe Hypertension Uncontrolled Hypertension
Therapeutic Antianginal therapy Antiarrhythmia therapy Antihypertensive therapy Bronchodilators Vasodilators	

EXERCISE PHYSIOLOGY

The normal cardiovascular system must be able to react to exercise by delivering more oxygen to hard working muscles by:

1. increasing heart rate
2. increasing blood pressure
3. increasing stroke volume
4. increasing oxygen extraction by the capillary beds

The ability to increase oxygen consumption depends on:

1. ability to increase respirations
2. ability to increase tidal volume
3. ability to increase oxygen diffusion

Maximal Oxygen Uptake and Cardiac Output

The maximal oxygen consumption per minute per kilogram of bodyweight is limited by cardiac output. Depending on the patient's conditioning, cardiac output increases with exercise and the stroke volume increases as increased venous flow occurs. The rise in stroke volume plateaus just prior to maximal exercise. The normal stroke volume at rest is about 50 to 80 ml of blood. The formula to calculate the cardiac output is stroke volume x heart rate. The average cardiac output at rest is around 5.6 litres per minute. In a well-conditioned person the cardiac output may increase to 30 litres of blood per minute.

For submaximal exercise involving large muscle groups, the oxygen uptake increases proportionally to the workload up to a maximum limiting value. Beyond this plateau, increases in workload are not associated with an increase in oxygen consumption and the body then relies on anaerobic glycolysis to supply the energy required and exhaustion is soon reached.

The maximal oxygen uptake represents a defined limit that is a reproducible measure of physiological fitness. The range of maximal oxygen uptake for sedentary middle-aged males is about 30 to 45 ml/kg/min, with values of 80 to 85 ml/kg/min in endurance athletes such as runners and cross-country skiers. Women generally have values about 15 percent lower than males because of different body composition.

Table 25-2(a). Men - maximum oxygen uptake (cc/kg/min).

Age	Low	Fair	Average	Good	High
20 - 29	< 25	25 - 33	34 - 42	43 - 52	53 ⁺
30 - 39	< 23	23 - 30	31 - 38	39 - 48	49 ⁺
40 - 49	< 20	20 - 26	27 - 35	36 - 44	45 ⁺
50 - 59	< 18	18 - 24	25 - 33	34 - 42	43 ⁺
60 - 69	< 16	16 - 22	23 - 30	31 - 40	41 ⁺

Table 25-2(b). Women - maximum oxygen uptake (cc/kg/min).

Age	Low	Fair	Average	Good	High
20 - 29	< 24	24 - 30	31 - 37	38 - 48	49 ⁺
30 - 39	< 20	20 - 27	28 - 33	34 - 44	45 ⁺
40 - 49	< 17	17 - 23	24 - 30	31 - 41	42 ⁺
50 - 59	< 15	15 - 20	21 - 27	28 - 37	38 ⁺
60 - 69	< 13	13 - 17	13 - 23	24 - 34	35 ⁺

In measuring levels of exercise, the word METS is often used. A METS is a metabolic equivalent and is approximately 3.5 ml O₂/kg/min, which is a resting oxygen consumption. METS are a convenient way of measuring oxygen consumption. Oxygen consumption at rest is 1 MET, and the use of METS

allows the intensity of effort to be expressed as a multiple of the resting value.

Table 25-3. Cardiorespiratory fitness levels.

Fitness Level	ml of oxygen per kg per minute	METS
Poor	3.5 - 13.9	1.0 - 3.9
Low	14.0 - 24.9	4.0 - 6.9
Average	25.0 - 38.9	7.0 - 10.9
Good	39.0 - 48.9	11.0 - 13.9
High	49.0 - 56.0	14.0 - 16.0

EXERCISE TOLERANCE TESTING METHODS

Laboratory Equipment

The typical exercise tolerance test laboratory will be equipped with the following:

- (a) Treadmill and bicycle and/or hand ergometers
- (b) ECG recorders and monitors (preferably with 12 lead capability)
- (c) Blood pressure cuff, stethoscope, sphygmomanometer
- (d) Emergency resuscitation cart
- (e) Defibrillator
- (f) Bed (or stretcher for resting ECGs and recovery)

Exercise Test Protocols

The basic principle of all graded exercise tests is a progressive increase in workload of a large muscle group (usually of the legs) to a point of fatigue, target heart rate being reached (where applicable) or termination because of abnormal responses. Ideally, the first stage should be of low enough intensity and act as a warm-up to allow the patient to proceed to at least one stage of higher intensity.

In submaximal tests, the patient is stopped at some predetermined endpoint based on heart rate, age or other physiological criteria. This is usually sufficient to provide the physician with guidelines for diagnostic or therapeutic efficacy.

Exercise is usually terminated by chest pain, dyspnea, presyncope, electrocardiographic changes or inappropriate blood pressure response such as a decline or failure of systolic pressure to rise during exercise. Decline of the blood pressure below the starting level is generally regarded as an ominous sign, and an indication for prompt termination of the study.

Multi-stage exercise testing accompanied by continuous ECG monitoring and periodic blood pressure measurement is considered the most useful

type of testing. There are several different protocols in use today with the more popular ones being the Bruce and the Naughton protocols. These are summarized in Figure 25-4.

Maximal and submaximal tests are usually performed on a treadmill, but bicycle ergometers are frequently used especially with patients with some ambulatory difficulties. However, maximum heart rates and maximum oxygen uptakes are usually lower than with treadmill tests. The Master Step test may still be in use in some places, but it is now regarded as out-of-date as treadmills and bicycle ergometers are more effective.

Patients with peripheral vascular disease or musculoskeletal disorders who are unable to perform treadmill or bicycle ergometer exercise tests may be evaluated by arm exercise testing or drug injection which stresses the myocardium. Arm exercise is performed with an arm crank ergometer with the patient standing or sitting. Protocols may be continuous or discontinuous but discontinuous stages are better tolerated by the patient and also permit blood pressure measurement.

Table 25-4. Treadmill Protocols

BRUCE					MODIFIED BRUCE				
Stage	Duration (mins)	Speed (mph)	Grade (%)	METS	Stage	Duration (mins)	Speed (mph)	Grade (%)	METS
1	3	1.7	10	5	1	3	1.7	0	1.7
2	3	2.5	12	7	2	3	1.7	5	2.8
3	3	3.4	14	10	3	3	1.7	10	5.4
4	3	4.2	16	13	4	3	2.5	12	7.0
5	3	5.0	18	16	5	3	3.4	14	10
6	3	5.5	20	19	6	3	4.2	16	13
7	3	6.0	22	22	7	3	5.0	18	17

NAUGHTON				
Stage	Duration (mins)	Speed (mph)	Grade (%)	METS
1	2	1.0	0	1
2	2	2.0	0	2
3	2	2.0	3.5	3
4	2	2.0	7.0	4
5	2	2.0	10.5	5
6	2	2.0	14.0	6
7	2	2.0	17.5	7

Table 25-5. Target heart rate (age-rate).

MHR 100%	90%	SMHR 85%	80%	70%	MHR 100%	90%	SMHR 85%	80%	70%
20 - 200	180	170	160	140	45 - 175	157	148	140	122
21 - 199	179	169	159	139	46 - 174	156	147	139	122
22 - 198	178	168	158	138	47 - 173	155	147	138	121
23 - 197	177	167	157	138	48 - 172	154	146	137	120
24 - 196	176	166	156	137	49 - 171	153	145	136	120
25 - 195	175	165	156	136	50 - 170	153	144	136	119
26 - 194	174	164	155	136	51 - 169	152	143	135	118
27 - 193	173	164	154	135	52 - 168	151	142	134	118
28 - 192	172	163	153	134	53 - 167	150	141	133	117
29 - 191	171	162	152	134	54 - 166	149	141	132	116
30 - 190	171	161	152	133	55 - 165	148	140	132	115
31 - 189	170	160	151	132	56 - 164	147	139	131	115
32 - 188	169	159	150	131	57 - 163	146	138	130	114
33 - 187	168	158	149	131	58 - 162	145	137	129	113
34 - 186	167	158	148	130	59 - 161	144	136	128	113
35 - 185	166	157	148	129	60 - 160	144	136	128	112
36 - 184	165	156	147	129	61 - 159	143	135	127	111
37 - 183	164	155	146	128	62 - 158	142	134	126	111
38 - 182	163	154	145	127	63 - 157	141	133	125	110
39 - 181	162	153	144	127	64 - 156	140	132	124	109
40 - 180	162	153	144	126	65 - 155	139	131	124	108
41 - 179	161	152	143	125	66 - 154	138	130	123	108
42 - 178	160	151	142	125	67 - 153	137	130	122	107
43 - 177	159	150	141	124	68 - 152	136	129	121	106
44 - 176	158	149	140	123	69 - 151	135	128	120	106
					70 - 150	135	127	120	105

PATIENT MONITORING

Electrocardiography

Monitoring of the patients' ECG is an essential part of all types of exercise testing. Most exercise ECG recording systems use a modified 10-electrode combination, permitting continuous monitoring and recording of the 12 standard limb and precordial leads. The sensitivity for the detection of ischemic ECG changes is increased when 12-lead ECG monitoring is used.

Preparation of the skin sites for electrode placement is the most **important** component in determining satisfactory ECG monitoring in exercise testing. (See patient preparation for more information).

Blood Pressure

Frequent blood pressure readings should be taken prior to (resting), during exercise and in the recovery phase. Blood pressure response provides useful diagnostic information that contributes to the interpretation of the test. A standard binaural stethoscope and an adjustable manometer are most often used, but there are also automatic monitors available for blood pressure measurement during exercise.

Blood Pressure Monitoring Technique

- 1) The arm to be used for monitoring, should be free of clothing. Centre the blood pressure cuff, indicated by an arrow or dot on the cuff, over the brachial artery on the inside of the arm. The lower edge of the cuff should be at least 1 inch above the elbow crease. Fit the cuff snugly and secure it.
- 2) Support the arm, ensuring the cuff is at the level of the heart. The blood pressure will be falsely elevated if the brachial artery is below heart level, or will be falsely depressed if the brachial artery is above heart level.
- 3) Locate the brachial artery, which is usually just medial to the biceps tendon. Place the bell of the stethoscope lightly over the brachial artery.
- 4) Inflate the cuff quickly to at least 180 mmHg, then deflate the cuff slowly, about 3 mmHg per second. Note the level at which you first hear two consecutive beats. This reading will be the systolic pressure.
- 5) Continue to lower the pressure slowly until the sounds change in tone or become muffled and then disappear. This reading will be the diastolic pressure. Deflate the cuff to zero pressure. The occasional patient may have sounds that never disappear but continue on to zero, as is the case in patients with aortic regurgitation.

It may be impossible to obtain brachial blood pressures on a patient with severe peripheral vascular disease.

Auscultatory gap is a silent interval between the systolic and diastolic pressures. If the cuff is not sufficiently inflated it is possible to miss the higher systolic pressure entirely. These pressures should be recorded as, ie. 175/100 with an auscultatory gap from 150 to 135.

- 6) The meniscus of the mercury manometer should be level with the eye, when taking your pressure readings, unless using the tilted floor model.
- 7) Repetitive readings should be avoided as readings become false due to venous congestion. After an unsuccessful attempt, wait 1 to 2 minutes before reinflating the cuff.
- 8) If brachial pressures are soft or if the blood pressure has dropped very low such as may occur during Dipyridamole Thallium testing or as a vagal response following intense exercise, the stethoscope may not pick up the heart sounds. The systolic pressure may then be taken by palpation. Find the radial artery, at the outer edge of the wrist, thumb side. Keeping the fingers on the pulse, inflate the cuff until the pulse is no longer palpable. Deflate the cuff very slowly and note the level at which the pulse is once again felt. This is the systolic pressure. You cannot obtain a diastolic pressure using this method.
- 9) If auto, please place cuff and take measurements as per manufacturers instructions to ensure accuracy. Please note, newer dial type manometers are replacing mercury units in many facilities. Please follow their specific application instructions to ensure accuracy.

Rated Exertion

A useful tool in evaluating effort is the Borg scale of rated perceived exertion (RPE). The RPE scale has been shown to be a reproducible measure of effort regardless of age and sex. The numeric scale correlates with heart rate, ventilation, maximum VO_2 and is unaffected by beta blockers.

Rating Scale

0	Nothing
0.5	Very, very weak
1	Very weak
2	Weak
3	Moderate
4	Somewhat strong
5	Strong
6	
7	Very strong
8	
9	
10	Very, very strong

CONDUCTING THE TEST

Explanation of the Test

The details of the test should be explained to the patient. Many patients are apprehensive about having an exercise tolerance test and a careful explanation, including a demonstration of how to get on, walk, and get off the treadmill, will help to relieve their anxiety. Patients should be shown how to keep a steady pace and not to use excessive support on the rails for balance as errors in calculating exercise capacity will result. Patients should be instructed to report any symptoms or unusual sensations before, during, or after the exercise test. Any medications should also be reported before starting the test. Patients should be encouraged to ask questions or raise any concerns they have about the test.

Patient Preparation

Satisfactory ECG monitoring is dependent on proper electrode site preparation. Skin sites must be cleaned with alcohol and then abraded with fine sandpaper (there are commercially available products) to remove surface epidermis and oils. Male patients may have to be shaved first. The electrodes can then be applied firmly in the following positions:

Upper limb leads - high on the shoulders or clavicles

Lower limb leads - bottom of the rib cage

V₁ - fourth intercostal space at right sternal border

V₂ - fourth intercostal space at left sternal border

V₃ - mid-point between V₂ and V₄

V₄ - fifth intercostal space at midclavicular line

V₅ - same level as V₄ at anterior axillary line

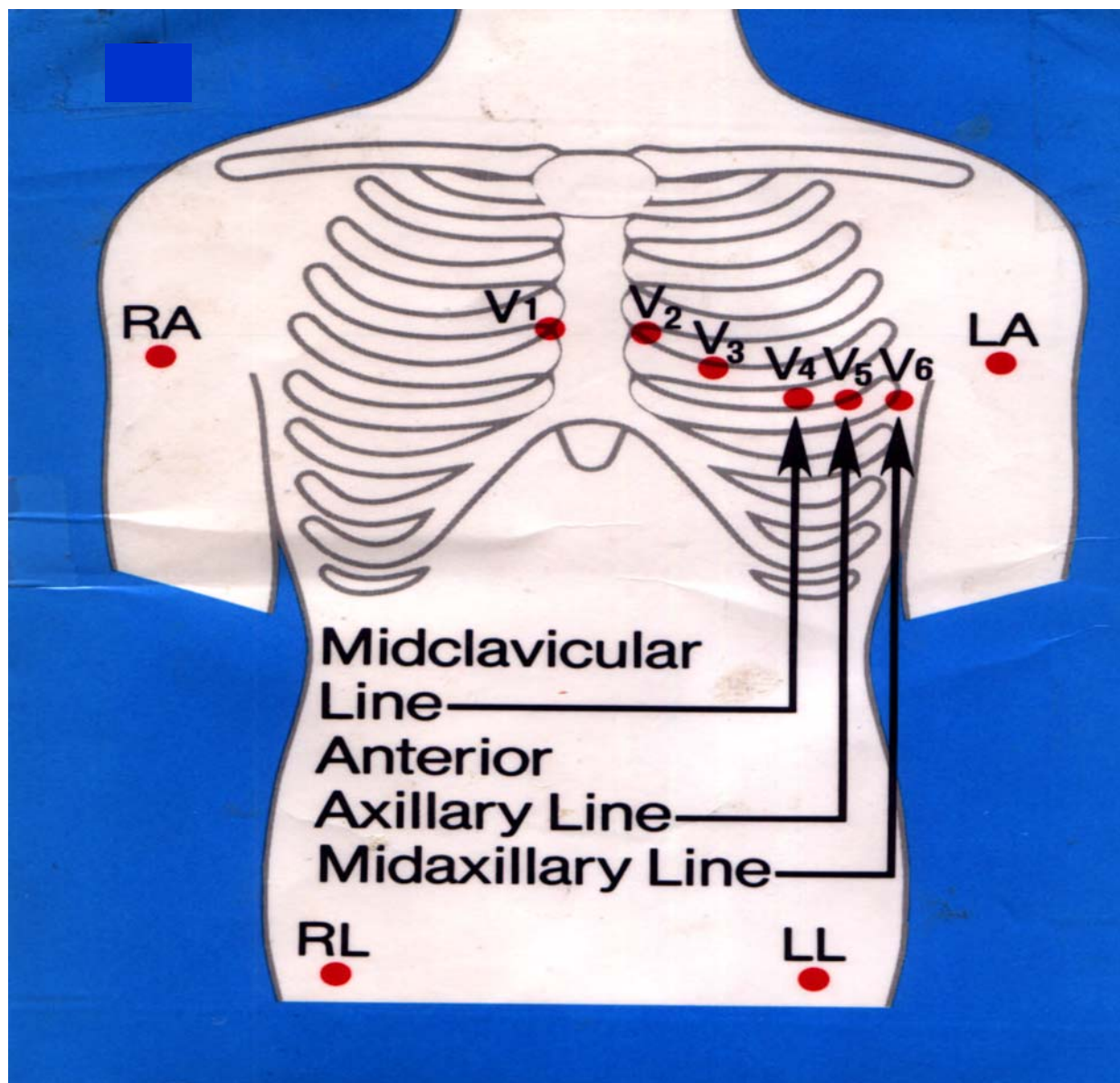
V₆ - same level as V₄ and V₅ at mid-axillary line

Torso placement of the limb leads results in some loss of information from the limb leads, but precordial leads are largely unaffected.

Most exercise test systems allow the patient cable to be worn around the patients' waist with a belt. The individual electrode wires are usually colour coded to facilitate attachment to the specific electrodes.

Modern computerized exercise tolerance testing systems will check the impedance at each electrode site to ensure optimum contact with the skin and will also allow a tap test to be performed on each electrode. Leads that are noisy or have a high impedance should be replaced before continuing with the test. Tape or elastic netting (over the chest area) may be used to stabilize the electrodes. The objective is to reduce motion artifact and obtain the clinically acceptable tracing or monitor leads. Please see instruction/operator's manual for machine calibration and expected parameters. Also for female patients wearing their bras helps reduce motion artifact for "large women".

Figure 25-2. Electrode Positions used in exercise testing.



Move RL and LL to hip area for Treadmills. This can be institute specific.

Measurements

Exercise test protocols may vary in duration, speed and elevation, etc., but generally a standard set of measurements should be obtained. These measurements are recorded during the rest, exercise and recovery phases of the test. Before exercise, the ECG is recorded with the patient in a supine position, or a sitting position as per your institutions instructions, and in a standing position. Some protocols or laboratories require an ECG recorded after 30 sec of hyperventilation. Significant changes in the ST segment and T wave may occur in the standing position or with

hyperventilation.

Blood pressure is also recorded during the rest phase, usually in the standing position.

The heart beat is monitored continuously by oscilloscope and recordings are made at specific intervals at rest, exercise and recovery. Twelve lead ECG's or selected leads (rhythm strips) can be recorded at anytime. Any abnormalities in rate rhythm or conduction must be recorded for the permanent record.

Blood pressure is recorded at specific intervals, usually the same intervals as the ECG. Patients should be queried every 1-2 minutes, or at the end of each stage of exercise, for symptoms or fatigue.

The recovery phase may include 1-2 minutes of walking (at a reduced speed and grade, or workload if a bicycle ergometer is used) and up to 6-8 minutes of resting in a seated position. The recovery duration can vary according to abnormal responses to the test and the heart rate and blood pressure values need not be at pre-exercise levels, but should be stable before the test is discontinued. Some laboratories use a supine recovery position immediately following exercise. The increase in venous return may increase ischemic ECG changes.

EXERCISE TEST RESPONSES

Symptomatic

Muscle fatigue, dyspnea, and maximum predicted heart rate are the normal

Responses

endpoints for the termination of an exercise test. These responses may occur in a relatively short time, therefore it is necessary to observe and monitor the patient to avoid excessive stress.

The exercise test may be discontinued before reaching the patient's maximum effort because of abnormal responses to exercise. The criteria for immediate termination of the test include angina, dizziness, dyspnea, leg cramps, declining systolic blood pressure and other indications of left ventricular failure.

In some cases, the object of the test may be to evaluate antiarrhythmic or antianginal therapy, so that continuing with the test may be justified.

The most common symptoms produced by exercise testing are angina and dyspnea. The onset of typical angina during exercise is an accurate predictor of coronary artery disease. The onset of angina, dyspnea, or fatigue at low exercise levels is usually predictive of multi-vessel disease.

Mild angina and atypical chest pain may allow the test to continue for

short periods if ECG and blood pressure findings are stable. In some laboratories, in the absence of significant ECG changes, the presence of angina may be established with the administration of sublingual nitroglycerin, and then repeating the test.

Cardiovascular Responses

Heart rate and blood pressure increases usually occur proportional to exercise. Age predicted maximum heart rate values may be obtained from published tables or estimated from equations. A common method used to estimate age predicted maximum heart rate is: $\text{Max HR} = 220 \text{ minus the age}$. However, many drugs used in the treatment of cardiovascular disease can materially affect the rate response to exercise, particularly beta blockers.

Sub-maximal tests may obtain up to 85% of the age predicted maximum heart rate. However, patients with heart disease may show a limited heart rate increase in response to exercise. This is called a chronotropic response.

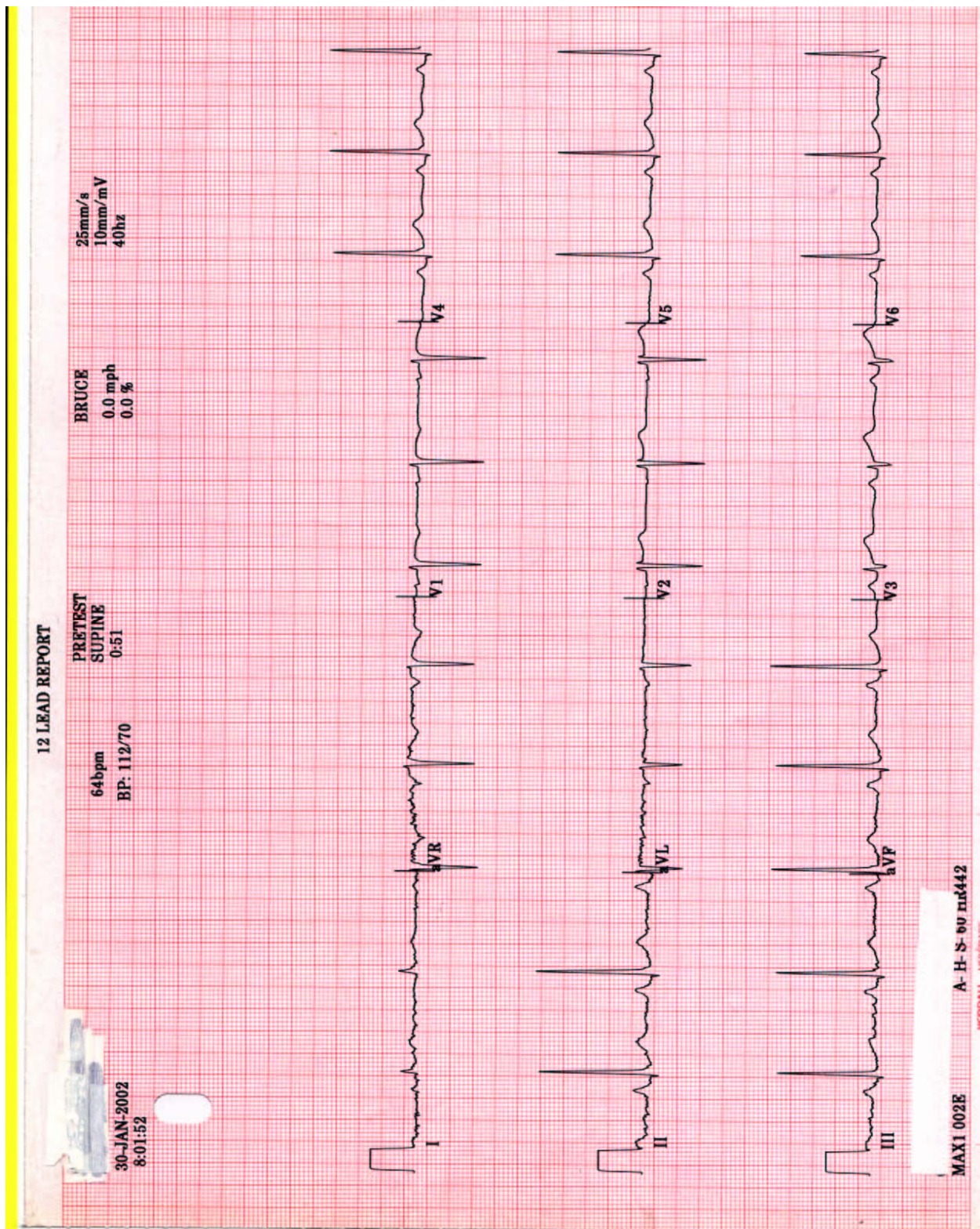
Maximum blood pressure response usually occurs at peak heart rate. Normal blood pressure values vary with exercise (160-220/50-90). Hypertensive blood pressure responses is usually described as >210 systolic and >100 diastolic. Many physicians will discontinue exercise testing when the systolic pressure reaches 230 or the diastolic pressure reaches 110.

Hypotensive or limited blood pressure responses are often seen in patients with severe ischemic heart disease or heart failure. A poor rise or decrease in systolic pressure is a sign of reduced ventricular function that requires the termination of the test. A drop of 10 mg in systolic pressure during exercise may indicate presence of disease.

ELECTROCARDIOGRAPHIC RESPONSES

Normal Responses Normal changes of the electrocardiogram that occur during exercise include rate-related shortening of the Q-T interval and superimposition of the P and T waves, decreasing R wave amplitude, and increasing T wave amplitude.

The following are a series of ECG's on a 44 year old male with chest pain.

Figure 25-3(a). Baseline electrocardiogram.

Stage 1

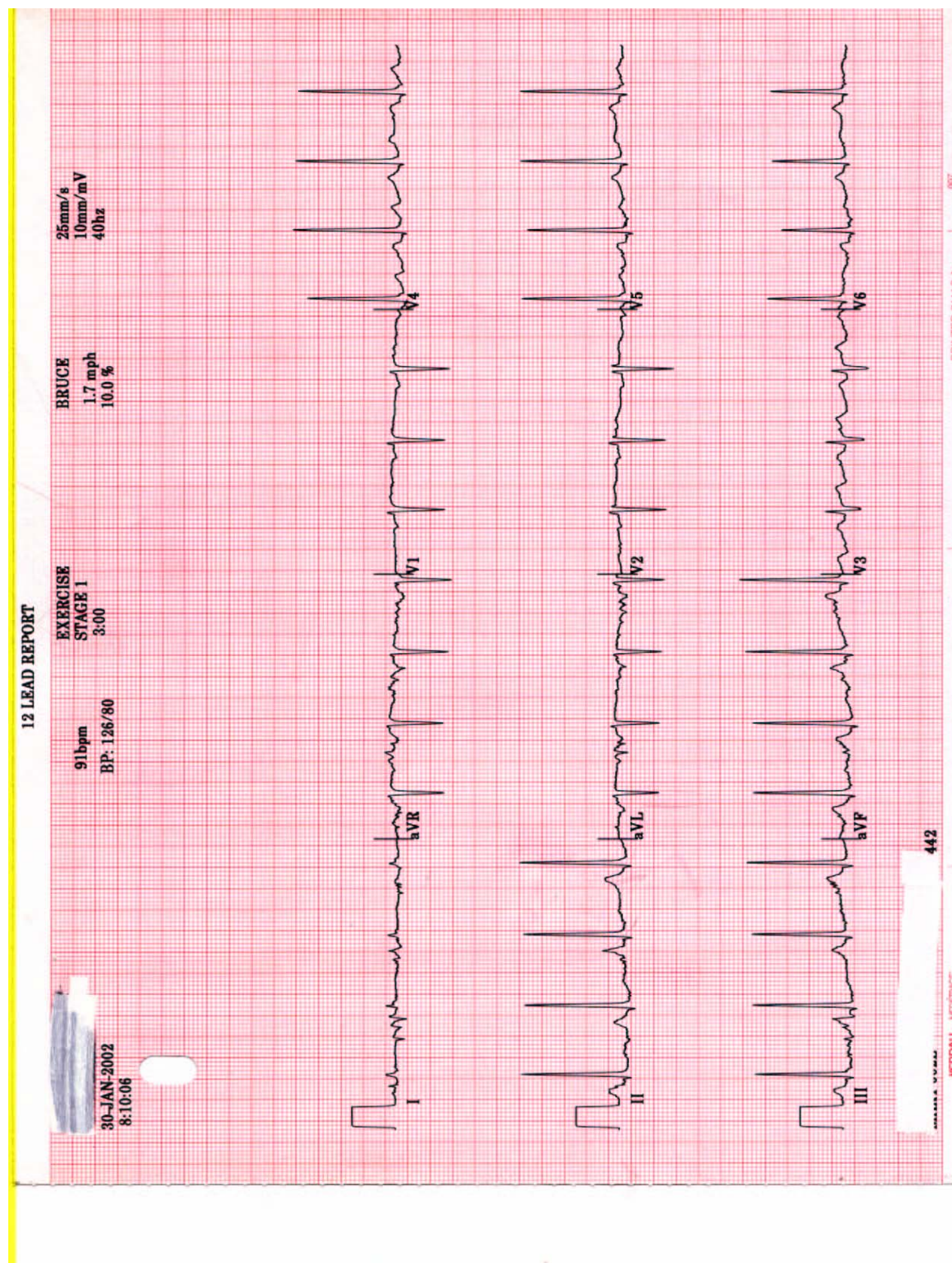


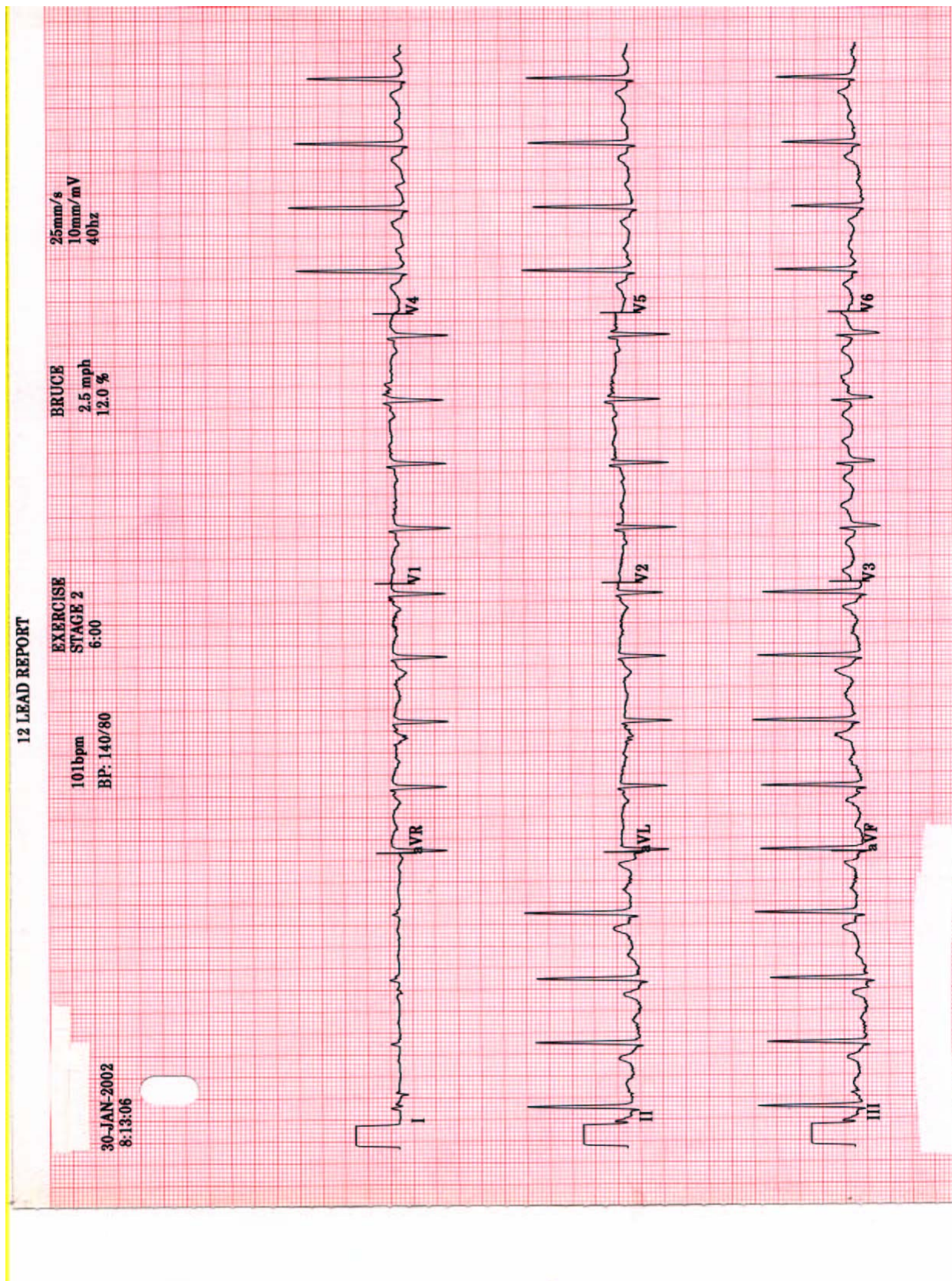
Figure 25-3(b). Stage 2

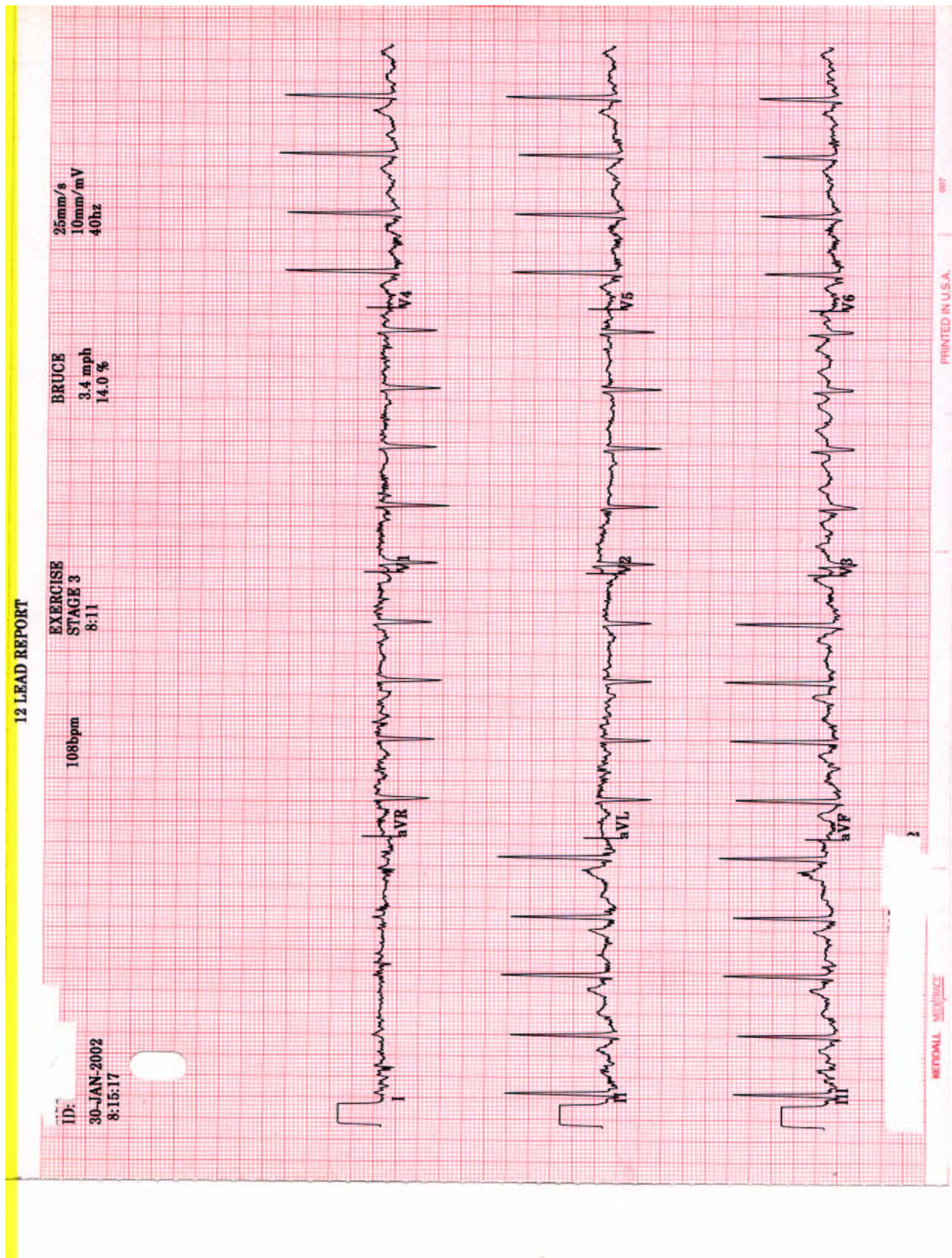
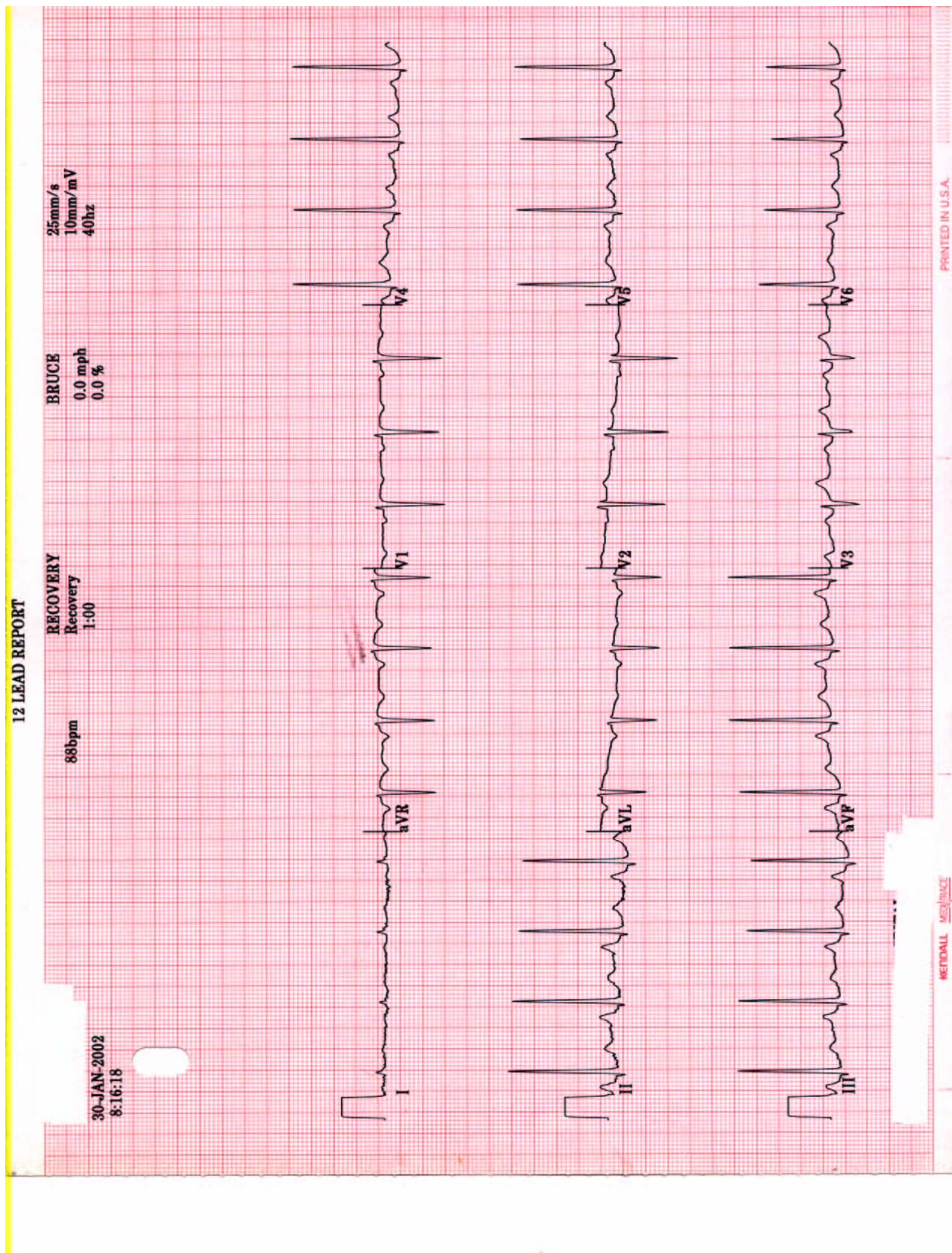
Figure 25-3(c). Stage 3

Figure 25-3(d). Recovery

Recovery continued.

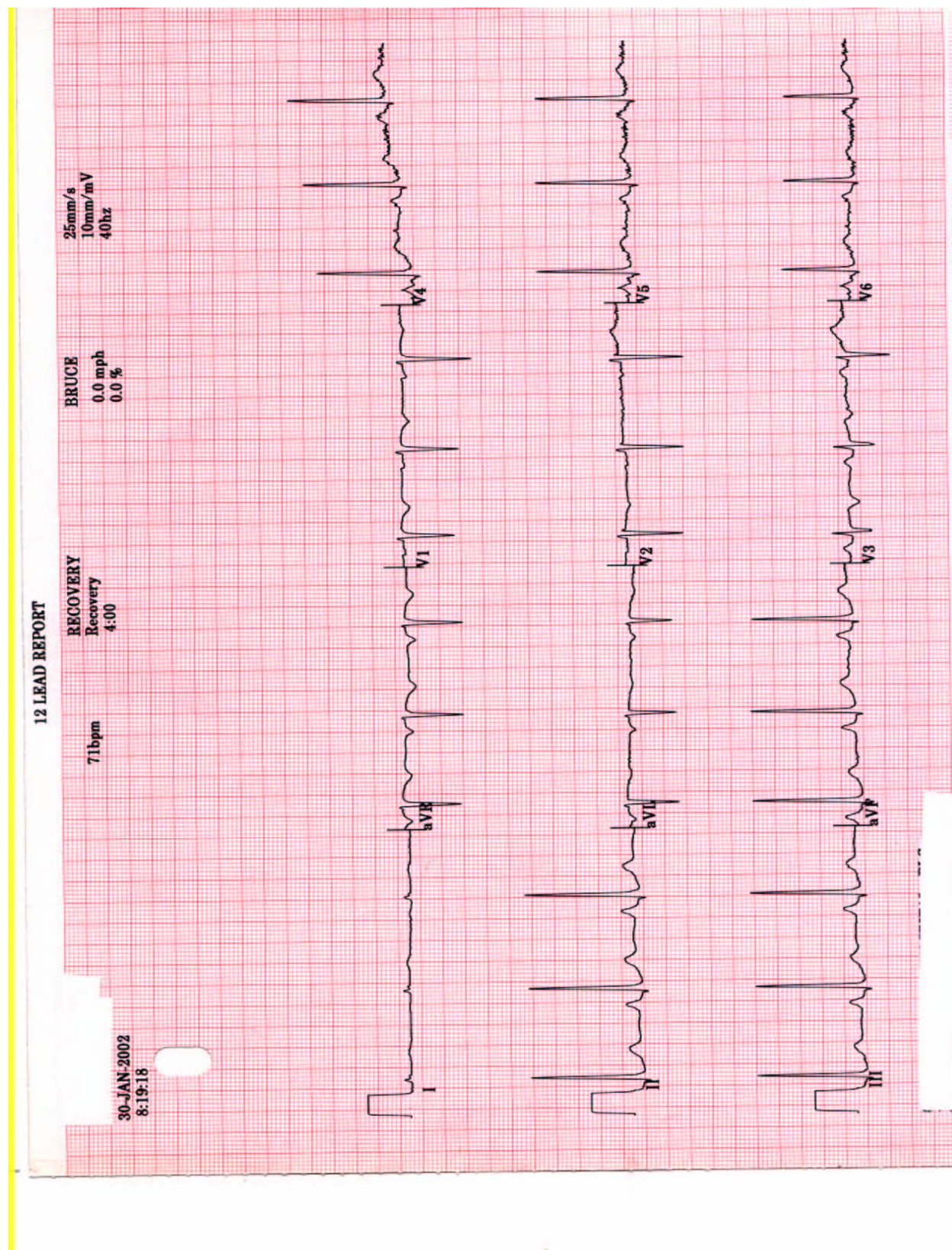
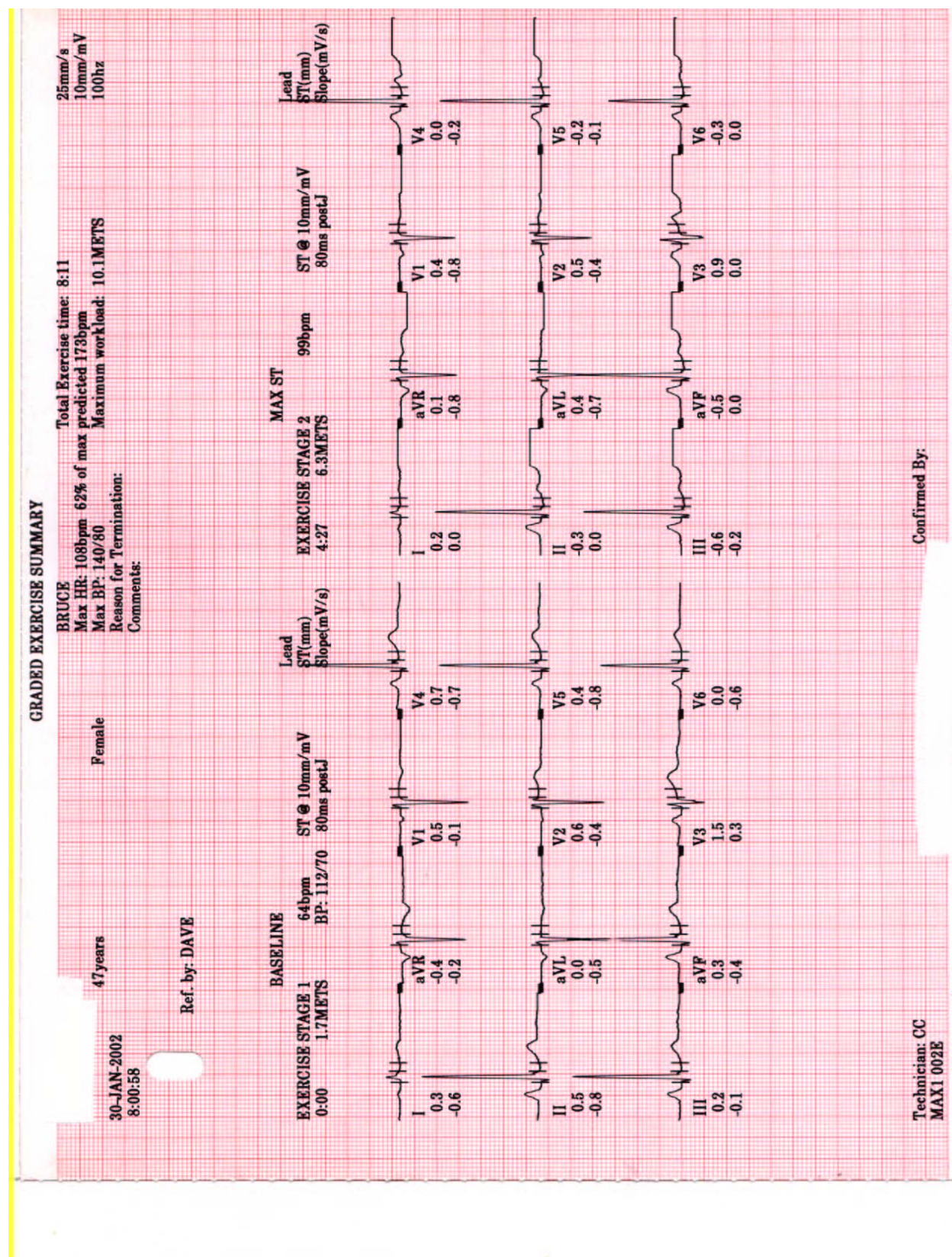
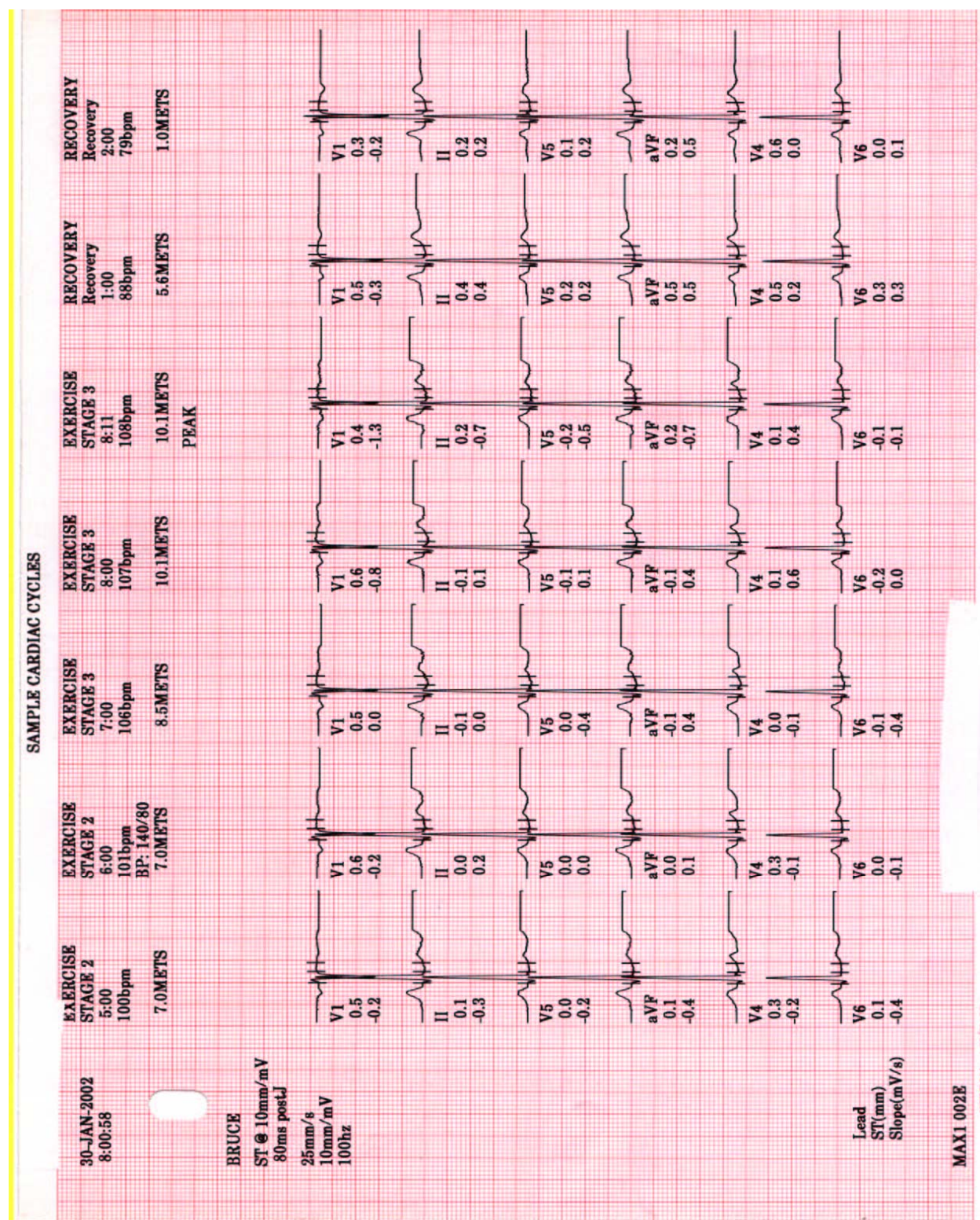


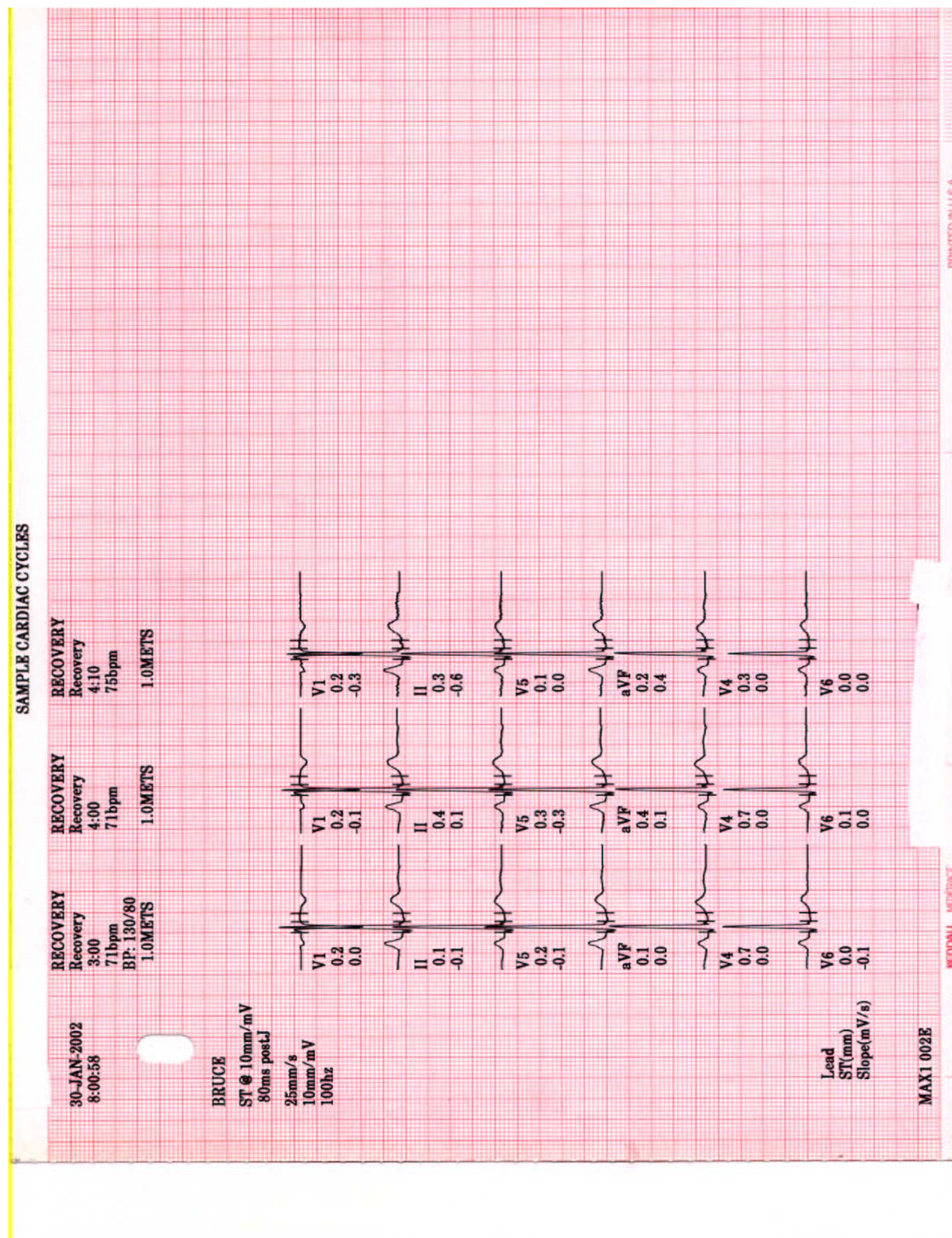
Figure 25-3(e). Exercise Summary



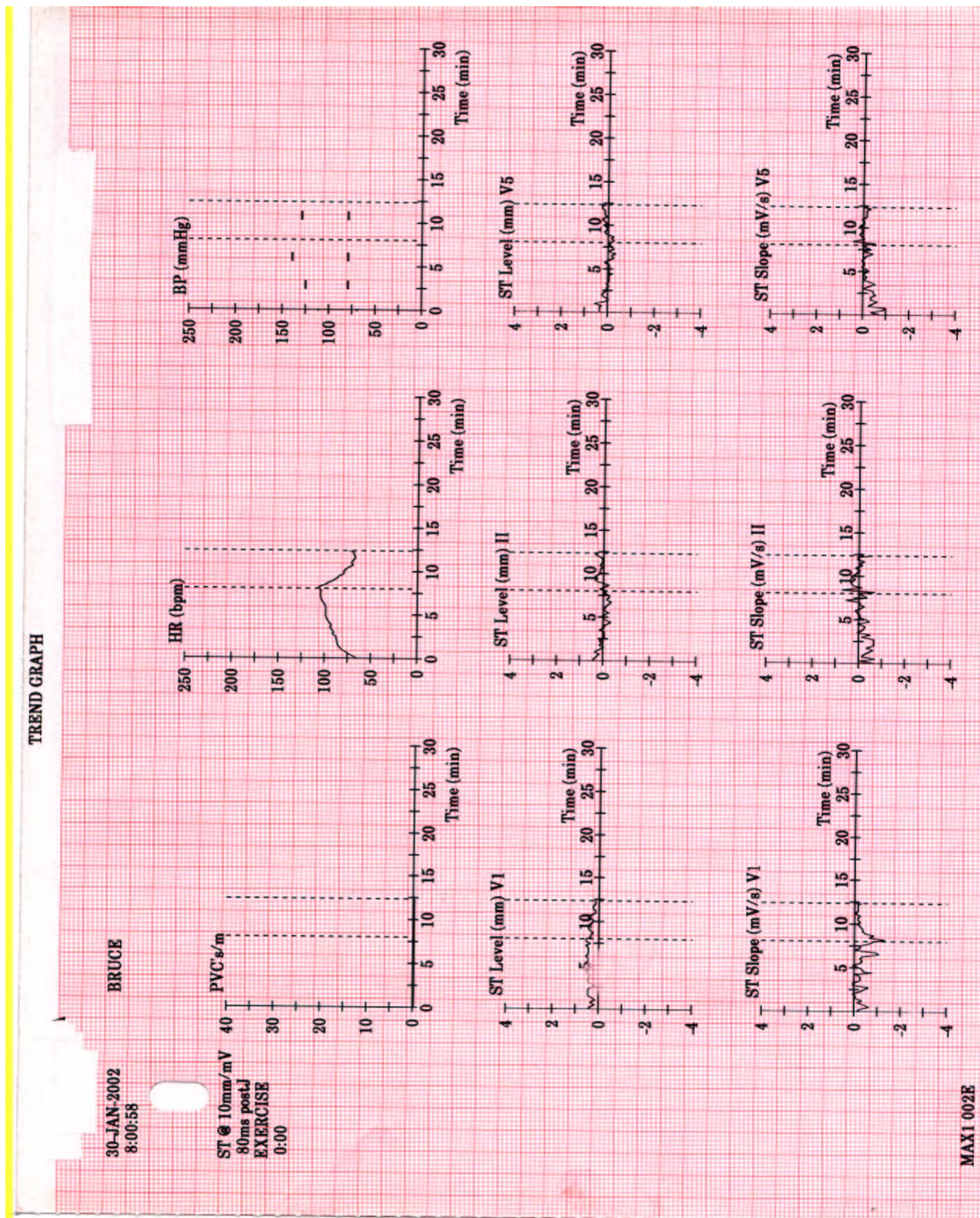
Exercise Summary continued.



Exercise Summary continued.



Exercise Summary continued.



ABNORMAL RESPONSES

**ST Segment
and T Wave
Abnormalities**

ST segment depression is considered the criteria for diagnosing myocardial ischemia. Depression of the ST segment of -1.0 mm or below the baseline lasting 80 msec or longer is accepted as significant evidence of myocardial ischemia. The pattern of ST depression varies from flat or horizontal to downsloping and may be affected by resting ECG abnormalities such as hypertrophy or bundle branch blocks. Pharmacological therapy such as digitalis may also affect ST segment depression. (In some cases the presence of digitalis may prevent diagnostic interpretation of the ST segment.)

Myocardial ischemia is usually proportional with the onset, degree, and duration of ST depression. There is no established rule for discontinuing exercise based on ST depression, but some laboratories use 2-4 mm as an arbitrary value. As some exercise tests are symptom-limited this is quite often the case anyway.

Myocardial oxygen demand is determined mainly by heart rate, ventricular wall tension, and contractility. As a result, myocardial oxygen demand increases during exercise, and the rate of myocardial blood flow also increases proportionally. The subendocardium is the most vulnerable area for ischemia when myocardial blood flow is jeopardized. Left ventricular stroke volume is diminished because of reduced force and velocity.

Transmembrane potentials are also altered by ischemia, as it creates a region of abnormal diastolic current that is detected by the ECG electrodes. The predominant ECG change of subendocardium ischemia is ST segment depression. ST elevation is produced with extensive transmural ischemia, which extends to the epicardial surface.

Other factors that may limit subendocardial blood flow and produce ischemia, in the presence of normal coronary arteries, are ventricular hypertrophy, hypertension, and hypoxia.

ST segment elevation is occasionally seen during exercise. This is most commonly seen in leads directly over areas of paradoxical motion or aneurysm. Acute transmural ischemia may also show ST elevation.

Changes in the polarity and amplitude of the T wave frequently occur during exercise. Some of these changes occur in healthy individuals and should be interpreted along with other test results. These changes include flattening and inversion of the T wave due to hyperventilation and hypokalemia. Individuals that show inverted resting T waves may show positive T waves on exercise and this may be associated with corresponding ST segment depression.

Figure 25-4(a). Criteria for diagnosis of myocardial ischemia.

Horizontal or downsloping ST segment depression ≥ 1 mm
 Horizontal or upsloping ST segment elevation ≥ 1 mm
 Upsloping ST segment depression that is ≥ 1.5 mm depressed at 80 msec beyond the J point

Figure 25-4(b). Findings suggestive of myocardial ischemia.

Horizontal or downsloping ST segment depression > 0.5 mm
 Upsloping ST segment depression that is between 0.7 and 1.5 mm at 80 msec
 Hypotension during exercise
 Frequent high-grade, ventricular ectopy
 Exercise-induced chest pain typical of angina
 Normalization of abnormal ST segments or resolution of T wave inversion
 A new third heart sound or murmur at peak exercise.

Figure 25-4(c). Responses suggestive of severe ischemic heart disease.**Electrocardiographic responses**

ST depression > 2.5 mm
 ST segment depression beginning before three minutes exercise time
 Downsloping ST segment depression or ST segment elevation
 ST segment depression lasting more than eight minutes into the recovery period
 Serious dysrhythmias at low heart rates (< 130 beats per minute)

Non ECG responses

Chronotropic incompetence (heart rate < 120 beats per minute during peak exercise)
 Hypotension (> 10 mm Hg fall in systolic blood pressure while exercising)
 Inability to exercise past three minutes

The following is a series of ECG tracings on a 40 year old male with chest pain.

Figure 25-5(a). Sample Positive Treadmill Test

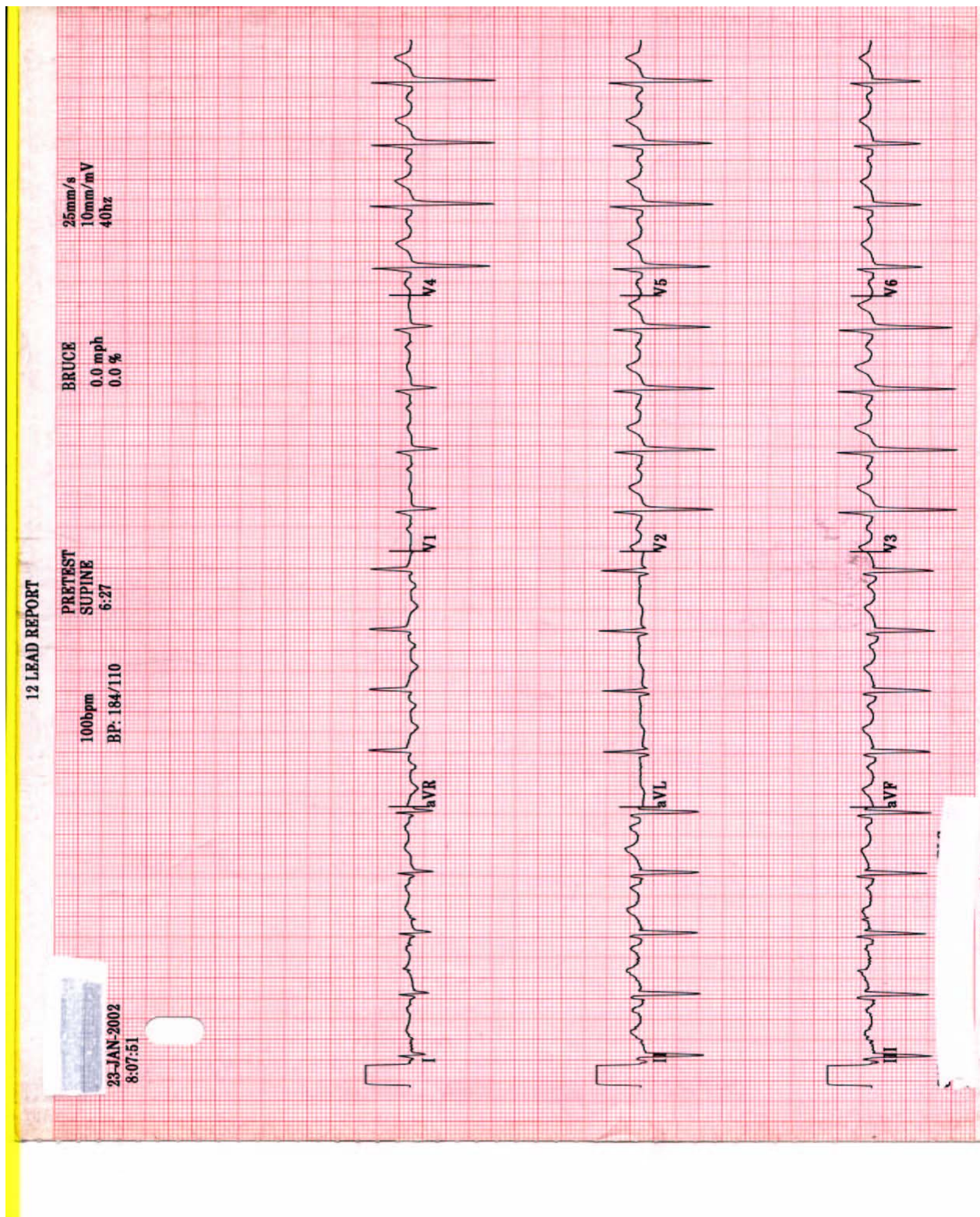


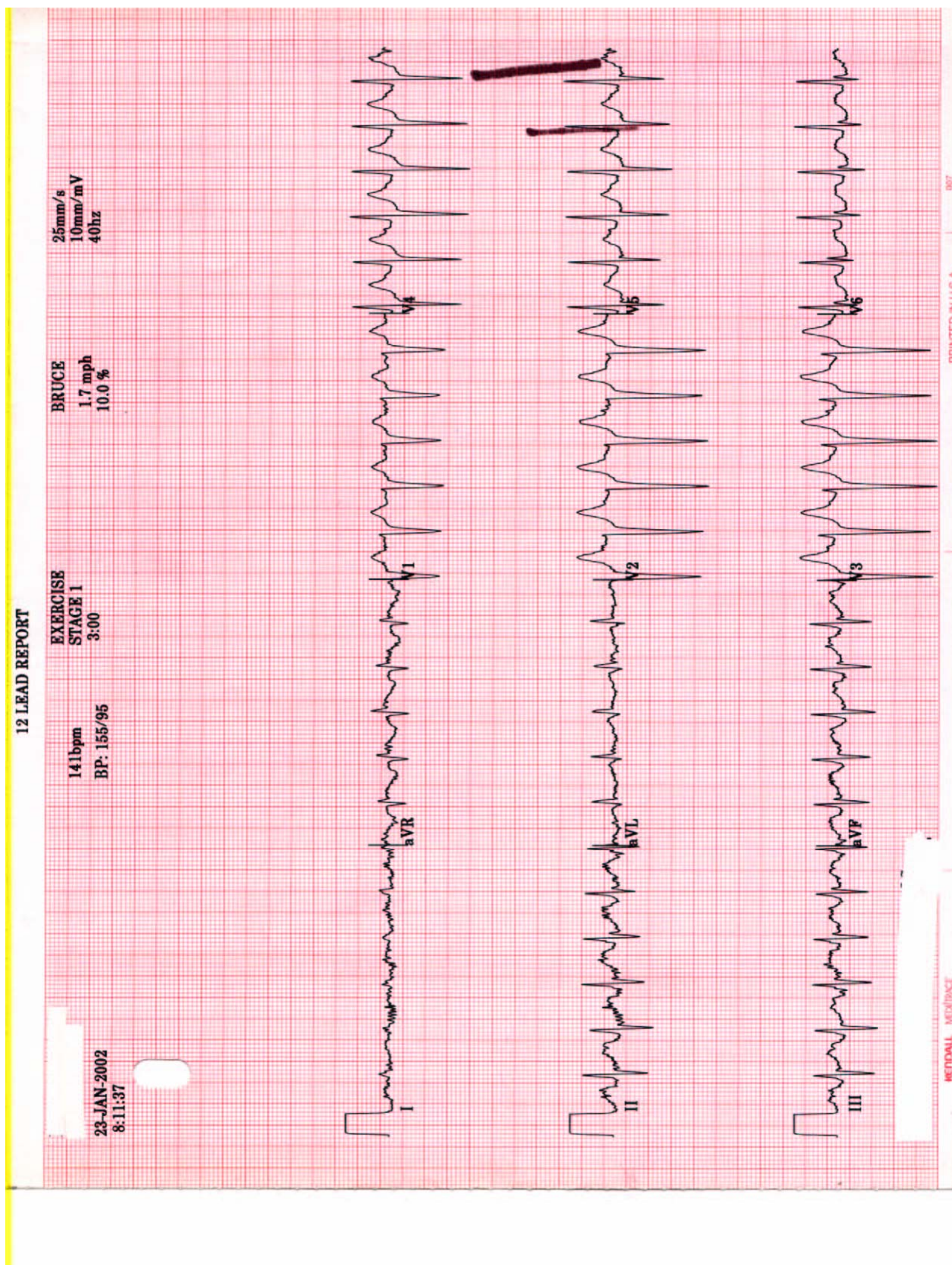
Figure 25-5(b). 1 minute exercise Bruce protocol

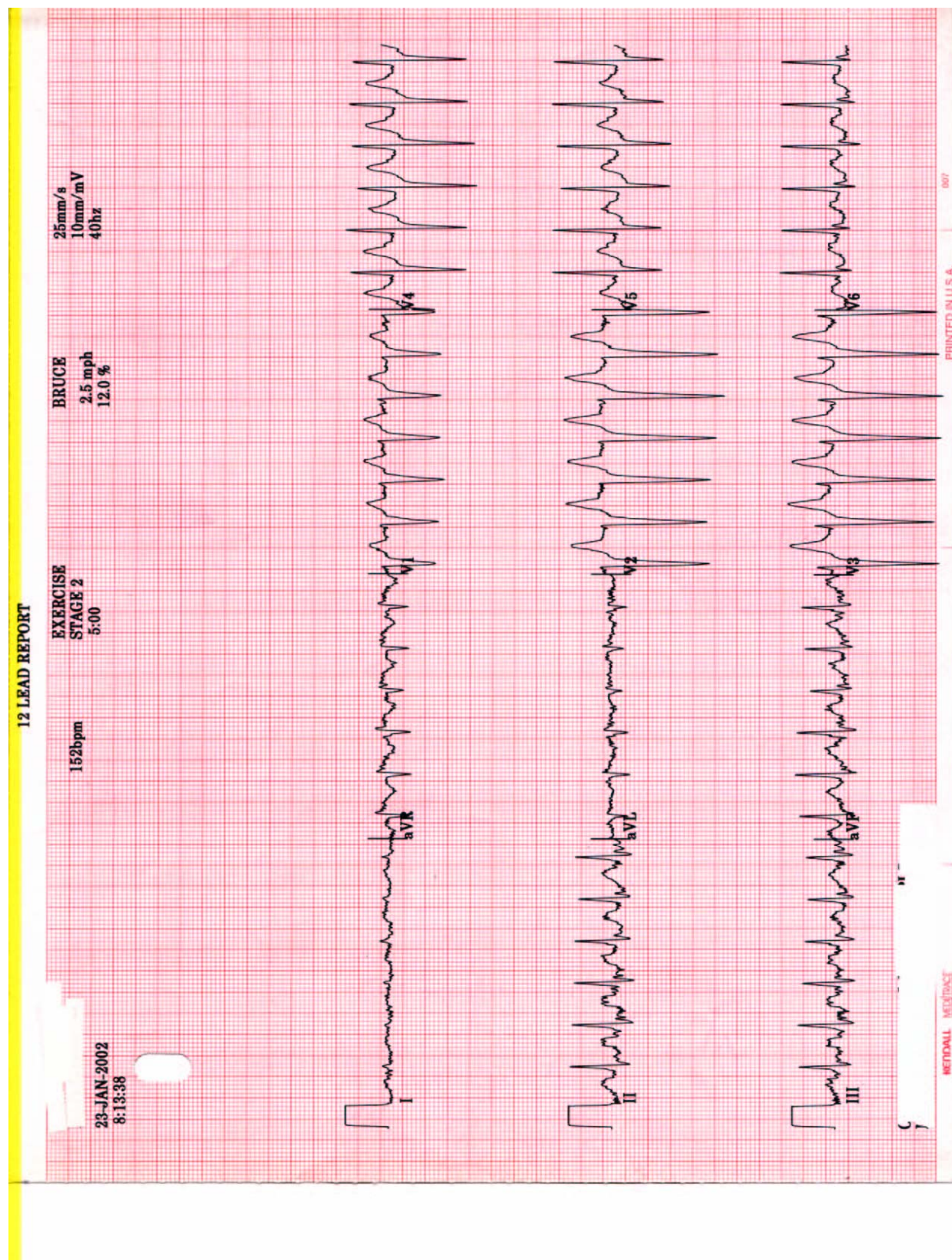
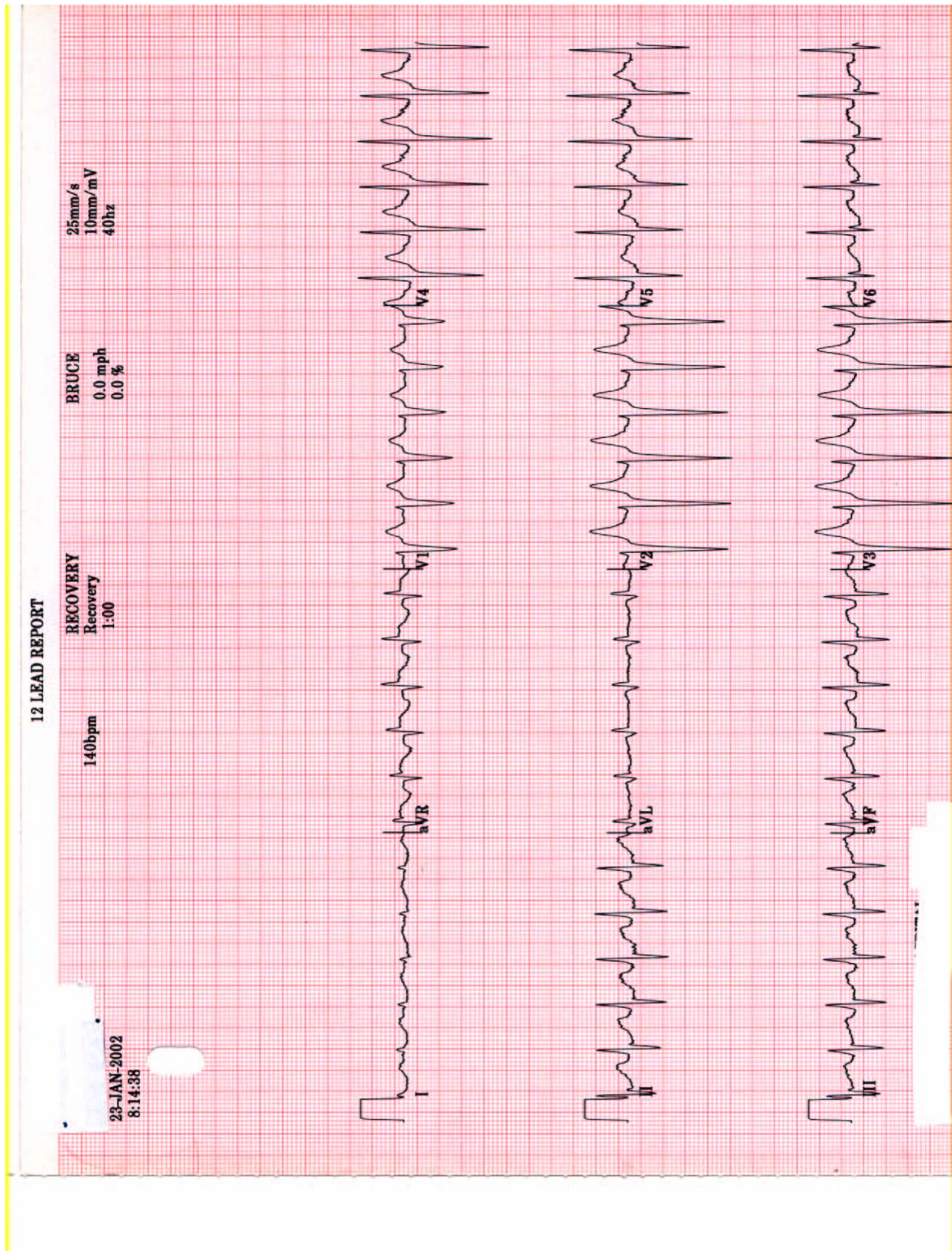
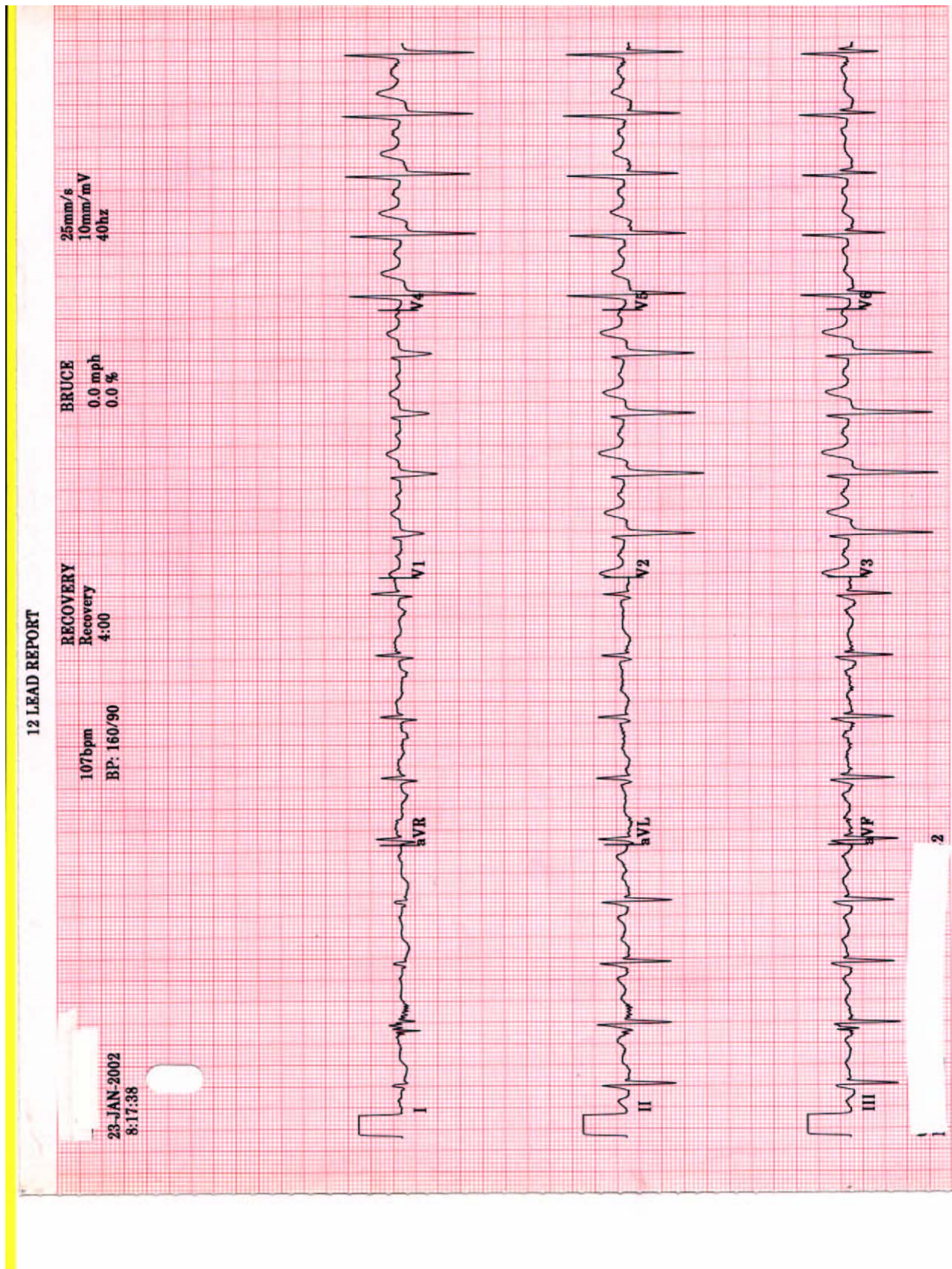
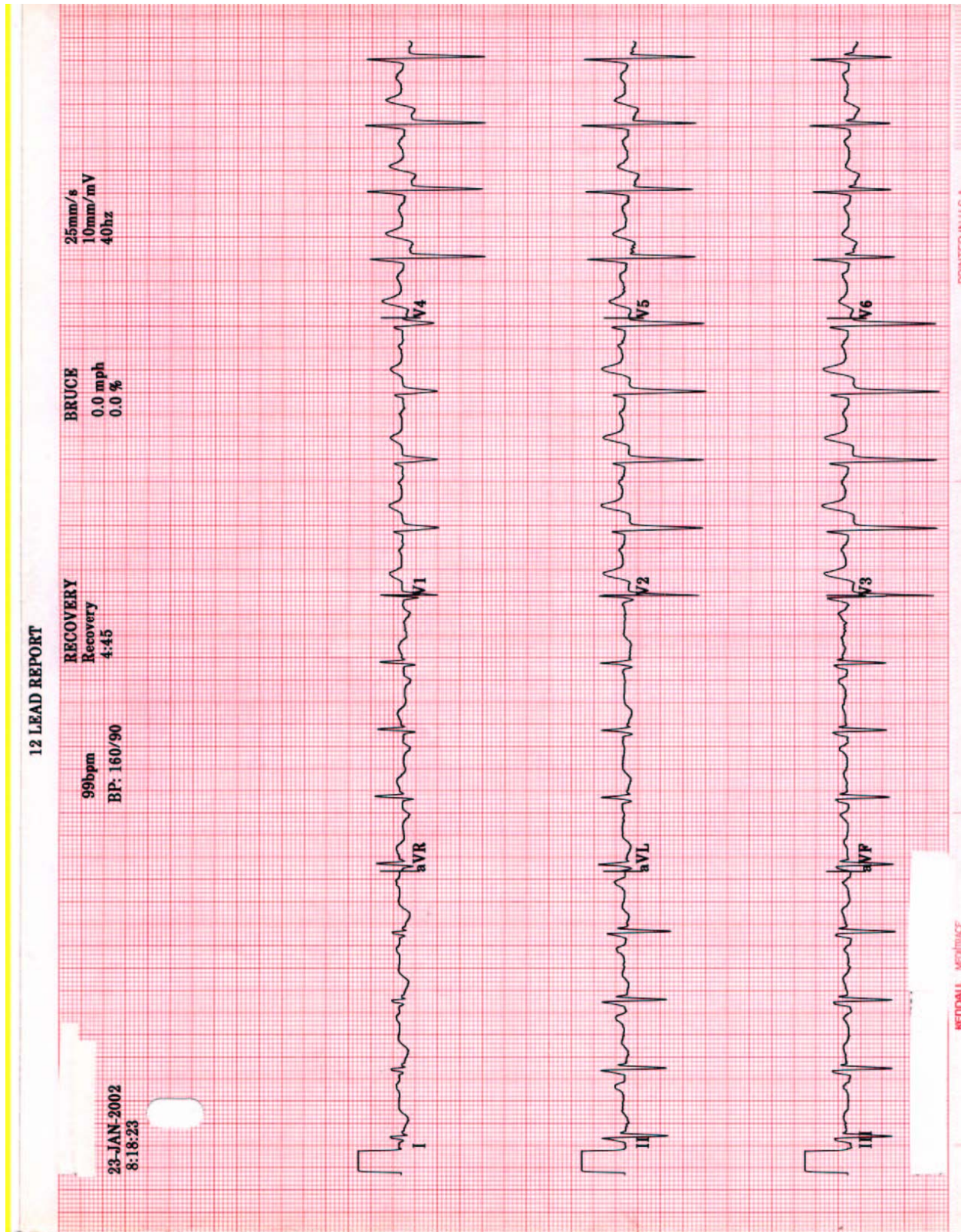
Figure 25-5(d). Stage 2

Figure 25-5(e). Recovery

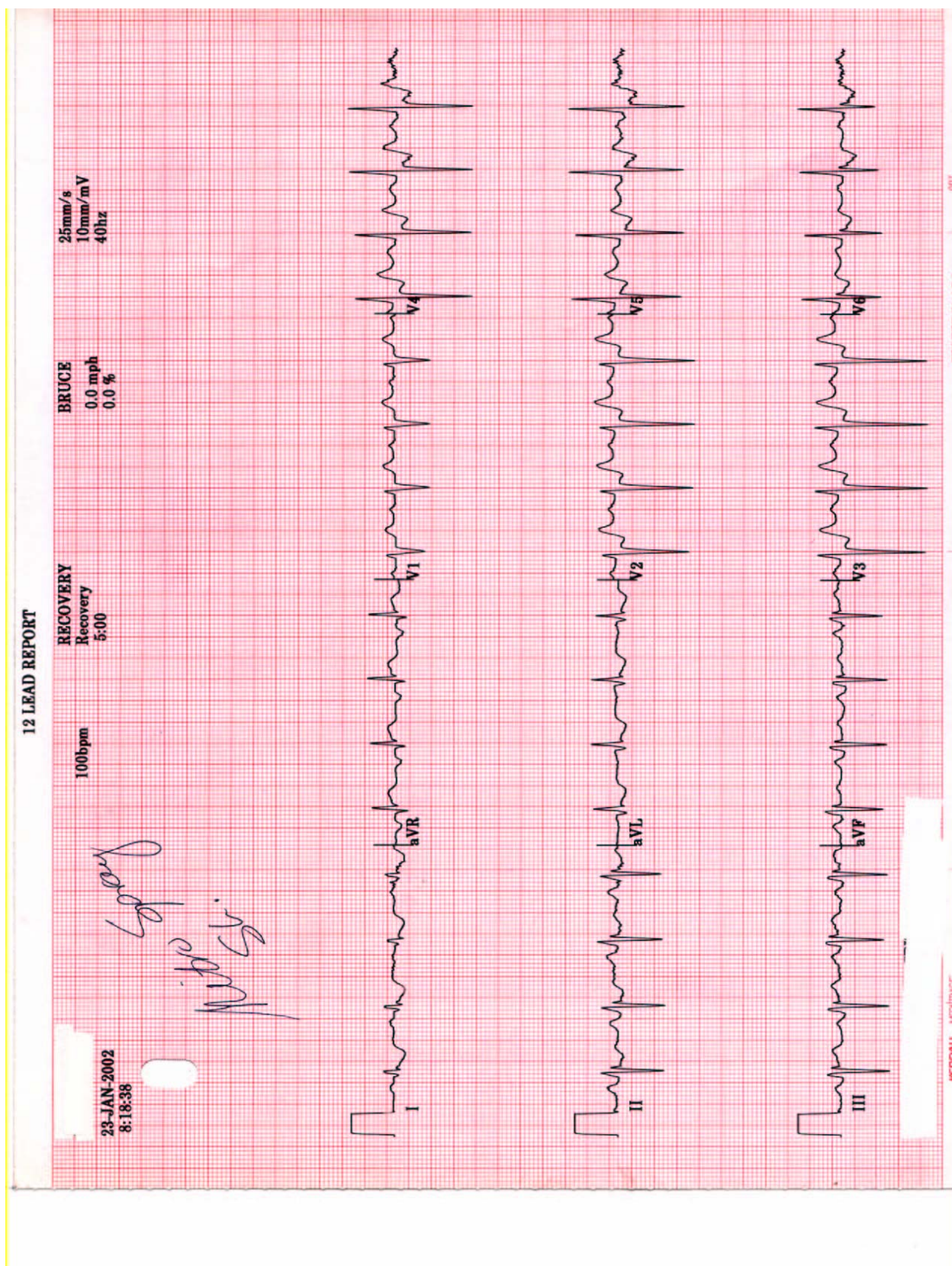
Recovery continued.



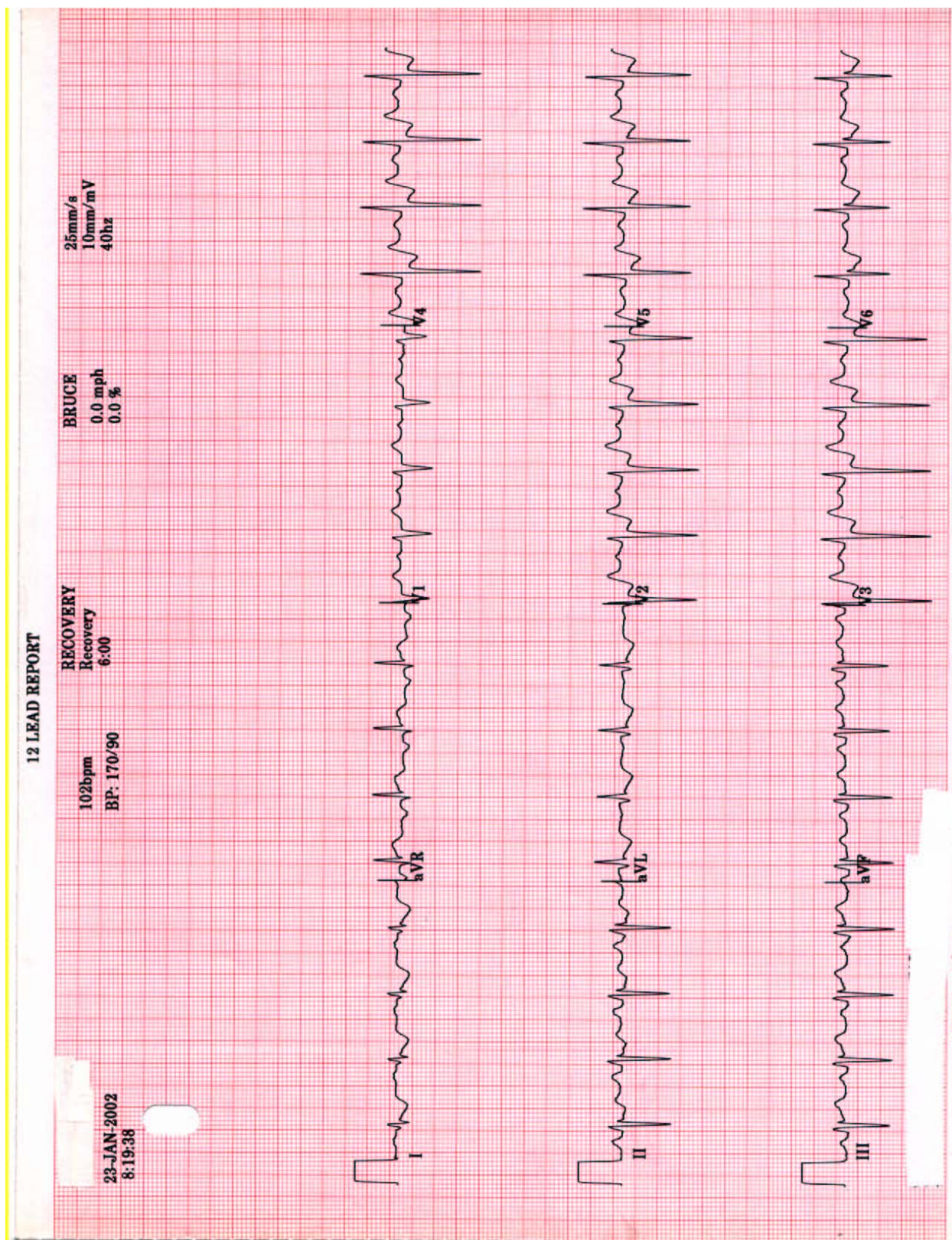
Recovery continued.



Recovery continued.



Recovery continued.



Recovery continued.

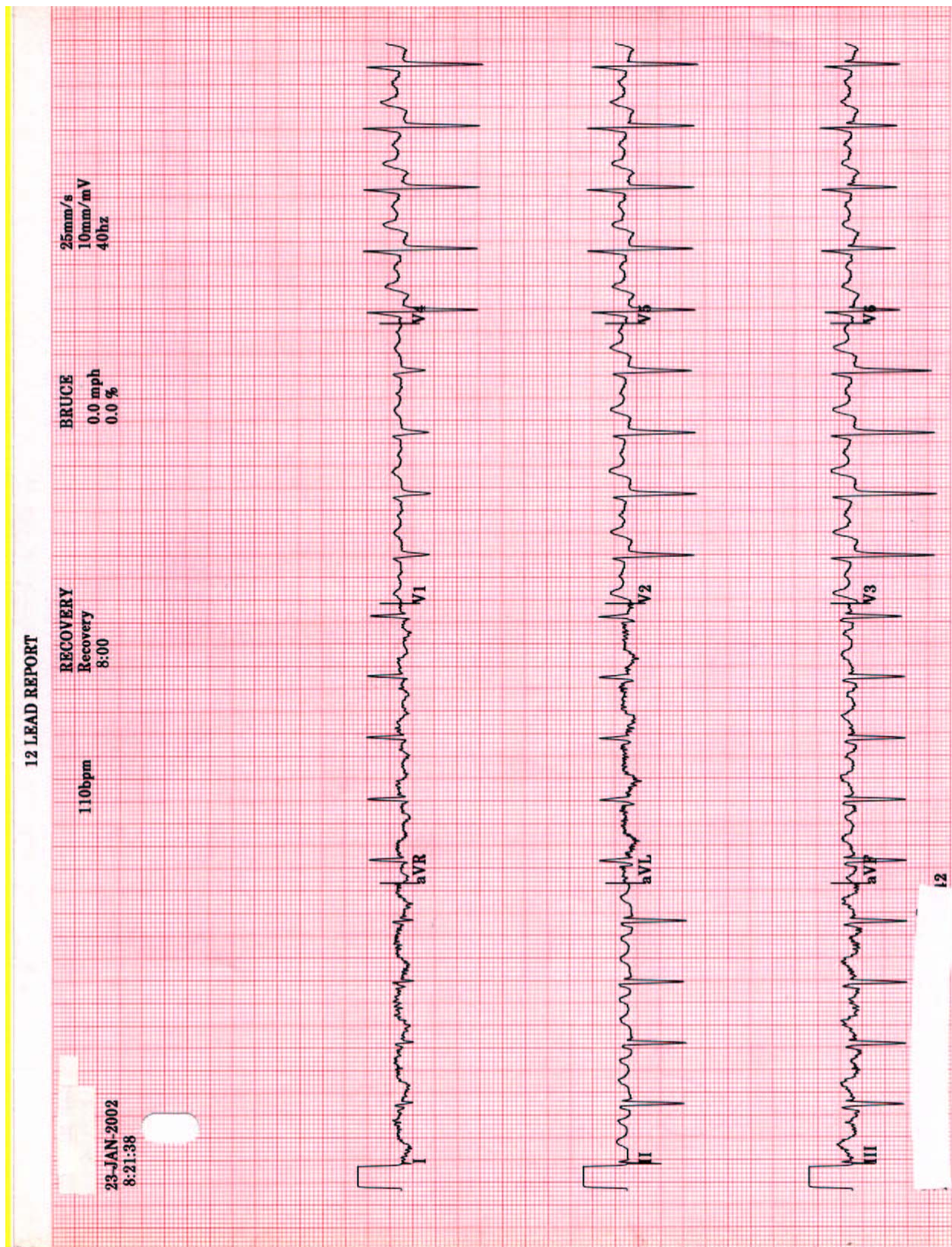
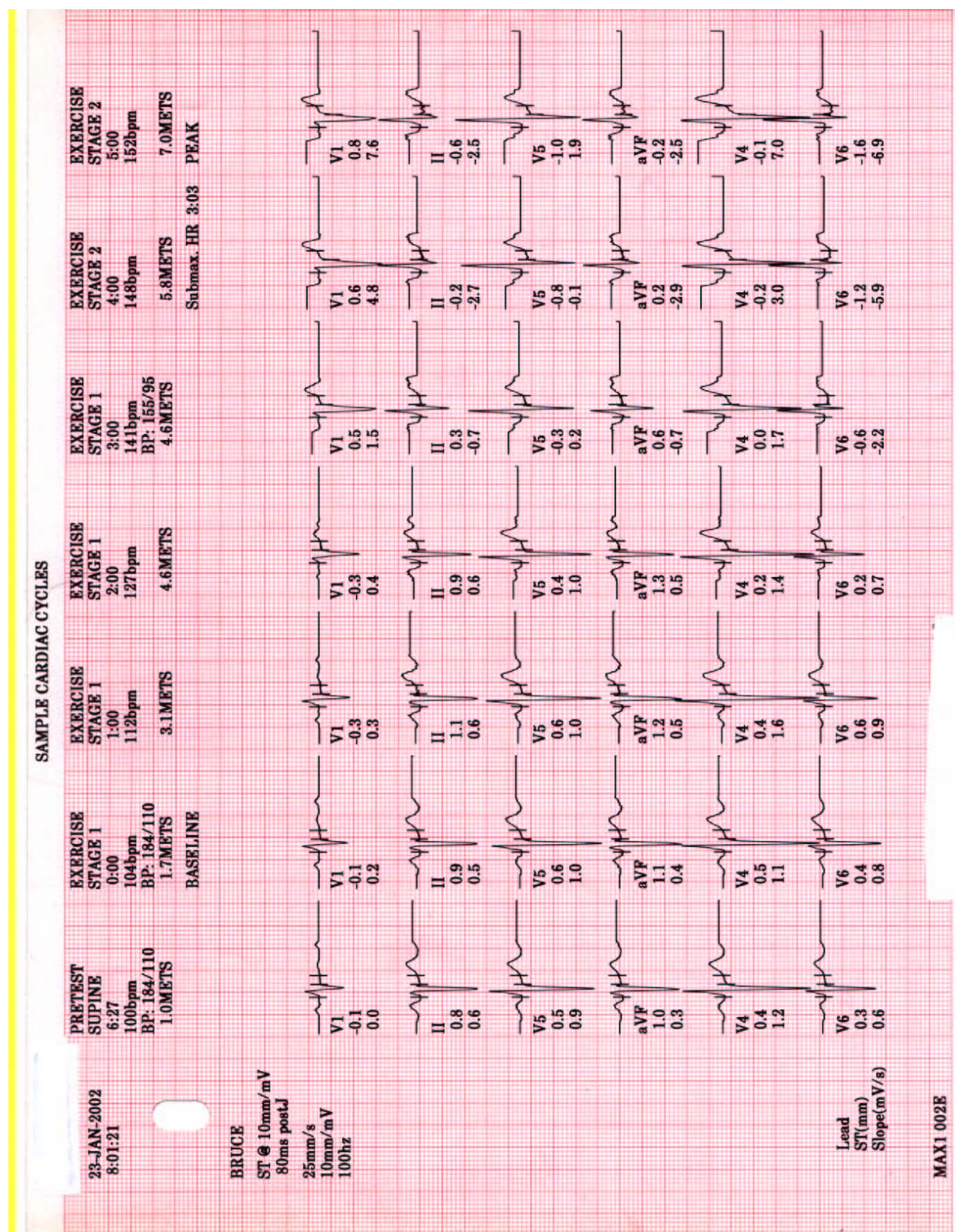
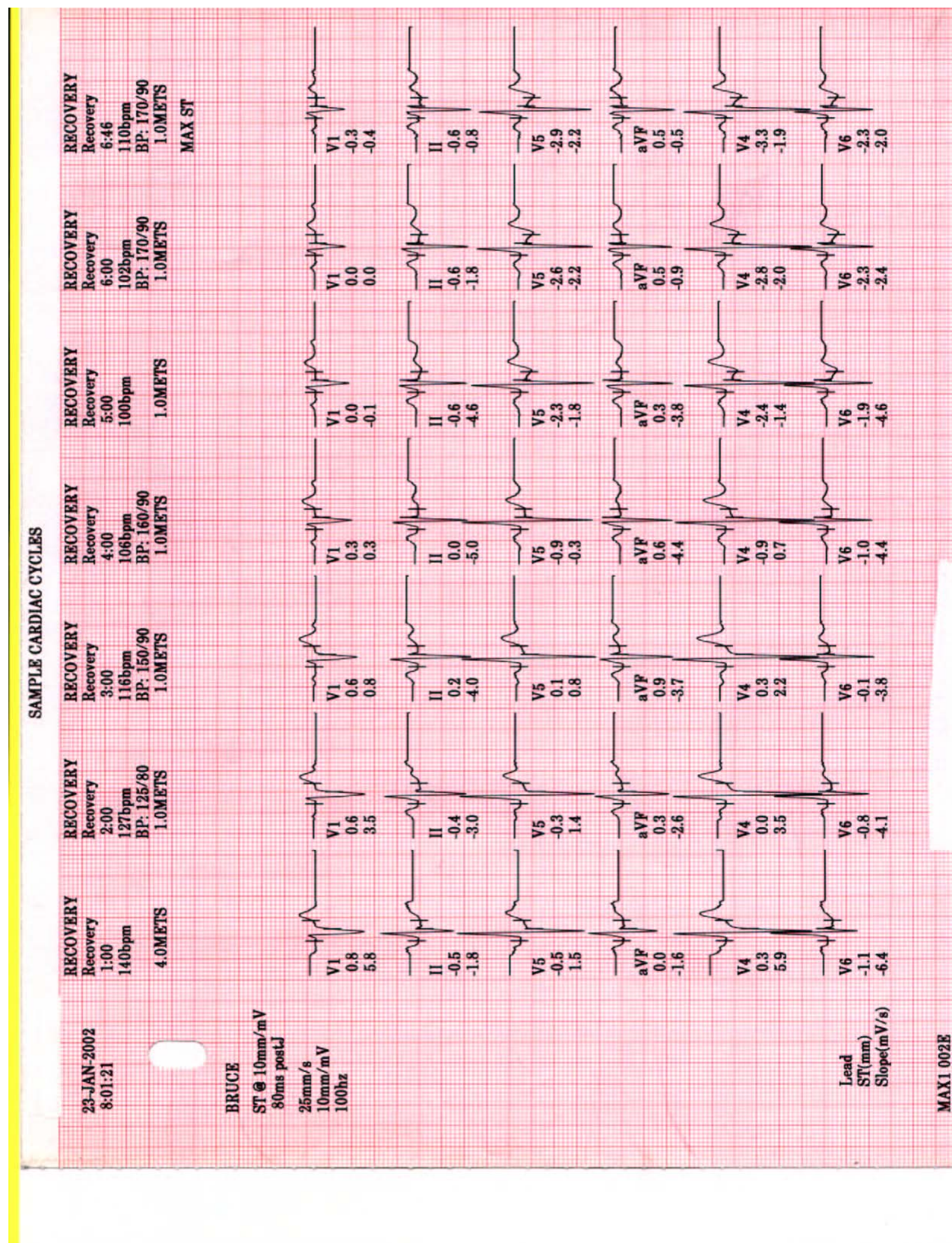


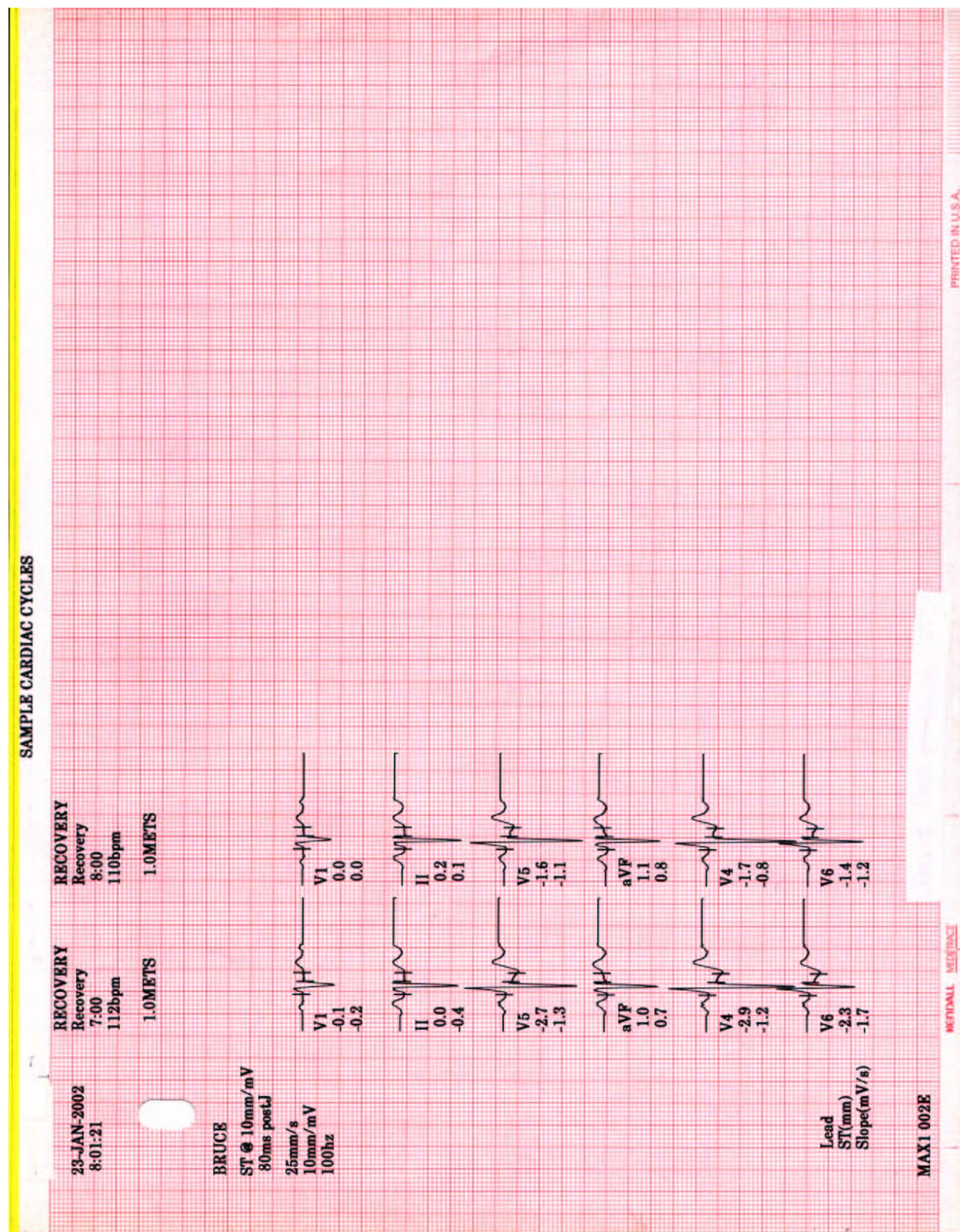
Figure 25-5(f). Summary ST segments



Summary ST Segments continued.



Summary ST Segments continued.



Summary ST Segments continued.

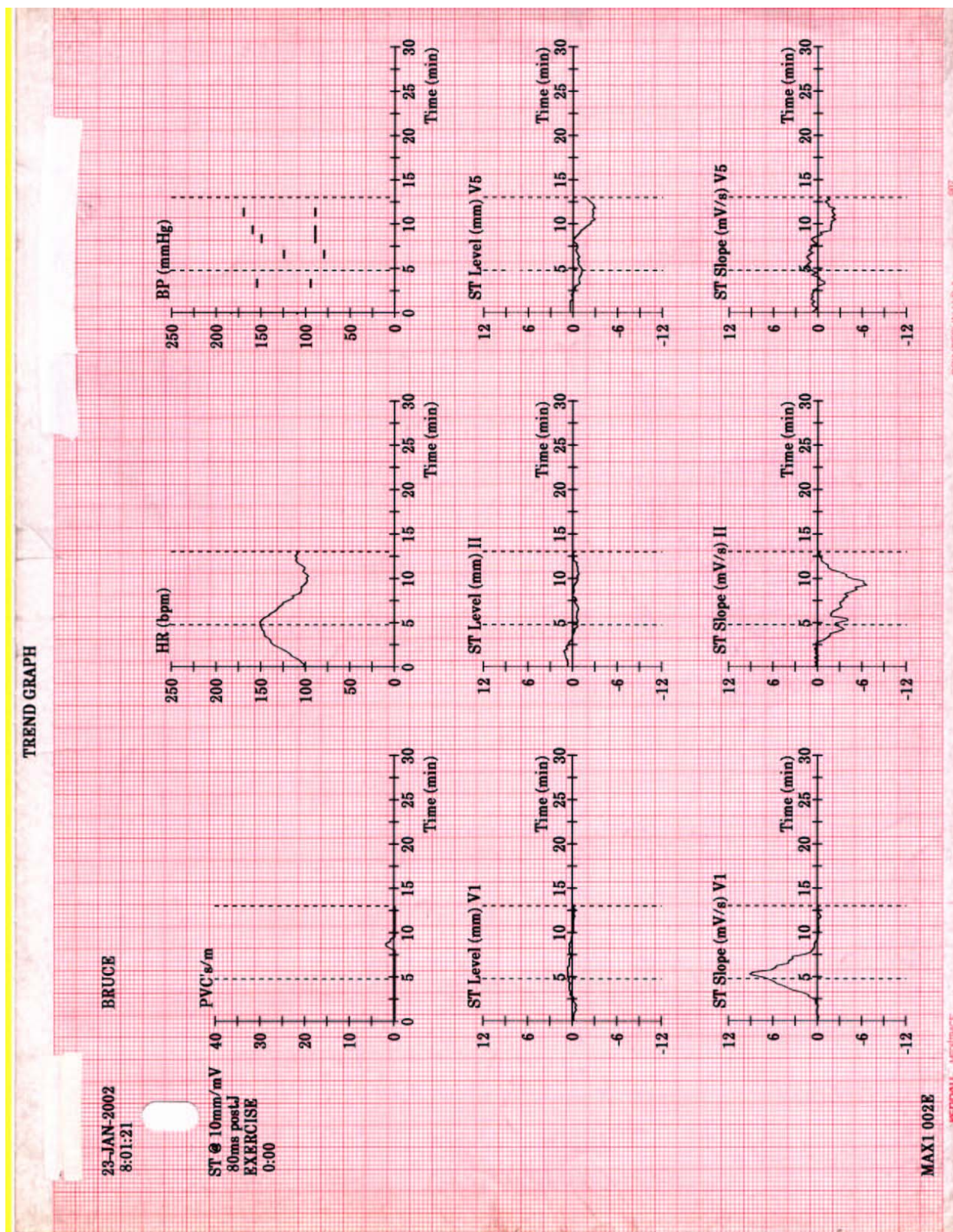


Figure 25-5(g) 2nd Example of Abnormal Response – New Patient

Ward
Telephone:

EXERCISE STRESS TEST REPORT

Patient Name: [REDACTED]
 Patient ID: [REDACTED]
 Height: 0 cm
 Weight: 0 kg

DOB: [REDACTED]
 Age: 72
 Gender: Male
 Race: --

Study Date: 2002/09/05
 Test Type: --
 Protocol: BRUCE

Referring Physician: --
 Attending Physician: [REDACTED]

Medications:
 --

Medical History:
 --

Reason for Test:
 IHD

Exercise Test Summary

Phase Name	Stage Name	Time in Stage	Speed (mph)	Grade (%)	HR (bpm)	BP (mmHg)	Comment
PRETEST	WARM-UP	03:54	0.90	0.00	80	98/60	1:46 SITTING
EXERCISE	STAGE 1	03:00	1.70	10.00	91	110/64	1:30 No symptoms
	STAGE 2	03:00	2.50	12.00	100	120/64	5:47 No symptoms
	STAGE 3	03:00	3.40	14.00	114	120/64	8:51 No symptoms
	STAGE 4	02:01	4.20	16.00	123		9:55 ARM PAIN
RECOVERY		04:56	0.00	0.00	83	118/72	

The patient exercised according to the BRUCE for 11:01, achieving a work level of Max. METS: 13.40. Resting heart rate initially 79 bpm, rose to a max. heart rate of 123 bpm which represents 83 % of the maximal age-predicted heart rate. Resting blood pressure 98/60 mmHg, rose to a maximum blood pressure of 138/70 mmHg. The exercise test was stopped due to ARM PAIN WITH SOME ECG CHANGES.

Interpretation

Summary: Resting ECG: normal. Functional Capacity: above average (>20%). HR Response to Exercise: appropriate. BP Response to Exercise: normal resting BP - appropriate response. Chest Pain: none. Arrhythmias: none. ST Changes: Depression upsloping. Overall Impression: Positive stress test typical of ischemia.

Conclusions

MILDLY POSITIVE TREADMILL TEST WITH MILD ISCHEMIA ON ECG

Physician _____ Technician _____

2nd Example of Abnormal Response continued

TABULAR SUMMARY

Patient ID: 2002/09/05 13:47:07 72 years Male

Meds:

Test Reason: IHD

Medical History:

Ref. MD: Ordering MD:

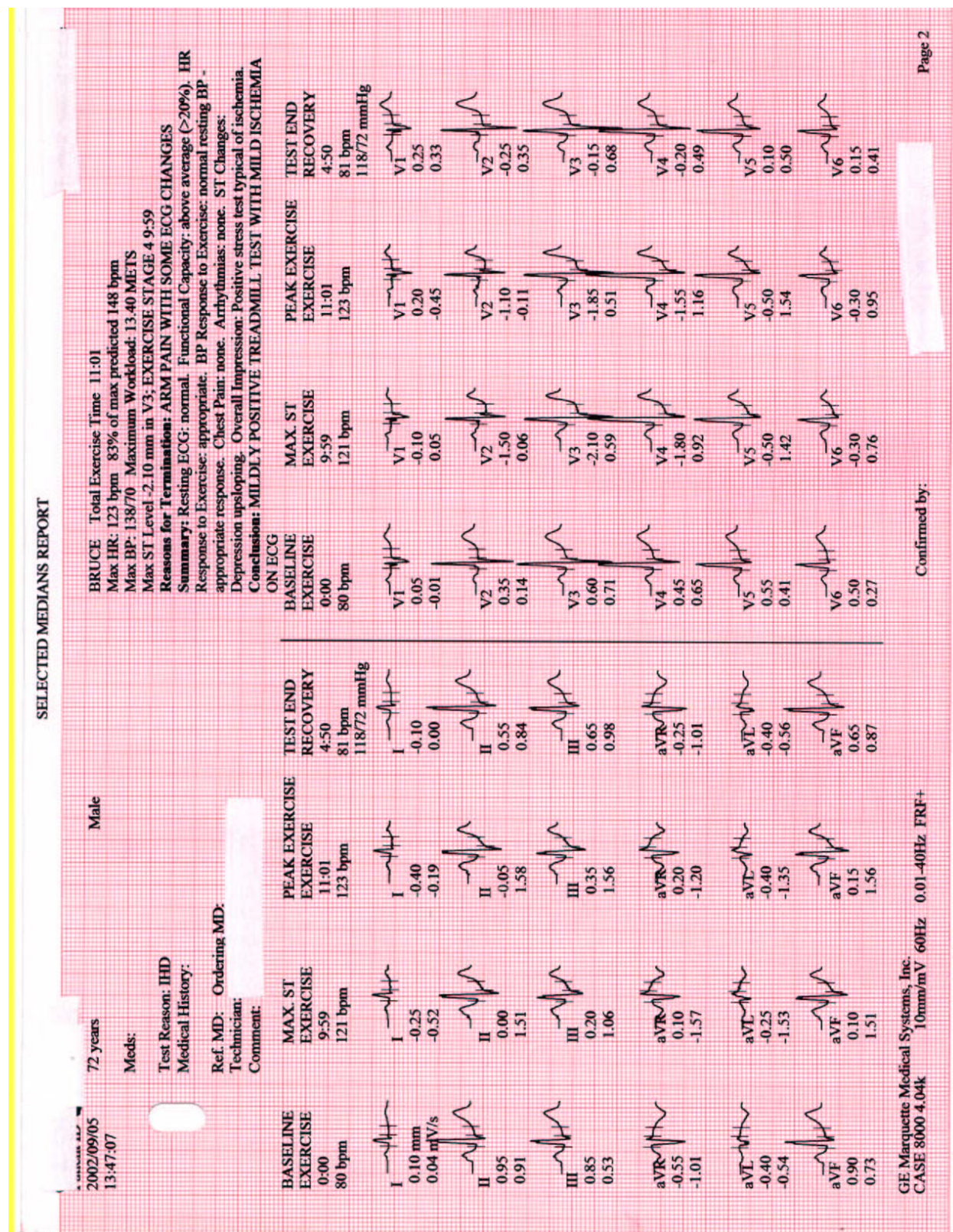
BRUCE Total Exercise Time 11:01
 Max HR: 123 bpm 83% of max predicted 148 bpm
 Max BP: 138/70 Maximum Workload: 13.40 METS
 Max ST Level -2.10 mm in V3; EXERCISE STAGE 4 9:59
Reasons for Termination: ARM PAIN WITH SOME ECG CHANGES
Summary: Resting ECG: normal. Functional Capacity: above average (>20%). HR Response to Exercise: appropriate. BP Response to Exercise: normal resting BP - appropriate response. Chest Pain: none. Arrhythmias: none. ST Changes: Depression upsloping. Overall Impression: Positive stress test typical of ischemia.
Conclusion: MILDLY POSITIVE TREADMILL TEST WITH MILD ISCHEMIA ON ECG

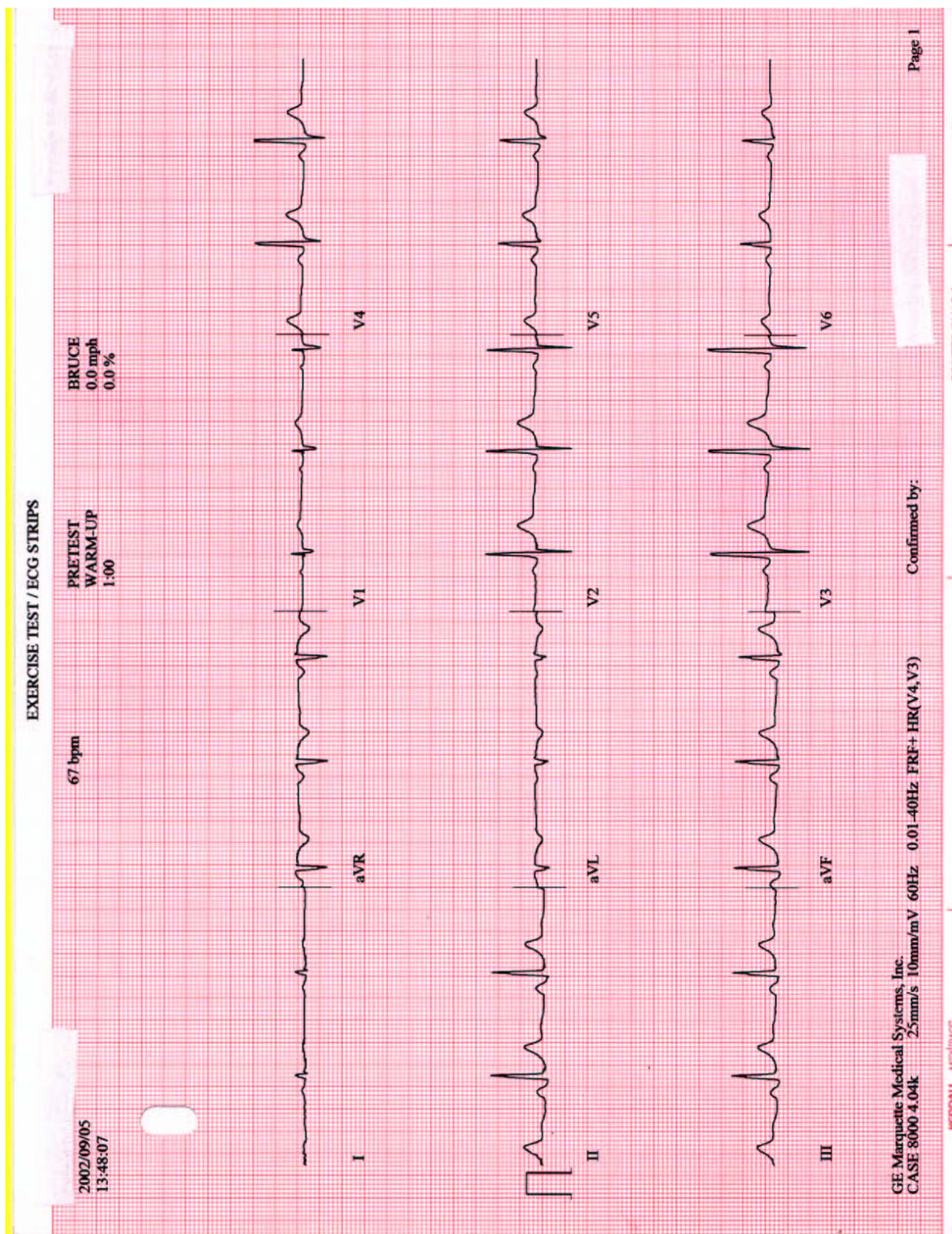
Phase Name	Stage Name	Time in Stage	Speed (mph)	Grade (%)	Workload (METS)	HR (bpm)	BP (mmHg)	RPP (*100)	VE (/min)	ST Level V3(mm)	Comment
PRETEST	WARM-UP	03:54	0.90	0.00	1.6	80	98/60	78	0	0.60	1:46 SITTING
EXERCISE	STAGE 1	03:00	1.70	10.00	4.6	91	110/64	100	0	0.35	1:30 No symptoms
	STAGE 2	03:00	2.50	12.00	7.0	100	120/64	120	0	-0.70	5:47 No symptoms
	STAGE 3	03:00	3.40	14.00	10.1	114	120/64	136	0	-1.15	8:51 No symptoms
	STAGE 4	02:01	4.20	16.00	13.4	123	120/64	97	0	-1.85	9:55 ARM PAIN
RECOVERY		04:56	0.00	0.00	1.0	83	118/72	97	0	-0.05	

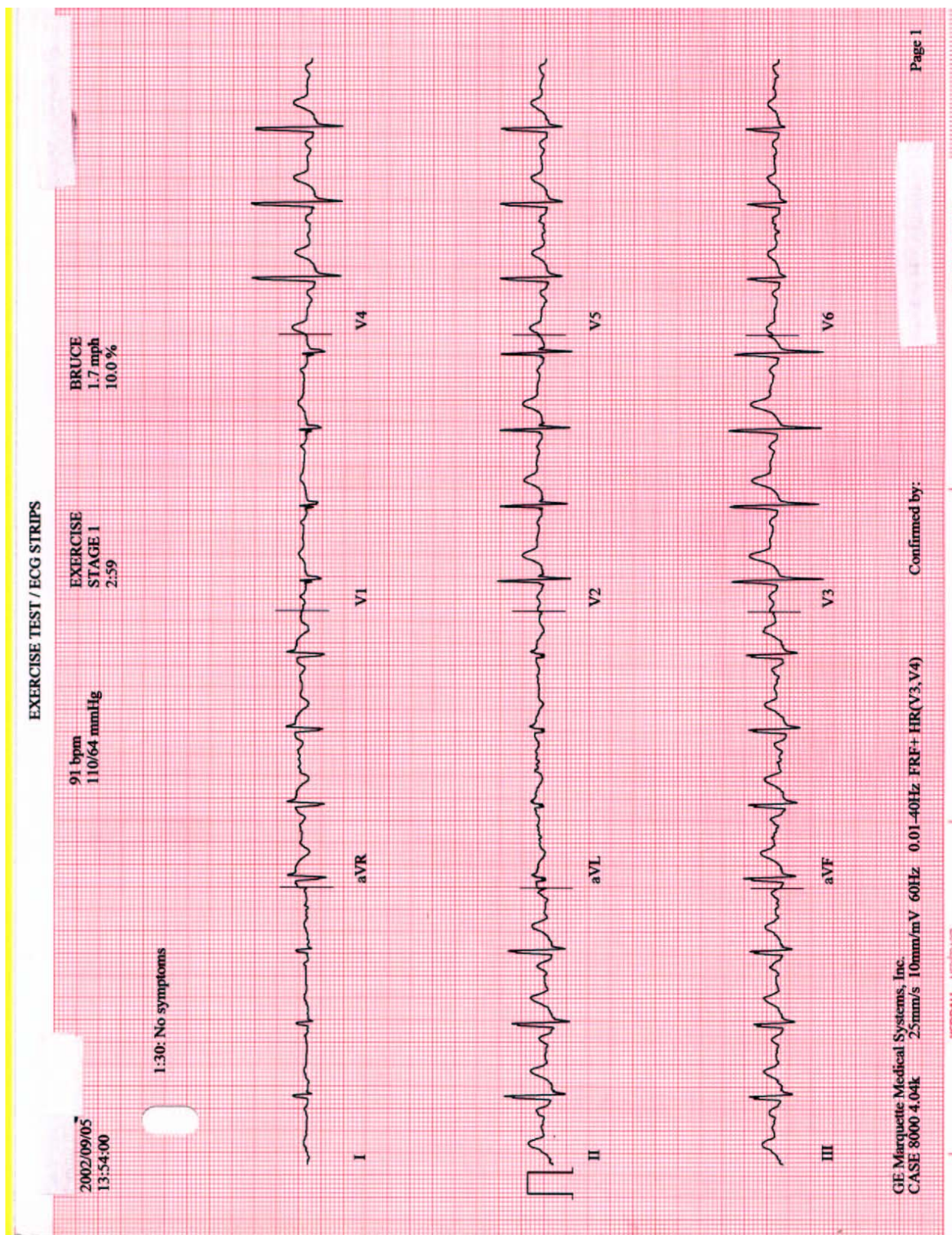
GE Marquette Medical Systems, Inc.
 CASE 8000 4.04k

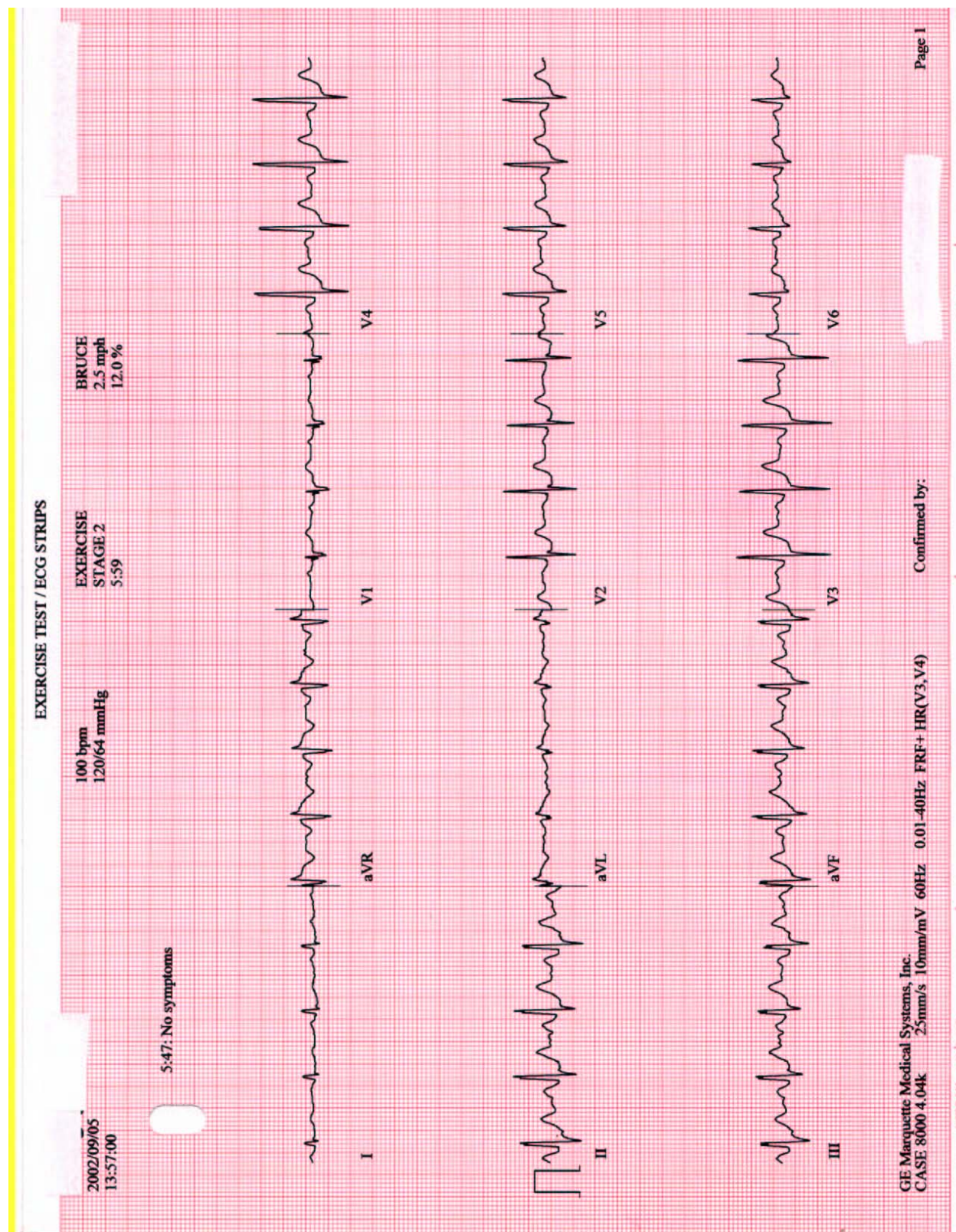
Confirmed by: _____

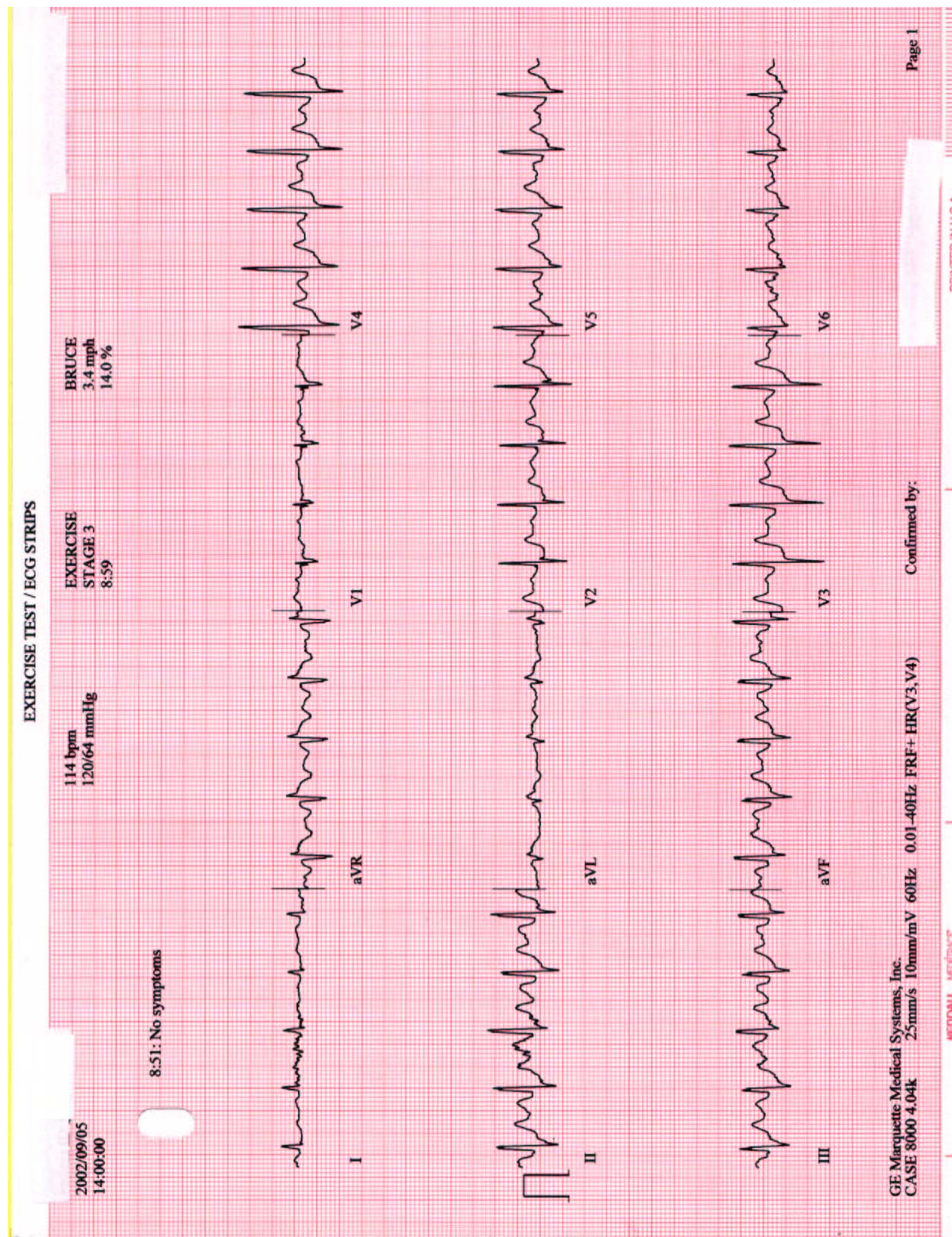
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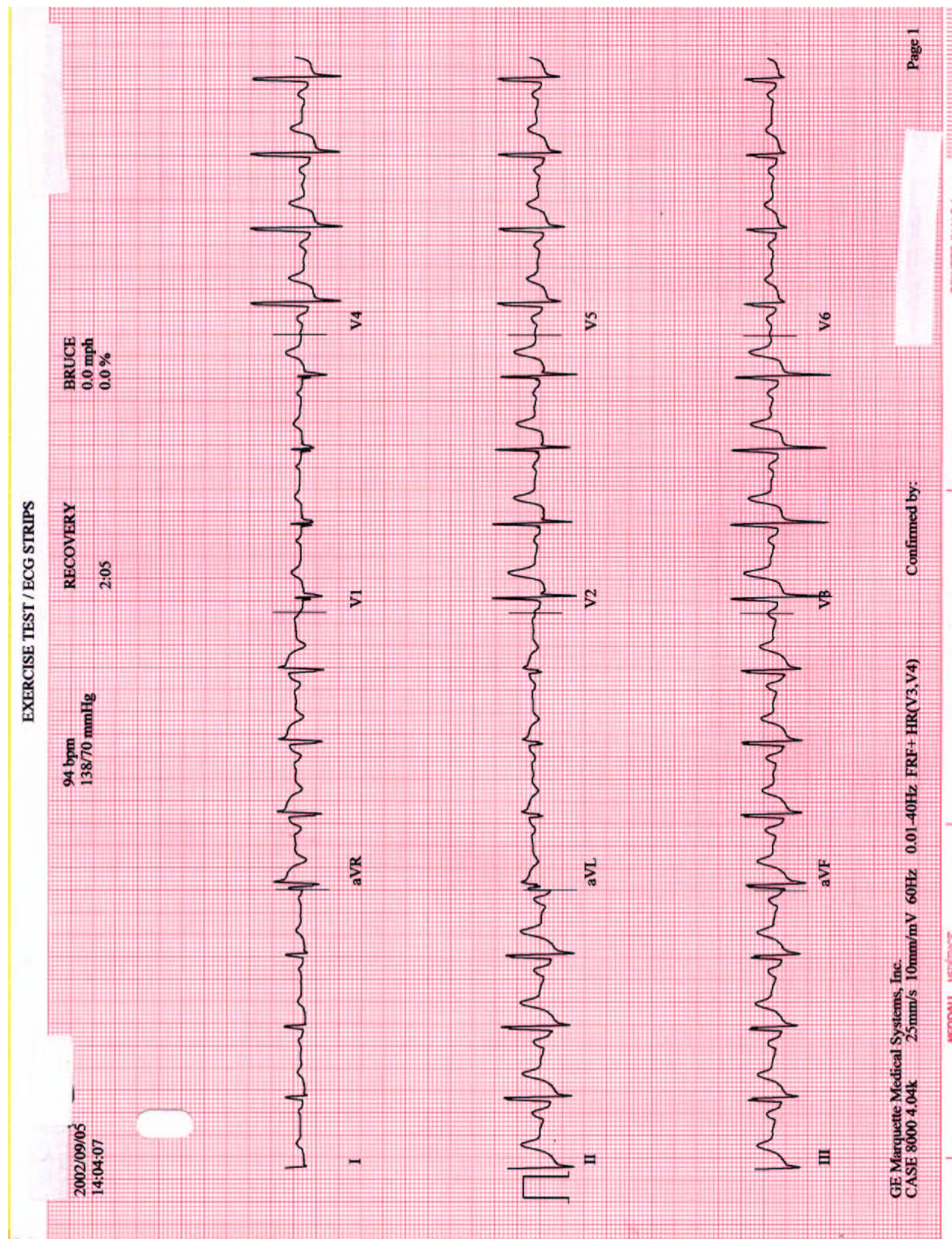
2nd Example of Abnormal Response continued

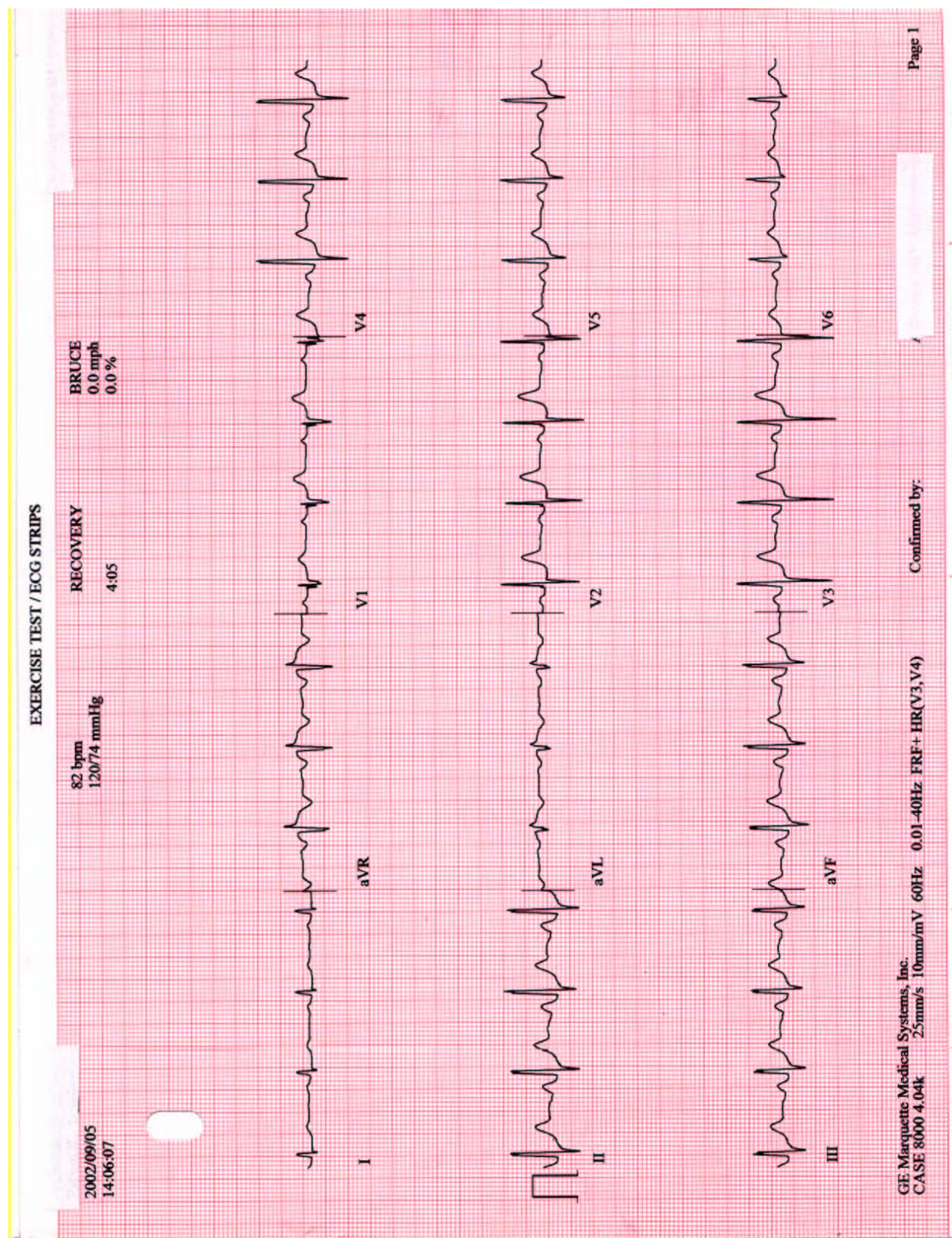
2nd Example of Abnormal Response continued

2nd Example of Abnormal Response continued

2nd Example of Abnormal Response continued

2nd Example of Abnormal Response continued

2nd Example of Abnormal Response continued

2nd Example of Abnormal Response continued

Rhythm Disturbances

Exercise induced arrhythmias can develop in healthy subjects as well as in patients with cardiac disease. These arrhythmias include everything from sinus node dysfunction to ventricular fibrillation. Exercise testing can manifest arrhythmias such as ventricular ectopic activity or can suppress them.

Sinus Rhythm

Sinus tachycardia is the normal response to exercise. The failure to generate sinus tachycardia is an abnormal finding and may indicate chronotropic impairment.

Occasionally, rate-dependent bundle branch block (mainly left) is precipitated with exercise, and less occasionally A-V blocks may be seen.

Supra-Ventricular Arrhythmias

Atrial ectopic activity is common and requires no special precautions. Atrial fibrillation and atrial flutter may also occur during exercise and may be an indication of organic heart disease or secondary to metabolic, endocrine, or drug effects.

Supraventricular tachycardia (SVT) may be induced by exercise. Treatment may be required if discontinuation of exercise or vagal stimulation does not terminate the rhythm.

Ventricular Arrhythmias

Exercise induced ventricular arrhythmias are regarded more seriously. The potential for the development of ventricular arrhythmias such as ventricular tachycardia, ventricular fibrillation and ventricular standstill exist. Isolated premature ventricular contractions (PVC's) are relatively common among healthy individuals and more so among individuals with coronary artery disease. Studies have shown a greater degree of coronary artery disease in patients with exercise and post-exercise induced ventricular activity. PVC's are usually suppressed with exercise in healthy young adults, however in older age groups suppression of PVC's may show coronary artery disease.

The criteria for terminating an exercise test because of ventricular activity includes increasing frequency, multifocal beats, coupling of beats and tachycardia. Coincidental ischemia or symptoms may also affect termination.

Rhythm Disturbances

EXERCISE STRESS TEST REPORT

Weight: 0 kg

Study Date: 2002/08/29
Test Type: --
Protocol: BRUCE

Medications: --

Medical History: --

Reason for Test:
--

Exercise Test Summary

Phase Name	Stage Name	Time in Stage	Speed (mph)	Grade (%)	HR (bpm)	BP (mmHg)	Comment
PRETEST	WARM-UP	01:32	0.70	0.00	75		
EXERCISE	STAGE 1	03:00	1.70	10.00	64	138/70	2:27 No symptoms
	STAGE 2	03:00	2.50	12.00	71	140/68	
	STAGE 3	03:00	3.40	14.00	105	146/68	
RECOVERY		02:54	0.00	0.00	82	160/70	

The patient exercised according to the BRUCE for 8:59, achieving a work level of Max. METS: 10.40. Resting heart rate initially 95 bpm, rose to a max. heart rate of 136 bpm which represents 82 % of the maximal age-predicted heart rate. Resting blood pressure 130/70 mmHg, rose to a maximum blood pressure of 160/70 mmHg. The exercise test was stopped due to Arrhythmias.

Interpretation

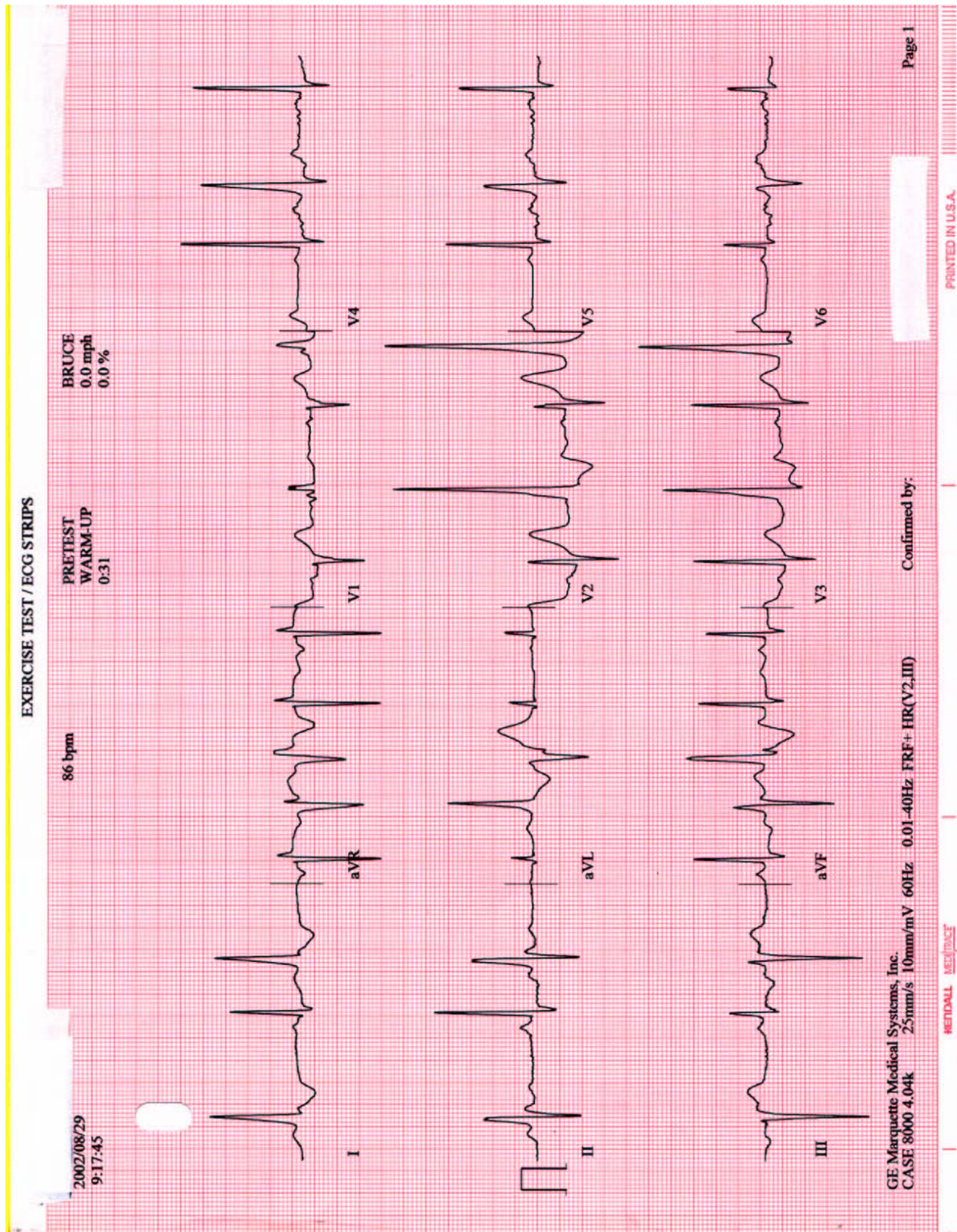
Summary: Resting ECG: left ventricular hypertrophy, premature ventricular contractions. Functional Capacity: normal. HR Response to Exercise: appropriate. BP Response to Exercise: normal resting BP - appropriate response. Chest Pain: none. Arrhythmias: ventricular premature beats-triplets. ST Changes: Depression downsloping.

Conclusions

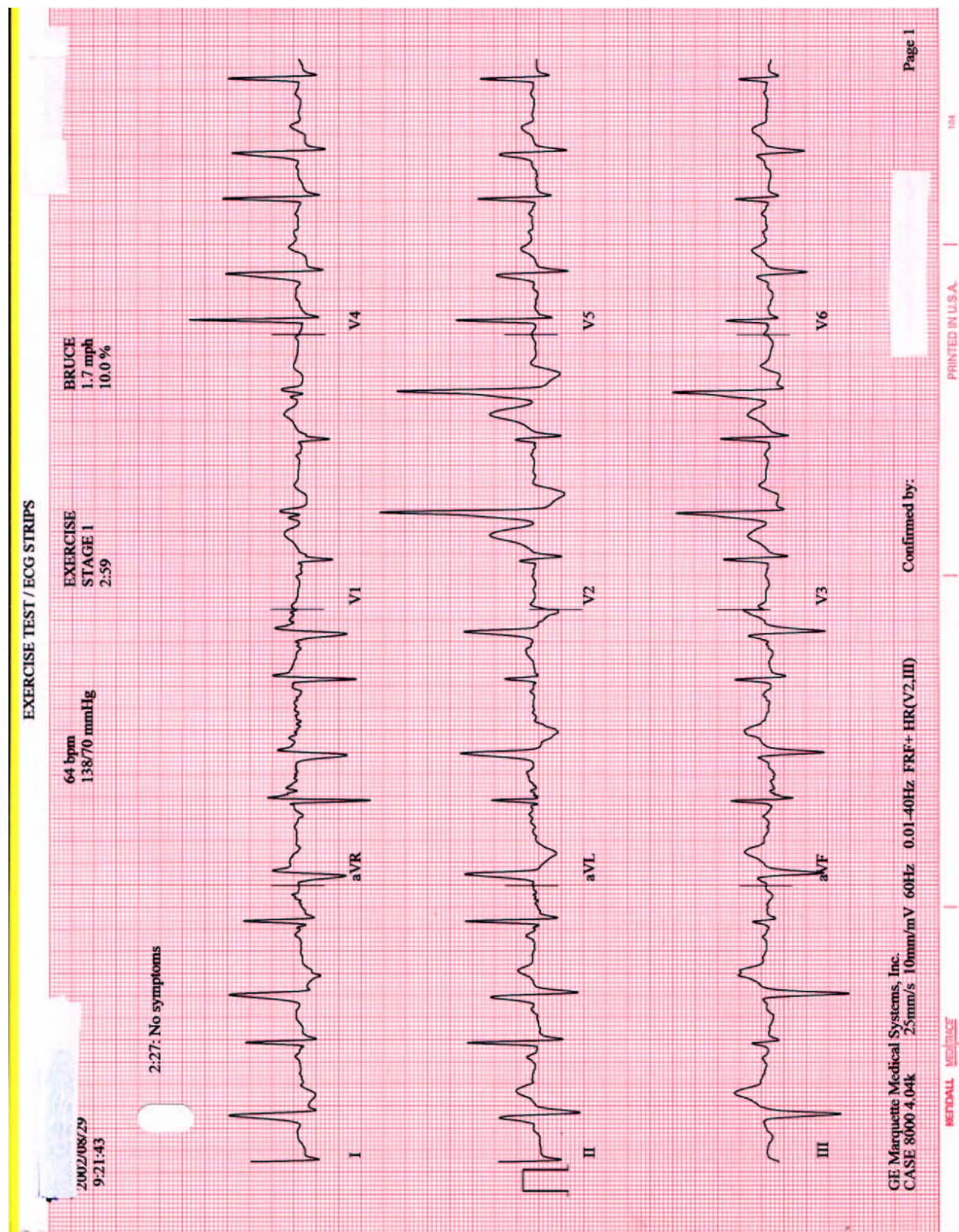
IN BIGEMINY THROUGHOUT; SALVOS AT PEAK EXERCISE. PLAN-ADD ATENOLOL 25 MG/DAY

Physician _____ Technician _____

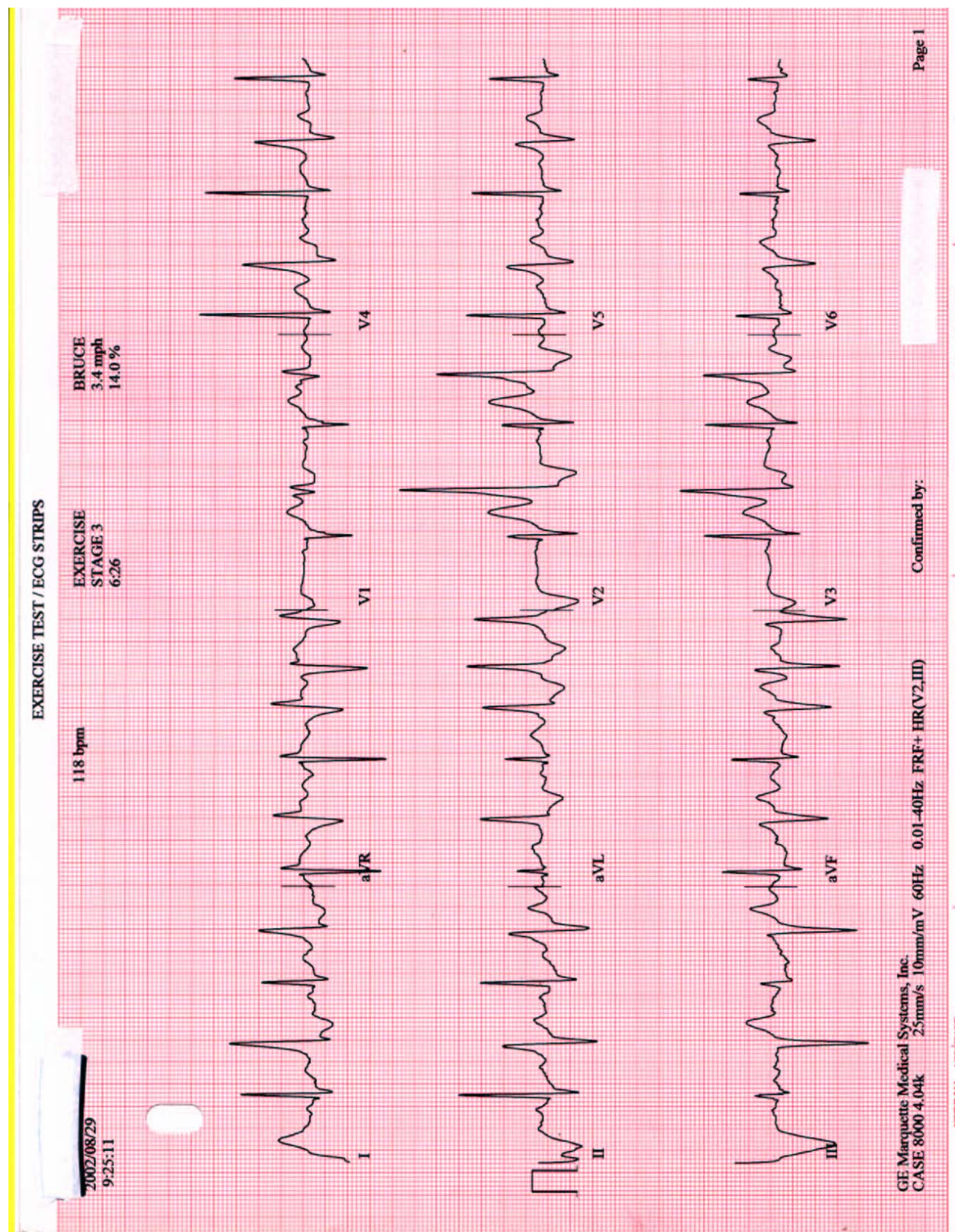
Rhythm Disturbances continued



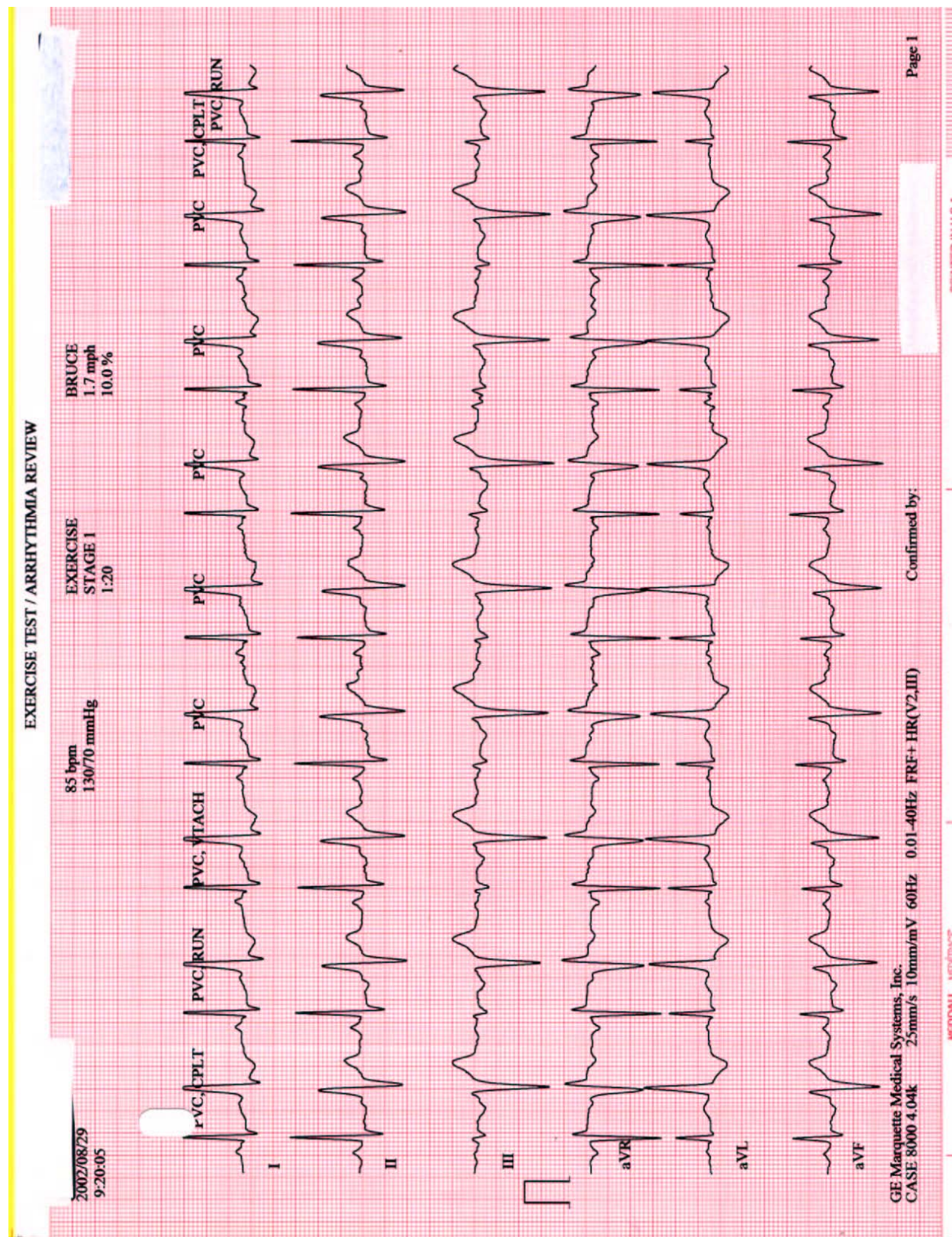
Rhythm Disturbances continued



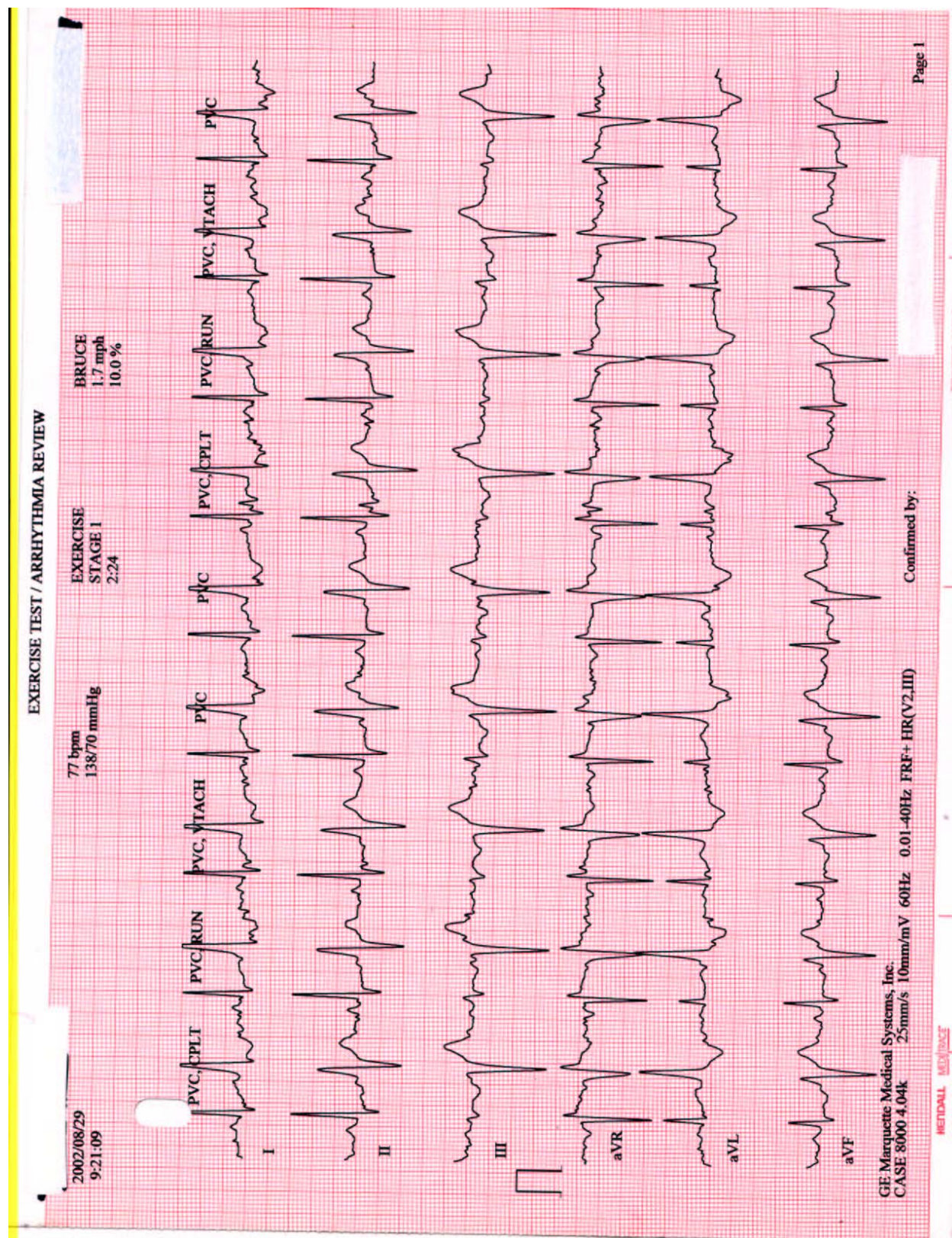
Rhythm Disturbances continued



Rhythm Disturbances continued



Rhythm Disturbances continued



CRITERIA FOR DISCONTINUING AN EXERCISE TOLERANCE TEST

Symptoms	Symptoms such as angina, leg fatigue or cramping, dizziness or shortness of breath of sufficient severity that the patient wishes to discontinue.
Inappropriate Blood Pressure Response	Systolic blood pressure which has declined 20 mm Hg or more from peak and/or to less than resting systolic pressure is usually indicative of a declining cardiac output and the test should be terminated promptly, particularly if any of the other criteria are present.
Poor Cerebral Perfusion	Symptoms such as ataxia, confusion, dizziness or presyncope are included. This actually does not often occur and is most often seen in people with a poor chronotropic response (ie: heavily Beta-blocked, high grade A-V block, etc.). The common cause of presyncope is probably hyperventilation, possibly caused by anxiety.
Electrocardiographic Criteria	1. ST depression equal to or greater than 4 mm. It is usually not necessary to terminate a study for lesser degrees of ST depression alone unless there are other reasons for stopping. 2. Increasingly frequent and complex ventricular ectopic activity. 3. Sustained or unsustained ventricular tachycardia. Physician assessment is required. Most often the test is terminated. 4. Sustained supraventricular tachycardia or atrial fibrillation. No harm is likely to come to the patient if you continue, but you likely will not learn any more if you do, so you might as well discontinue and deal with the arrhythmia.

COMPLICATIONS OF EXERCISE TOLERANCE TESTING

Exercise tolerance testing can be kept extremely safe, even for seriously disabled cardiac patients. The key is to understand and recognize the criteria for discontinuing an exercise test, or those for not even starting (ie: contraindications). This applies to all persons involved whether they be technologists, nurses, or physicians. The incidence of myocardial infarction induced during clinical exercise testing of cardiac patients is stated to be one in 25,000, and of deaths one in 10,000. However, a closer look at cases of misadventure usually shows that some clinical clue was present such that the study should not have been done or should have been abandoned earlier.

Ventricular Tachycardia and Ventricular Fibrillation

These are medical emergencies requiring immediate action and should be handled according to the standard Advanced Cardiac Life Support (ACLS) protocols. Thus, at least one person in the room and in the patient's presence at the time of the occurrence should be ACLS trained or have equivalent practical experience. Although a method of prompt communication with the "99 Code Blue, specific to each hospital team" (Cardiac/Respiratory Arrest Team) is desirable, those responsible for the conduct of exercise testing must be equipped and trained to deal immediately themselves with either of these emergencies. Speed is of the essence, and will usually assure a successful outcome.

Prolonged Angina Post-Exercise or Myocardial Infarction

Angina during exercise testing should usually resolve within 5 minutes or less. If it does not (particularly if the patient has been given nitroglycerine), the patient should be considered as having an impending myocardial infarction and managed accordingly.

Supraventricular Tachycardia or Atrial Fibrillation/Flutter

Unlike the above, these arrhythmias are seldom life-threatening, even if provoked during an exercise test. However, it is nonetheless desirable, if possible to return the patient to his or her initial rhythm, and happily this can usually be done with standard measures. Exercise induced supraventricular tachycardia is frequently self-limiting, so that if the patient is stable, waiting a few minutes before doing anything is prudent.

Table 25-6. Summary of arrhythmias.

Rhythm	P Wave	PR Interval	QRS Rate and Rhythm	Comment
Sinus	Before each QRS	0.12 to 0.20	60 - 100. Regular	
Sinus arrhythmia	Before each QRS	0.12 to 0.20	60 - 100. Phasic variation with respiration	
Sinus bradycardia	Before each QRS	0.12 to 0.20	Less than 60 regular	Not often below 40
Sinus tachycardia	Before each QRS	0.12 to 0.20	Greater than 100. Regular, but may vary a little	Usually 100-160. May be higher in children
Atrial premature beat	Premature P may have different configurations	May be < 0.12 or > 0.20	If the APC is conducted, a premature QRS will be present	Usually no compensatory pause
Atrial tachycardia	Before each QRS. May be hidden	May be < 0.12 or > 0.20	140-200. Absolutely regular usually	QRS normal usually. Abrupt onset & termination. Carotid pressure may terminate attack
Atrial flutter	200-300. Saw-tooth baseline	Constant or variable	75-250 depending on amount of A-V block. Regular or irregular	Carotid pressure produces temporary slowing, if any
Atrial fibrillation	300 or more. Irregular, undulant baseline ("F" waves)	Variable	60-250 depending on degree of A-V block. Irregular	"F" waves may be shown better in V ² than lead II
Ventricular premature contraction	None preceding the premature QRS			Compensatory pause usually. QRS configuration different, more than 0.10, usually
Ventricular tachycardia	Usually not seen. If present, are not related to QRS	Variable	150-250 usually. Regular or nearly regular	QRS broad, different more than 0.10, usually
Ventricular fibrillation	None		No well defined QRS complexes	No palpable pulse and no audible
1st degree A-V block	Before each QRS	0.21 or more	Regular	May be a warning that 2nd or 3rd degree block will follow
2nd degree A-V block	Each QRS preceded by a P wave but some P waves not conducted	Normal or long	Rate often slow. Regular with occasional "dropped"	May be a warning that complete A-V block will follow
3rd degree A-V block (complete heart block)	Occur regularly but without relationship to QRS	Variable	Below 60 - usually. Regular - usually	Spells of syncope common (Adams-Stokes attacks). Pacemaker is in ventricles

PREDICTIVE VALUE OF EXERCISE TOLERANCE TESTING

Sensitivity and specificity of the test will determine the predictive value and diagnostic capability of exercise tolerance testing. Using the exercise ECG as the primary diagnostic criteria for ischemic heart disease. When an exercise test is interpreted as a positive indication of ischemia and coronary artery disease is not present, this is called a false positive exercise test (most often seen in females). False positive occur in approximately 10% of patients tested as exercise tolerance testing is 90% accurate.

Table 25-7a. Causes of false positive results include:

- (a) Mitral valve prolapse
- (b) Resting ECG abnormalities, specifically ST segment and T abnormalities
- (c) Wolff-Parkinson-White syndrome
- (d) Hypertension
- (e) Digitalis effect
- (f) Cardiomyopathy
- (g) Hypokalemia
- (h) Hypertrophy
- (i) Ventricular arrhythmias, such as PVC's or bigeminy

A false negative test result occurs when the exercise test shows non-diagnostic ECG changes when in fact Coronary Artery Disease is present.

Table 25-7b. Causes of false negative results include:

- (a) Inadequate exercise workload or submaximal heart rate
- (b) Single vessel disease
- (c) Excellent collateral circulation
- (d) Not enough leads to detect ECG changes
- (e) Patient's physical limitations reached before any abnormalities appear
- (f) Medication related i.e., β -blockers

SPECIAL CONSIDERATIONS

Patient with Recent Myocardial Infarction or Open Heart Surgery

A low to moderate intensity exercise test prior to discharge from hospital following acute myocardial infarction is a frequently performed and useful study for the following purposes:

- (a) As a test of the safety and wisdom of discharge
- (b) For prognostic stratification

- (c) As a test of the adequacy of current management and as a guide to further management
- (d) As a method of reassurance and confidence-building for the patient and spouse or family

The following considerations should prevail:

- (a) The initial intensity should be very low
- (b) A protocol with small increments of intensity between stages should be chosen
- (c) A maximal effort is seldom necessary or desirable. The above objectives can usually be met with low to moderate levels of exertion. Occasionally limiting symptoms will appear which, in fact, make it a maximal effort study.
- (d) It is probably wise to discontinue earlier on the basis of symptoms or ECG findings than one might otherwise do.

Exercise testing soon after surgery is rarely indicated and patients will usually be limited by their incisions, wound-healing, anemia, etc. The same general considerations would apply as those to pre-discharge post myocardial infarction patients.

**Patients with
Chronic
Obstructive
Pulmonary
Disease**

These patients are often quite limited and a very low initial intensity followed by small increments may be required. Auscultation before and after exercise should be performed, and if there is evidence of any acute respiratory infection superimposed on the chronic lung disease, the study should probably be abandoned.

**Patients with
Pacemakers**

In general, patients with a permanent pacemaker can be exercised; however the information derived from the test will depend on the indication for the test.

Indications:

- (a) Myocardial ischemia - This indication is somewhat limited; however some valuable information can be determined. If there is a VVI pacemaker and there is no intrinsic cardiac rhythm, only paced beats will occur and the ST-T changes will be uninterpretable for myocardial ischemia. Other information is of value including the presence of angina pectoris during exercise, the exercise duration, and reason for stopping exercise, blood pressure and heart rate response.

For dual chamber pacemakers, if there is atrial tracking but ventricular pacing throughout, again the ST-T changes will be uninterpretable. An attempt could be made to reprogram the

pacemaker to allow for intrinsic QRS-T complexes, for instance by increasing A-V conduction. The above mentioned information from exercise testing with a VVI pacemaker applies also in this situation.

- (b) Rate Responsive Pacemakers - Exercise testing in this situation allows determination if the exercise heart rate is adequate and optimal for the patient. Ideally, one should be prepared to reprogram the rate response curve or threshold and re-exercise the patient to optimise the rate response.
- (c) Implantable Defibrillators or Anti-Tachycardia Pacemakers - Most defibrillators are activated by a preset rate, ie. if tachycardia occurs the defibrillator may be activated. Some use more sophisticated algorithms so that occurrence of sinus tachycardia at the preset rate will not activate the device.

It is therefore useful to determine the peak exercise heart rate to see if it is near the preset rate where the defibrillator is activated.

For anti-tachycardia pacing, exercise testing will also help determine if the pacemaker is activated for sinus tachycardia. If so, it should be reprogrammed to prevent this.

Note: Anti-tachycardia pacing is a part of some of the implantable defibrillator such as the PCD by Medtronic.

Paediatric Exercise Tolerance Testing

Exercise tolerance testing is quite useful in paediatric Cardiology. Indications may include the following:

- (a) To detect cardiac abnormalities which are not present at rest such as exercise induced arrhythmias.
- (b) To act as a check on the severity of certain valve problems such as aortic stenosis when ECG changes may be apparent with exercise.
- (c) A useful guide to the progression of a cardiac lesion and help to decide the need for surgery.
- (d) To similarly show improvement after surgery and be valuable in follow-up.

Difficulties in exercising children include small size and inability to walk on a treadmill or pedal a bicycle. Treadmill testing is preferred using a modified Bruce protocol for smaller children so that the speed of the treadmill is kept constant after the fourth stage and only the grade is increased. This is because children can only take very small steps and above 3.4 miles per hour, the number of strides becomes markedly increased.

The simple exercise test should include exercise on the treadmill with monitoring of the electrocardiogram and the blood pressure. The criteria for terminating the exercise test is much the same for children as for adults, ie: increasing or complex ventricular arrhythmias or a 20 mm Hg drop in systolic pressure.

Normal values in children for the Bruce protocol are outlined in an article by Cummings Adele in the American Journal of Cardiology, volume 41, page 69, published in 1978.

Radionuclide Imaging

Radionuclide myocardial perfusion studies combined with exercise tolerance testing are often useful in determining myocardial ischemic changes at submaximal workloads and heart rate. Patients with pulmonary or orthopaedic limitations who are unable to perform near maximal exercise levels can be adequately assessed in this way. Also, patients with ECG abnormalities such as Bundle Branch Blocks, WPW syndrome, or those on Digitalis therapy that prevent satisfactory interpretation of the exercise ECG may be evaluated. Myocardial perfusion studies are useful in evaluating patients with angina and a normal exercise ECG (false negative test result), as well as patients with an abnormal exercise test and no chest pain (false positive result).

Radionuclide studies are usually done in conjunction with a Nuclear Medicine Laboratory, who provide the pharmaceutical and do the imaging. The exercise tolerance test is performed in the usual manner with the radionuclide being injected near peak exercise one minute prior to completion. The most common agent used is Thallium (201-Tl).

Persantine

Persantine is a coronary vasodilator frequently used with radionuclides in patients that are unable to adequately exercise due to physical disabilities (peripheral vascular disease, elderly, etc.). Usually the patient exercises minimally (approximately 2 – 4 minutes). Even at this low level of exercise the heart rate is enhanced and blood flow is redirected from the abdomen to the legs. Exercise that will enhance heart rate helps uptake more thallium into the heart muscle producing better images.

Exercise Nuclear Imaging

Exercise tests with nuclear imaging use myocardial perfusion imaging agents, such as thallium-201, technetium (Tc)-99m sestamibi or tetrofosmin, which are injected 1 minute before the end of exercise. Images are subsequently obtained at 15 minutes for thallium 201 and at 15 to 60 minutes after exercise for Tc-99m sestamibi. Tc agents can be used with a rest/stress protocol or a stress/rest protocol. Tc-99m sestamibi offers several advantages over thallium. Sestamibi has a half-life of 6 hours, compared with 73 hours for thallium, and it also has a higher photon energy. This shorter half-life enables the injection of a higher isotope dose, resulting in improved image quality with greater resolution and less attenuation. Another unique property of Tc-based agents is the lack of redistribution. As such, images may be obtained for up to 4 hours after injection. Cardiac images are usually displayed in tomographic

slices from 3 different axes: the short axis, vertical long axis, and horizontal long axis. This allows visualization of the heart in 3 dimensions so that multiple myocardial segments can be viewed individually, without the overlap of segments that occurs with planar imaging. Perfusion defects that are present during exercise but not seen at rest indicate myocardial ischemia. Perfusion defects that are present during exercise and persist at rest suggest previous MI.

Exercise with Tc99m sestamibi imaging has shown an accuracy similar to that of exercise with thallium-201 imaging in the detection of myocardial ischemia. For planar imaging, the sensitivity and specificity of Tc99m sestamibi have been measured at 84% and 83%, compared with 83% and 88% for thallium; for single photon emission computerized tomography (SPECT) imaging, they were 90% and 93%, respectively, compared with 89% and 76% for thallium. The greater specificity of Tc99m perfusion imaging is primarily due to less soft-tissue and diaphragmatic attenuation. The overall segment agreement with Tc99m sestamibi and thallium-201 is 88% with planar and 92% with SPECT imaging.

Exercise Echocardiography

Echocardiographic images at rest are compared with those obtained while the patient performs stationary cycling or those obtained immediately after treadmill exercise. Images must be obtained within 1 to 2 minutes (preferably <1 minute) after exercise, because abnormal wall motion begins to normalize after this point. Rest and stress images are compared side by side in a cineloop display that is gated (ie, synchronized) to the QRS complex. Myocardial contractility normally increases with exercise, whereas ischemia causes hypokinesis, akinesis, or dyskinesis of the affected segments. A test is considered positive if wall motion abnormalities develop with exercise in previously normal territories or worsen in an already abnormal segment. The overall sensitivity of exercise echocardiography for detecting CAD ranges from 71% to 97%, with greater sensitivities in multivessel disease. The specificity ranges from 64% to 100%. Patients with a normal exercise echocardiogram have a low risk for future cardiac events, including revascularization procedures, MI, or cardiac death. Complications during exercise echocardiography are no different from those during exercise ECG testing, because the echocardiography procedure itself has no known risks.

CARDIAC MEDICATIONS**Table 25-8.** Calcium channel blockers.

Drug	Indications for use	Dose
Verapamil	Supraventricular tachycardias (re-entrant) Atrial flutter and fibrillation Coronary artery spasm Not recommended for accessory pathways Use investigationally in IHSS and hypertension Exertional angina	Oral - 80-120 mg every 6 to 8 hours OOA-1 hr I.V. - 5-10 mg over 1-2 minutes OOA = 1-2 minutes Peak = 1 hr. May repeat in 15-30 minutes if no response
Nifedipine	Coronary artery spasm Hypertension Cerebral artery spasm Suggested for Raynaud's disease Exertional angina	Oral - 10-30 mg every 8 hours OOA = less than 20 minutes Sublingual - 10 mg must puncture capsule OOA = less than 3 minutes Peak (oral 1-2 hours
Diltiazem	Coronary artery spasm Angina Exertional angina Hypertension Preservation of myocardium on heart-lung bypass machine After myocardial infarction (drug of choice of elderly)	Oral - 30-90 mg every 6 to 8 hours OOA = 30 minutes Peak = 30 minutes to 2 hrs I.V. - investigational, 75-150 µg/ml

Table 25-9. Investigational antidysrhythmic agents.

Drug	Class	Use	Dosage
Tocainide	IB	Premature ventricular complexes Symptomatic ventricular tachycardia Prevention of ventricular tachycardia/ventricular fibrillation after myocardial infarction	Oral - 400-600 mg every 8 to 12 hours taken with meals; daily dose total 1200-2400 mg
Flecainide	IC	Premature atrial complexes and ventricular complexes	Oral - 200-400 mg/daily, given in divided doses every 12 hours
Encainide	I	Premature supraventricular and ventricular complex	Oral - 25-75 mg every 6 to 8 hours (total dosage 75-240 mg/day); monitored to QRS widening up to limit of 50% I.V. - 1 mg/kg for 15-20 minutes
Lorcainide	IC	Premature ventricular complexes especially after myocardial infarction	Oral - 100-200 mg every 12 hours
Mexilitine	IB	Premature ventricular complexes	Oral - 200-300 mg every 8 hours Loading - 250 mg over 5 minutes continuous infusion 60-90 mg/hr
Ethmozine	I	Premature ventricular complexes	Oral - 200-300 mg every 8 hours
Cibenzoline	I	Supraventricular tachycardia in Wolff-Parkinson-White syndrome (WPW) Premature ventricular complexes/ventricular tachycardia	Oral 65-100 mg every 6 hours or 130-160 mg every 12 hours

Table 25-10. Antidysrhythmic drugs.

Generic Name	Trade Name	Indications for Use	Dosage
Digoxin	Lanoxin Novodigin	Paroxysmal supraventricular tachycardia Atrial flutter Atrial fibrillation Heart failure with associated S ₃	Loading - Oral - 1.25-1.5 mg in divided doses >12-24 hours I.V. - 0.75-1 mg in divided doses >12-24 hours Maintenance - 0.125- 0.5 mg daily, depending on clinical status
Quinidine	Quinidex Quiniglute Quinidine Sulfate or Gluconate	Atrial and ventricular dysrhythmias Wolff-Parkinson-White syndrome (WPW)	Oral - 200-400 mg 4- 6 times daily; total not to exceed 3-4 gm/day; less frequent dosing with sustained release IM - 200 mg 4-6 times daily I.V. - 300-750 mg; use only with extreme caution and review I.V. administration
Procainamide	Pronestyl Procaine S.R.	Mainly ventricular dysrhythmias Some atrial dysrhythmias WPW	Oral - 250-500 mg 4- 8 times per day Sustained release capsules - 500 mg 3-4 times a day
Disopyramide	Norpace Norpace CR (controlled release)	Ventricular dysrhythmias WPW	Oral - 100-300 mg/4 times per day; controlled release 2 times per day
Lidocaine	Xylocaine	Acute ventricular dysrhythmias Prophylactically to prevent ventricular fibrillation or ventricular tachycardia, especially in acute myocardial infarction Digoxin toxicity dysrhythmias	I.V. - 1 mg/kg I.V. bolus; 25 mg/min every 5-10 minutes, up to 225 mg; continuous I.V. infusion 1-4 mg/min
Phenytoin	Dilantin	Digoxin-induced dysrhythmias	I.V. - 100 mg-1 gm I.V.; no faster than 50 mg/min

Continued next page

Antidysrhythmic drugs continued

Bretylium	Bretylol	Life-threatening ventricular dysrhythmias	I.V. - 5 mg/kg I.V. bolus, may repeat up to 10 mg/kg if necessary
Propranolol	Inderal	Supraventricular tachycardia Atrial flutter and fibrillation Digoxin-induced dysrhythmias Other effects; angina, hypertension, WPW	Oral - Angina: 10-80 mg 3-4 times a day Hypertension: 160-480 mg/day I.V. - 0.5-3 mg I.V. in 1 mg increments
Metoprolol	Lopresor	Angina Afterload reduction Hypertension	Oral - Angina: 50-100 mg/day in divided doses every 8-12 hours Hypertension: 100-450 mg/day
Atenolol	Tenormin	Angina Hypertension	Oral - Angina: 100 mg/day Hypertension: 50-100 mg/day
Nadolol	Corgard	Angina Hypertension Supraventricular tachycardia	Oral - Angina: 40-240 mg/day Hypertension: 80-320 mg/day
Timolol	Blocadren	Chronic supraventricular tachycardia Angina Hypertension	Oral - Angina: 15-45 mg/day in divided doses every 6-8 hours Hypertension: 20-40 mg/day
Pindolol	Visken	Hypertension Chronic angina	Oral - Angina: 15-40 mg/day Hypertension: 5 mg 2 times a day
Amiodarone	Cordarone	Ventricular dysrhythmias Supraventricular tachycardia because of accessory pathway	Oral - 200-800 mg/day until clinical responses; then varies with clinical response I.V. - 5-10 mg/kg over 10 minutes
Verapamil	Isoptin Calan	Supraventricular tachycardia Atrial flutter/fibrillation	Oral - 80-120 mg 3-4 times a day I.V. - 5-15 mg

Continued next page

Antidysrhythmic drugs continued.

Nifedipine	Procardia	Angina Coronary artery spasm	Oral - 10-30 mg 3-4 times a day Sublingual - 10 mg PRN for angina
Diltiazem	Cardizem	Angina	Oral - 30-90 mg 4 times a day
Isoproterenol	Isuprel	Symptomatic bradycardia or sinoatrial block Torsade de pointes Asystole	I.V. 2-20 µg/min, titrated to clinical response
Atropine sulfate	Atropine	Symptomatic bradydysrhythmias Asystole	I.V. - 0.5-1 mg; repeat up to 2.0 mg total

SUMMARY

1. In summary Exercise Tolerance Testing is the recording the patient's cardiovascular response to exercise, using a treadmill or bicycle ergometer, and monitoring the patient's electrocardiogram, blood pressure and symptoms.
2. The most common application is diagnosis and evaluation of suspected or known cardiovascular disease.
3. The technologist is responsible for maintaining the exercise tolerance test equipment, preparing the patient, and monitoring and recording the data.
4. The technologist should be familiar with the indications, clinical uses and the contraindications of exercise tolerance testing.
5. The importance of the explanation of the test procedure to the patient, proper skin preparation and lead application is essential to test quality.
6. The cardiovascular system reacts to exercise by increasing heart rate, blood pressure, and stroke volume. The ability to increase oxygen consumption depends on increased inspiration, increased tidal volume, and increased oxygen diffusion. A convenient method of measuring oxygen consumption is the metabolic equivalent or MET.
7. The basic principle of all graded exercise tolerance tests is a progressively increasing workload of a large muscle group to a point of termination due to fatigue, abnormal responses or symptoms. There are many different exercise tolerance protocols in use today. Generally a standard set of measurements (ECG, blood pressure) are obtained during rest, exercise and recovery phases.

8. The normal endpoints for the termination of an exercise tolerance test are muscle fatigue, dyspnea, and maximum predicted heart rate. An exercise tolerance test may be discontinued before reaching these endpoints due to abnormal symptomatic, cardiovascular or electrocardiographic responses.
9. The technologist must understand and recognize the criteria for discontinuing an exercise tolerance test, and respond accordingly.
10. Special considerations should be given to patients with:
 - (a) Recent myocardial infarction
 - (b) Recent surgery
 - (c) Pulmonary disease
 - (d) Pacemakers
 - (e) Radionuclide imaging
 - (f) And pediatric patients

SELF ASSESSMENT LEARNING GUIDE

1. Define Exercise Tolerance Testing and state what applications in which it can be used.
2. List some of the duties of the technologist performing an exercise tolerance test.
3. List at least six of the major contraindications to exercise testing.
4. The maximum oxygen consumption per minute per kilogram of body weight is limited by:
 - (a) The patient's fitness
 - (b) Heart rate
 - (c) Lung volume
 - (d) Cardiac output
5. Cardiac output is the product of _____ x _____.
6. What is METS?
7. Describe the difference between maximal and submaximal tolerance testing.
8. Why is electrode site preparation and electrode application so important?
9. List the criteria for immediate termination of an exercise test.
10. What is a chronotropic response to exercise?
11. What does a poor rise or decline in systolic blood pressure during exercise a sign of?

12. ST depression of -1.0 mm lasting 80 msec or longer is suggestive of:
 - (a) Poor skin preparation
 - (b) Low cardiac output
 - (c) Angina
 - (d) Myocardial ischemia
13. What effect does digitalis have on the ST segment?
14. Myocardial oxygen demand is determined by:
 - (a)
 - (b)
 - (c)
15. Describe complications of exercise testing.
16. What does "false positive" and "false negative" mean?
17. What is the purpose of an exercise test following an acute myocardial infarction and what special considerations should be made?
18. What indications are there for exercise testing a patient with a pacemaker implanted?
19. What are some of the indications for performing an exercise test on a pediatric patient?
20. What are some of the indications for performing an exercise myocardial perfusion study?

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