NINE-LEAD HOLTER MONITORING USING A LEAD-SWITCHING TECHNIQUE FOR THE DETECTION OF ISCHEMIC ST CHANGES

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We devised a technique to record a greater number of leads (a 9-lead monitor) by connecting a lead-switching adaptor to a commercially available 3-channel Holter recorder (9-lead DCG). Anodes were attached from positions V1 to V6 (CM1 to CM6), and to high lateral (HL), low lateral (LL) and low back (LB). A cathode was attached to the manubrium of the sternum. The CM5 lead was continuously recorded on channel 1. The device is able to switch continuously every 20 sec among leads CM6, LB, HL and LL on channel 2, and among leads CM1, CM4, CM2, and CM3 on channel 3.

Electrocardiograms were simultaneously recorded with both the 9-lead DCG and the conventional 12-lead ECG systems during treadmill testing in 67 patients with coronary artery disease. In addition, 6 patients with acute myocardial infarction were studied with the 9-DCG to test ST elevation.

The sensitivity and specificity of leads CM2 to CM6, HL, LL, and LB in detecting ST depressions that occurred in each corresponding lead of the 12-lead ECG lead were very high ($p < 0.0001$). The LB lead in particular was noteworthy for its markedly high specificity (94%) and sensitivity (83%) in detecting ST depressions occurring in leads II and aVF.

Our lead-switching technique is useful when an increase in the number of leads is required in the DCG method. The LB lead, an anode on the low back, may be specific to detect inferior myocardial ischemia.

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HOLTER electrocardiographic monitoring is a useful diagnostic method for detecting the transient myocardial ischemia that occurs in patients with coronary artery disease. Holter monitoring is used in patients with unstable angina pectoris^{1,2} vasospastic angina³ silent ischemic episodes^{4–6} and for the assessment of antianginal agents⁷. This method, however,

sometimes misses ischemic ST changes because of the limited number of leads or inappropriate placement of electrodes^{8,9}.

In a previous study, we devised an adaptor to record 3-lead electrocardiograms using a commercially available 2-channel Holter recorder, and tested the system in patients with coronary artery disease⁹. We missed some ST changes in that study.

The purpose of this study was to devise a monitoring method with a greater number of leads (a 9-lead monitor) using a commercially available 3-channel Holter

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Fig.1. Illustration of electrode positions. Electrode HL was attached to the intersection of the left fourth intercostal space and the anterior axillary line; electrode LL to the intersection of the left costal arch and the anterior axillary line; and electrode LB to the intersection of the inner line of the left scapula and diaphragm at the maximum inspiratory phase. Electrodes V1 to V6 were attached to the same positions as the corresponding leads of a standard 12-lead ECG recording. Potential differences between V1 and M, V2 and M, V3 and M, V4 and M, V5 and M, V6 and M, HL and M, LL and M, LB and M, were referred to as CM1, CM2, CM3, CM4, CM5, CM6, HL, LL and LB, respectively.

Fig.2. Our Holter recording system. B shows the lead-switching adaptor.

system, and to test the method in diagnosing both ischemic ST depressions and ST elevations by comparing its findings with those of the conventional 12-lead electrocardiogram.

METHODS

Fig. 1 shows the electrode positions of our 9-lead Holter system (9-lead DCG). The electrodes were attached to positions V1 to V6 of a standard 12-lead ECG recording. Electrode HL was attached to the intersection of the left fourth intercostal space and the anterior axillary line (or high lateral position), electrode LL was attached to the intersection of the left costal arch and the anterior axillary line (or low lateral position), and electrode LB was attached to the intersection of the inner line of the left scapula and diaphragm at the maximum inspiratory phase (or low back position). These 9 electrodes were used as positive electrodes. Negative electrode M was attached to the manubrium of the sternum and electrode G was grounded.

Potential differences between electrodes V1 and M (CM1), V2 and M (CM2), V3 and M (CM3), V4 and M (CM4), V5 and M

Fig.3. Nine-lead Holter electrocardiographic recording before (A) and after (B) treadmill exercise testing in a 71-year-old male patient with a previous myocardial infarction. Details are described in the text.

(CM5), V6 and M (CM6), HL and M (HL), LL and M (LL), and LB and M (LB) were obtained by a recorder and a newly devised lead-switching adaptor.

The CM5 lead was continuously recorded on channel 1 without lead-switching. Leads CM6, LB, HL and LL were recorded on channel 2, and leads CM1, CM4, CM2 and CM3 were recorded on channel 3, using the lead-switching adaptor. Note that the CM4 lead was used after the CM1 lead, instead of the CM2 lead, because the morphological changes in QRS complexes between CM1 and CM4 could be more easily discriminated than those between CM1 and CM2. The adaptor was connected to a DMC3153 3-channel Holter recorder (Nihon-Koden Co.). Holter tapes were analyzed by a DMC 4000 scanner (Nihon-Koden Co.), and all of the electrocardiograms were printed on electrocardiographic paper at 25 mm/sec with a calibration of 10 mm=1 mV. The electrocardiograms were checked carefully with particular emphasis on ST changes. Fig. 2 shows the commercially available 3-channel Holter recorder (shown by 'A') and our adaptor (shown by 'B'). The entire system is powered by a 9-volt battery.

Clinical application

Seventy-three patients were studied: 67 (58 male, 9 female) with old myocardial infarctions or angina pectoris (ages 37 to 72 years, mean $\pm$ SD 57.6 ± 7.8 years) and 6 (5 male, 1 female) patients with acute myocardial infarctions (ages 41 to 69 years, mean $\pm$ SD 59.4 ± 10.0 years).

Thirty-three of these 67 patients had had previous acute myocardial infarction and the remaining 34 had angina pectoris. Patients with previous acute myocardial infarction had been hospitalized in our hospital during the acute phase of the disease and had been discharged at least 2 months before the start of this study. These patients had the following myocardial infarctions: 11 anterior, 18 inferior, 6 lateral, and 4 high posterior. If a patient had 2 or more localizations, they were all counted.

Patients with old myocardial infarctions and angina pectoris had had typical chest pain and/or had shown significant ST changes during treadmill testing, which was performed prior to entry into this study. These patients underwent simultaneous electrocardiographic recordings with the 9-lead DCG and conventional 12-lead ECG systems

Fig. 4. A 9-lead Holter electrocardiographic recording (9-lead DCG, A) and a comparison of the electrocardiographic morphologies depicted by the corresponding leads of the 9-lead DCG and 12-lead electrocardiogram (12-lead ECG, B) in a 59-year-old female patient with unstable angina, resulting in acute anteroseptal myocardial infarction. Marked ST elevations were observed in the anterior leads and reciprocal ST depressions were seen in the inferior leads with both electrocardiographic methods.

during treadmill testing to evaluate the reliability of the new Holter method in detecting ST changes. A submaximal treadmill test was performed using the Bruce protocol.

ST changes were defined as positive when they persisted for at least 1 min and met one of the following criteria:

(1) Horizontal or downsloping ST depression of 0.1 mV or greater at 80 msec after the J point.

(2) ST elevation of 0.2 mV or greater at 80 msec after the J point.

The sensitivity and specificity of the 9-lead DCG in detecting ST changes that occurred in the 12-lead ECG were examined. Lead equivalents between the 9-lead DCG and 12-lead ECG were as follows: leads CM1 to V1, CM2 to V2, CM3 to V3, CM4 to V4, CM5 to V5, CM6 to V6, HL to I and aVL, LL to I and aVL, CM5 to II and aVF, LL to II and aVF, and LB to II and aVF.

Statistical analysis

The sensitivity and specificity of each lead of the 9-lead DCG in detecting ST depressions that occurred in the corresponding lead

of the 12-lead ECG were obtained from 2×2 contingency Tables. Row by column contingency Tables were studied by chi-square analysis with Yates' correction. A p value of less than 0.05 was considered significant.

RESULTS

Fig. 3A, B shows a 9-lead DCG that was recorded before (A) and after (B) treadmill testing in a 71-year-old man with previous myocardial infarction. The upper channel of each panel (a to d) shows the recording of the CM5 lead without lead-switching. On channels 2 and 3, the leads switched accurately at the arrows. Marked ST depressions were observed in leads CM5, CM6, HL, and LL after exercise testing (B), although these changes were mild before exercise (A). The patient complained of precordial pressure during these ST depressions.

Fig. 4A shows a 9-lead DCG in a 59-year-old woman with angina pectoris. She was admitted on an emergency basis because of the frequent occurrence of anginal episodes and the subsequent acute anterior myocar-

Fig. 5. The 9-lead Holter recording (9-lead DCG) and the 12-lead electrocardiogram (12-lead ECG) obtained from a 64-year-old male patient with acute inferior myocardial infarction. ST elevations are shown in leads II, III and aVF of the 12-lead ECG, and in the corresponding leads (LB and LL) of the 9-lead DCG.

dial infarction. Leads switched accurately from HL to LL (a), from LL to CM6 (b), from CM6 to LB (c) and from LB to HL (d) on channel 2, and from CM2 to CM3 (a), from CM3 to CM1 (b), CM1 to CM4 (c) and CM4 to CM2 (d) on channel 3. Marked ST elevations were seen in leads CM2 and CM3.

Fig. 4B shows a comparison of electrocardiographic morphology in the corresponding leads of the 9-lead DCG and 12-lead ECG in the same patient. The 12-lead ECG was recorded during another anginal episode on the following morning. ST elevations are observed in leads V2, V3 and V4 of the 12-lead ECG, and in the corresponding leads (CM2, CM3 and CM4) of the 9-lead DCG.

Fig. 5 shows the 9-lead DCG and 12-lead ECG obtained from a 64-year-old man with acute inferior myocardial infarction. ST elevations are demonstrated in leads II, III and aVF of the 12-lead ECG, and in the corresponding leads (LB and LL) of the 9-

lead DCG.

Of the 67 patients who underwent simultaneous electrocardiographic recordings with the 9-lead DCG and 12-lead ECG methods, ST depressions were observed in 53 during treadmill testing by both methods. In the remaining 14 patients, no ST changes were observed by either method. The results of the 2 systems were consistent in all subjects.

Table I summarizes the sensitivity and specificity in each lead of the 9-lead DCG in detecting ST changes that occurred in the corresponding leads of the 12-lead ECG. No ST changes were seen in the CM1 lead. The sensitivity and specificity of leads CM2 to CM6 of the 9-lead DCG in detecting ST depressions that occurred in corresponding leads (V2 to V6) were very high ($p=0.0006$ in CM2 vs V2, and $p<0.0001$ in other corresponding leads). Leads HL and LL were also highly accurate in detecting ST depressions that occurred in the corresponding

TABLE I THE SENSITIVITY AND SPECIFICITY OF EACH LEAD OF THE 9-LEAD HOLTER MONITORING SYSTEM (9-LEAD DCG) IN DETECTING ST DEPRESSIONS THAT OCCURRED IN THE CORRESPONDING LEAD OF THE 12-LEAD ELECTROCARDIOGRAM (12-LEAD ECG)

9-lead DCG /12-lead ECG	Sensitivity (%)	Specificity (%)	Concordance rate: %	Statistical significance, p value
CM1/V1	0/0 (—)	53/53 (100)	100	—
CM2/V2	2/3 (67)	49/50 (98)	96	0.0006
CM3/V3	14/15 (93)	34/38 (89)	91	<0.0001
CM4/V4	39/40 (98)	12/13 (92)	96	<0.0001
CM5/V5	49/50 (98)	2/3 (67)	96	<0.0001
CM6/V6	50/51 (98)	2/2 (100)	98	<0.0001
HL/I, aVL	2/2 (100)	51/51 (100)	100	<0.0001
LL/I, aVL	2/2 (100)	51/51 (100)	100	<0.0001
CM5, II, aVF	33/35 (94)	2/18 (11)	66	0.880
HL/II, aVF	24/35 (100)	9/18 (50)	66	0.310
LL/II, aVF	31/35 (89)	8/18 (44)	74	0.176
LB/III, aVF	29/35 (83)	17/18 (94)	87	<0.0001

leads I and aVL ($p < 0.0001$ in each).

The CM5 lead is able to detect ST changes that occur in leads II and aVF as well as in the V5 lead. In the present study, although the sensitivity of lead CM5 in detecting ST depressions that appeared in leads II and aVF was very high (94%), its specificity was very low (11%). The LL lead, in which the anodes was placed on the low left-lateral portion of the anterior chest, was selected to obtain ST changes that occurred in leads II and aVF, but did not show very high specificity in detecting these changes (44%), although its sensitivity was high (89%) ($p = 0.0176$).

In contrast, the LB lead, in which the positive electrode was placed on the lower portion of the posterior chest and the negative electrode on the manubrium of the sternum, demonstrated both high sensitivity and high specificity in detecting ST depressions that occurred in leads II and aVF, (83% and 94%, respectively $p < 0.0001$).

Of the 6 patients with acute myocardial infarctions, 4 showed anteroseptal and 2 inferior myocardial infarctions. Three of the former cases showed ST elevations in leads V1 to V4, and the remaining patient showed ST elevations in leads V2 to V4 of the 12-lead ECG. These patients exhibited ST elevations in the corresponding leads of the 9-lead DCG. The latter 2 patients showed

ST elevations in leads II, III and aVF of the 12-lead ECG. On the 9-lead DCG, 1 exhibited ST elevations in the LB lead only, while the other patient showed ST elevations in leads LB and LL.

DISCUSSION

In recent years, 2- or 3-channel Holter recorders have been widely used. In 2-channel equipment, the use of V5-like and V1-like leads is common,¹⁰ and in 3-channel Holter equipment, an inferior lead tends to be added.

The primary object in Holter monitoring of patients with coronary heart disease is to not miss ischemic ST changes. In addition, to clarify the location and extent of the ischemic area, it would be useful for a Holter recorder to be able to monitor all 12 leads like a standard 12-lead electrocardiogram. However, increasing the number of channels by conventional methods makes the recorder and analyzer more expensive, heavier and more complicated.

We devised a new 9-lead electrocardiographic system using lead-switching adaptor in a commercially available 3-channel Holter recorder. The CM5 lead was recorded continuously on channel 1 without lead-switching. The device was connected to channels 2 and 3 to provide continuous switching every

20 sec between leads CM6, LB, HL and LL on channel 2, and leads CM1, CM4, CM2 and CM3 on channel 3.

However, it is questionable whether switching of leads every 20 sec can always detect short ST changes that occur in the non-recording leads. We selected a 20 sec interval for the switching of ECG leads. Biagini et al³ and Nademanee et al¹¹ reported that it took at least a few min after the actual onset of ST changes for chest pain to occur. We compared the duration from the beginning of the ST depression to the maximum alteration between ischemic and postural ST depressions using our posture sensor during Holter monitoring.¹² Durations of more than 1 min were observed in the majority of ischemic ST depressions (88%).¹³ Otherwise, ST depressions that are more than 1 mm from baseline for 80 msec after the J point and which last for at least 1 min are widely accepted to be ischemic in the Holter monitoring of patients with coronary artery disease.^{14,15} We believe, therefore, that ischemic ST depressions would not be missed by switching leads every 20 sec.

Although many Holter recording systems with different specifications are available, there is no consensus on a lead system for detecting ischemia. In 1985, the Committee on Electrocardiology and Cardiac Electrophysiology of the Council on Clinical Cardiology of the American Heart Association recommended 2 leads simulating a V1 and V5 lead axis for general use in Holter monitoring.¹⁰ However, no additional recommendations on lead selection were made in the guidelines reported by the ACC/AHA Task Force in 1989.¹⁶

In general, the reliability of each system's recording of ST changes has been tested by comparing it with the findings of the conventional 12-lead electrocardiogram during exercise testing.^{5,8,16} In a study by Tzivoni et al⁸ using a 2-channel Holter recording system with bipolar V3- and V5-like leads, the 2 tests produced consistent results in 138 of the 144 patients (96%). Nevertheless, none of the ST depressions occurring in leads I and aVL could be detected.

ST depressions would not have been detected in 2 of the 53 patients if the 2 leads of Tzivoni et al⁸ had been applied to our study.

In these 2 patients, ST depressions occurred in HL and LL leads. Therefore, the conventional precordial-lead of Holter monitoring seems to be insensitive to ischemic changes in the lateral wall.

Among leads CM1, CM2 and CM3, the CM3 lead could most frequently detect ST depressions (18 patients), while the CM1 lead could not detect any ST depressions, and the CM2 lead could detect ST depressions in only 3 patients. Therefore, CM3 is considered the best of the 3 in detecting ischemia.

The CM5 lead is known to be highly sensitive in detecting ST depressions that occur not only in the V5 lead but also in the inferior leads, II and aVF, of the 12-lead ECG. The present study confirmed its high sensitivity for the detection of ST depressions in leads II and aVF (94%). However, its specificity was very low (11%). In addition, the LL lead did not show very high specificity in detecting ST depression that occurred in the inferior leads.

In contrast, the LB lead was noteworthy for its markedly high specificity (94%) and sensitivity (83%) in detecting ST depressions that occurred in the inferior leads. It is likely that our LB lead could detect only inferior wall ischemia, since the positive electrode was attached to the low back and the negative electrode to the manubrium of the sternum, placing the heart directly between the positive and negative electrodes.

In patients with acute myocardial infarction, ST elevations that occurred in leads V2 to V4 of the 12-lead ECG were detected by leads CM2 to CM4 of the 9-lead DCG. In contrast, ST elevations that occurred in leads II, III and aVF could always be detected by the LB lead. To date, ST elevations that occurred in leads II, III, and aVF could not necessarily be detected with the Holter method because precordial leads have been preferentially selected.

Our 9-lead Holter ECG system is as sensitive as the 12-lead ECG system in detecting both ST depressions and elevations. The LB lead is considered especially useful in detecting inferior ischemia.

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