A New Method for Recording a Three-lead Electrocardiogram Using a Two-channel Holter System

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SUMMARY

A technique for recording a three-lead electrocardiogram (ECG) without increasing the number of channels and electrodes in a commercially available two-channel Holter recorder was devised. On channel 1, a V5-like lead (CM5 lead) was recorded for 24 consecutive hours. On channel 2, the device could switch continuously between a V2-like lead (CM2 lead) and a II- or III- or aVF-like lead (CMf lead) every 30 sec.

Fifty eight patients with angina pectoris were studied using this new device. There were 2 patients with variant angina pectoris, one of whom showed ST elevation in the CM2 lead coupled with ST depression in the CMf lead and the other ST elevation in the CMf lead coupled with ST depression in the CM2 lead. The number of patients having ST depression confined to the CM5 lead only, CM2 lead only and CMf lead only was 17, 2 and 3, respectively. In 41 patients, 127 transient episodes of ischemic type ST changes were observed during daily activity. Only 35 (28%) of these episodes were associated with anginal symptoms and the remaining 92 episodes occurred unrelated to such symptoms.

Accordingly, 3-lead Holter monitoring using this device is useful, particularly for the detection of variant angina, and makes it less likely for asymptomatic ischemic ST changes to be overlooked as compared to the 2-lead conventional Holter monitoring system.

Additional Indexing Words:
Newly devised 3-lead Holter monitoring technique Commercial 2-channel Holter system Ischemic ST changes

Until a decade ago, only a single channel Holter monitoring system had been used and the equipment had functioned adequately only for evaluation of arrhythmias but not for assessment of ST changes.1)–4)

Recently, a two-channel Holter system has been commonly used and has been shown to have high sensitivity and specificity for detecting significant coronary artery disease.5) However, such a high sensitivity and specificity might be explained by the careful selection of patients and the exclusion of

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patients with abnormal ST segments at rest.  

In unselected patients with ischemic heart disease, there is the possibility of missing significant ischemic ST changes due to the limited number of leads when a two-channel Holter monitor is used. If the number of channels could be increased in the commercial recorder, this problem would be solved. However, in so doing, the recorder and analyzer may become more expensive and more complicated.

In this paper, we devised a new apparatus for recording a 3-lead electrocardiogram (ECG) without increasing the number of channels and electrodes in the commercial 2-channel Holter recorder.

**Materials and Methods**

1) The device

A two-channel Holter ECG recorder (Avionics Co., Model 447) was used. On channel 1, the CM₅ lead (positive electrode: V₅ in standard 12-lead ECG; negative electrode: manubrium sterni) was selected in order to record a V₅-like ECG for 24 consecutive hours. On channel 2, the new apparatus described below was applied.

As shown in Fig. 1A, electrode 'a' was placed on the V₂ position of a 12-lead ECG and electrode 'b' on the intersection of the ninth rib and anterior axillary line. Electrode 'c' was placed on the manubrium sterni. ECGs similar to the V₂- (or V₃-) like lead (CM₂ lead) and the II- (or III- or aVF-) like lead (CM₁ lead) were recorded by obtaining the electrical differences between electrodes 'a' and 'c' and those between electrodes 'b' and 'c', respectively.

Fig. 1B shows the schema of input ports for electrode cords in the recorder. Ports 'X' and 'Y' were used for recording a CM₂-like lead. Ports 'a', 'c' and 'b' were used for the new system. Ports 'a', 'c' and 'b' (Fig. 1B) were connected with the cords from electrodes 'a', 'c' and 'b' (Fig. 1A), respectively. Electrode 'b' was used as the ground when an electrical difference between electrodes 'a' and 'c' was recorded. In a similar fashion, electrode 'a' was used as the ground when the electrical difference between electrodes 'b' and 'c' was recorded.

Fig. 2 shows a diagram of the apparatus. The oscillator generated rectangular pulses at 70 cycles/s. The frequency of the pulses was reduced by the divider and changed into four kinds of rectangular pulses with widths of 15, 30, 60 and 120 sec. Any one of the four pulses can be selected as needed. In this study, a pulse with a 30 sec interval was selected.

The pulses produced by the divider entered analog switches 2 and 4
Fig. 1. Illustrations of electrode positions (A) and electrode ports (B).

Fig. 2. A diagram of the apparatus. How it functions is explained in the text.

with a positive wave (A pulses). The pulses reduced by the divider were changed into negative pulses by the inverter and entered analog switches 1 and 3 (B pulses).
When the A pulse is working (Fig. 2) and analog switches '2' and '4' are on, the signal from electrode 'b' enters analog switch '2' to record the electrical difference between electrodes 'b' and 'c'. At the same time, the signal from electrode 'a' enters analog switch '4' and is grounded. Thereafter, when the A pulse changes into the B pulse and analog switches '1' and '3' are working, the signal from electrode 'a' enters analog switch '1' to record the electrical difference between electrodes 'a' and 'c'. Simultaneously, the signal from electrode 'b' enters analog switch '3' and is grounded. The whole system is powered by a 9 volt battery. The picture of this system is shown by an arrow in Fig. 3.

2) Clinical application

Fifty eight patients (50 male, 8 female) with angina pectoris were studied. They ranged in age from 37 to 86 years ($X\pm SD 58.4\pm10.5$). Twelve of the 58 patients had a history of myocardial infarction.

The patients were instructed to document the time of their usual daily activities and the presence or absence of anginal episodes including time, severity and duration. A standard 12-lead ECG was recorded from each patient before electrodes of the Holter monitoring system were placed.

The Holter ECG recordings were analyzed on the Avionics Electrocardioscanner (Model DCG 7) with particular emphasis on ST changes. A high speed printer (Fukuda Denshi Co., TR-210) which could print a 24 hour ECG in a very short time (12 min) was used. Electrocardiographic changes showing ST depression or ST elevation persisting for at least 1 min were printed out on standard electrocardiographic paper. ST changes were defined as significantly ischemic when they possessed one of the following criteria:

1) Horizontal or downsloping ST depression 0.1 mV or greater at 80 msec after the J point.
2) ST elevation 0.2 mV or greater at 80 msec after the J point.

Results

Fig. 4 shows a 3-lead Holter ECG recording using the device in a 62 year old female patient with angina pectoris. On channel 2 of recordings A and B, the QRST complexes from the CM2 lead suddenly switch to those from the CMf lead at the arrows. As shown in B, marked ST depressions associated with chest pain were observed in CM5, CM2 and CMf leads around 7:22 am.

Fig. 5 demonstrates simultaneous ECG recordings of a 3-lead Holter method (A) with a conventional 12-lead system (B) during treadmill exercise
testing in a 61 year old male patient with old antero-septal myocardial infarction. The test was terminated because of the occurrence of precordial pressure.

During and just after exercise, deteriorating ST depression in the CM₅ and CMf leads of the Holter system (A) was observed. The former ST depressions corresponded to the ST depressions in the V₅ lead (inclusive of V₆) and the latter ones to those in the inferior (II, III and aVF) lead of the 12-lead system (B). The configurations and depths of ST segment changes on the Holter system closely resembled those on the 12-lead system. In this patient, the artifact deviations of the Holter ECG baseline at the switching points (shown by the arrows) were larger than those in the previous case. However, these deviations returned to the preswitching levels within no more than approximately 1 sec. The star appears regularly every minute with this equipment (lower panel of A).

Fig. 6 shows a 3-lead Holter ECG recording during exercise in a 43 year old male patient with old infero-postero-lateral myocardial infarction. During and after exercise, marked ST depression in the CM₄ lead was observed only with the Holter system. The artifact deviations of the Holter ECG baseline at the switching points were minimum in this patient.

Fig. 7 demonstrates the 3-lead Holter monitoring obtained from a 53 year old male patient with Prinzmetal’s variant angina (variant angina). In channel 2 of B, the ST depression can be observed in the CM₄ lead, and, after the switching of leads (shown by the arrow), the ST elevation occurs in
Fig. 5. Simultaneous ECG recordings of the 3-lead Holter method (A) and the conventional 12-lead system (B) during treadmill exercise testing obtained from a 61 year old male patient with old antero-septal myocardial infarction. Marked ST depressions during and just after exercise are observed in the CM₅ and CM₆ leads on the Holter system (A) and in the V₃ (inclusive or V₄) and inferior leads (II, III and aVF leads) on the 12-lead system (B). CH₁: channel 1, CH₂: channel 2.
Fig. 6. Holter electrocardiograms of the 3-lead system during exercise obtained from a 43 year old male patient with an old infero-postero-lateral myocardial infarction. Control recording shows no significant ST changes (upper panel). Middle and lower panels reveal significant ST depressions in the CM2 lead only. Arrows demonstrate the switching points of leads. CH1: channel 1, CH2: channel 2.

Fig. 7. Holter electrocardiograms of the 3-lead system obtained from a 53 year old male patient with Prinzmetal’s variant angina showing ST segment elevation in the CMf lead while showing ST segment depression in the CM2 lead (lower panel). Upper panel shows control recording. CH1: channel 1, CH2: channel 2.
the CMf lead. These ST changes were recorded during sleep and caused the patient to wake because of chest pain. Nifedipine (10 mg, 4 times daily) was very effective in treating his anginal symptoms and there were no ST elevations in any Holter monitoring done after treatment was started.

In 41 of the 58 patients who underwent 3-lead Holter monitoring throughout a 24 hour period, transient positive ST changes were observed in one or more leads among the CM2, CM5 and CMf leads. There were 2 cases with variant angina. In one, ST elevation was observed in the CMf lead while ST depression occurred in the CM2 lead. In the other case, ST elevation was observed in the CM2 lead, while ST depression occurred in the CMf lead.

ST depression was observed in the CM5 lead in 6 of the 58 patients, in the CM3 lead in 39 of the patients and in the CMf lead in 22 of the patients (Fig. 8). In 17 patients ST depression was recorded in both the CM5 and CMf leads. The CM5 lead showed more marked ST depression than the CMf lead in 10 patients, while the CMf lead showed more marked ST depression than the CM5 lead in 5 patients. In 2 patients the degree of ST depression was similar in both leads. There were 2 patients with variant angina who had ST changes in both the CM5 and CMf leads as previously mentioned. In 3 patients ST depression was recorded in all 3 leads. All of them had the most marked ST depression in the CM5 lead.

In 41 of the 58 patients, 127 transient episodes of ischemic type ST changes were observed during usual daily activity or during treadmill exercise testing. Only 35 (28%) of these episodes were associated with anginal symp-
DISCUSSION

Most investigators agree that the V₅-like lead ECG should be recorded using 1 of the 2 channels, and either a II (or aVF)-like lead or a V₅-(or V₃-)like lead is commonly monitored using the other channel.

However, the 2-channel Holter system may miss some cases of transient ST elevation. In this study, 1 of the 2 patients with variant angina showed ST elevation in the CMf lead coupled with ST depression in the CM₂ lead, and the other showed ST elevation in the CM₂ lead coupled with ST depression in the CMf lead. Had we selected the CM₅ and CM₂ leads in the former case and the CM₅ and CMf leads in the latter case using the 2-lead Holter recorder, we would not have detected the ST elevations.

Kennedy⁷) reported that anterior descending coronary artery spasm produces ST elevation mainly in leads V₂ and V₃ and that right coronary artery spasm or circumflex branch spasm produces ST elevation mainly in leads III and aVF. On the other hand, lead V₅ was reported to be very nonspecific for localizing the coronary artery involved.

MacAlpin⁸) reported that ST changes in the V₅-like lead could be produced by obstruction of any of the major coronary arteries. Out of 339 cases of variant angina gathered from his own series and from the literature in which leads III and V₃ were recorded during an attack during which there was ST elevation in some lead, the ST elevation was documented in either III or V₃ in 333 of the cases (98.2%). As a result, he recommended that the above 2 leads should be used in addition to either leads V₅, V₆ or aVL.

It would be desirable for the Holter ECG recorder to monitor all 12 leads compatible with a standard 12-lead ECG. However, as the number of channels is increased, the more expensive, heavier and more complicated the recorder and analyzer become.

We devised a new technique to create a 3-lead ECG monitoring system without incurring the number of channels and electrodes in the commercial 2-channel Holter recorder. The device is able to switch continuously between a II- or III- or aVF-like lead and a V₅-like lead every 30 sec using 1 channel of a 2-channel recorder. The other channel continuously records a V₅-like lead ECG. Another advantage of the device is that it is light weight (50 g) and the total cost of all electrical parts is low (¥10,000).

However, it seems questionable whether the switching of ECG leads every 30 sec can always detect ST changes of very short duration within a
30 sec period.

Papers by Biagini et al\textsuperscript{9}) and Nademanee et al\textsuperscript{10}) showed that it took at least a few minutes after the onset of ST changes for chest pain to be produced. We compared the duration from the beginning of the ST depression to the maximum change between ischemic and postural ST depressions using our posture sensor\textsuperscript{11}) during Holter monitoring. Durations of more than 1 min were observed in the majority of cases of ischemic ST depression (88\%).\textsuperscript{12}) It is believed, therefore, that ischemic ST depression will not be missed by switching the leads of the ECG recording every 30 sec. If necessary, one of the four pulses with widths of 15, 30, 60 and 120 sec can be selected in our device.

In some patients, slight deviations of the ECG baseline were observed in switching from one lead to another. The degree of this deviation differs among individuals and over time even in the same individual. However, the majority of these deviations returned to the preswitching level within 1 sec, and there were no cases in which this took more than 3.2 sec. Therefore, such artifacts are not considered to present clinical or controversial problems in detecting ischemic ST changes.

As already discussed in this paper, at least 3 leads on the Holter system are necessary to detect ST elevations in patients with variant angina. The necessity of 3 or more leads in the Holter system in order to detect ST depression has not been previously reported or discussed.

In the present study, ST depression confined to the CM\textsubscript{5} lead only, the CM\textsubscript{f} lead only and the CM\textsubscript{2} lead only was observed in 17, 3 and 2 patients, respectively. Had we selected only 2 leads using the 2-channel Holter system, we would have missed some instances of ST depression.

Tzivoni et al\textsuperscript{5}) reported the high sensitivity and specificity of a 2-channel Holter recording system with bipolar V\textsubscript{5}- and V\textsubscript{5}-like leads in the detection of ischemic ST changes. However, the Holter system in their series was insensitive in recording ischemic changes confined to the high lateral wall, where ECGs show ST depression only in leads I and aVL on the 12-lead ECG system. Our device may detect ischemic changes which appear in the high lateral wall when an additional third lead is placed on the skin there.

In this study, 92 (72\%) of 127 ischemic changes were not associated with anginal symptoms. Schang et al\textsuperscript{13}) reported that 411 transient episodes of ischemic ST depression were noted during normal daily activities and that only 101 of them (25\%) were associated with angina. Biagini et al\textsuperscript{9}) reported that, in unstable anginal patients, 88\% of transient ST changes observed during Holter monitoring were either characterized by complete absence of symptoms or by only ill-defined sensations. Furthermore, they performed
coronary arteriography during asymptomatic ST-T changes, and, in 6 of 8 patients, the changes were associated with complete or incomplete coronary spasm. We reported that ischemic ST-T changes occurred in 16 of 22 patients (73%) with unstable angina when they were instructed to wash themselves vigorously for several minutes with a hot, wet cloth. However, only 5 of the 16 changes were associated with angina.14)

Recently, multichannel Holter equipment in which 3 independent ECG channels are recorded simultaneously have been commercially available (Nihon Koden, DMC-3153; Suzuken, Kenz-Cardiorec 301). However, our technique using 3 leads is quite different from theirs. Our technology allows the recording of the 3-lead ECG on a 2-channel recorder using 5 electrodes while their equipment has 3 tracks and 7 electrodes. In addition, our device is very simple and could easily connect to any conventional 2-channel Holter recorder.

Thus, our new technique is useful, particularly in the detection and diagnosis of variant angina, and makes it less likely that asymptomatic ischemic ST changes are overlooked as compared to the conventional 2-lead Holter monitoring method.

References

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