Computerized Vectorcardiography Telemetry: A New Device for Continuous Multilead ST-Segment Monitoring of Ambulatory Patients. A Preliminary Report

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Background: Continuous vectorcardiography ST-segment monitoring has become a well-established method in the surveillance of patients with acute myocardial ischemia. However, immobility of the vectorcardiography technique prevents monitoring of patients during ambulatory activities. Computerized vectorcardiography telemetry (CVT) with the capacity of real-time ST-segment analysis has been developed in an attempt to overcome this shortcoming. Recent data, however, indicate that changes in body position occasionally lead to pseudo-ischemic ST-segment changes during continuous ST-segment monitoring.

Aims: This report describes the technical features of the CVT system, presents clinical examples using CVT, and assesses the influence of changes in body position on ST-vector magnitude (ST-VM) during CVT, respectively.

Methods: Clinical cases involving CVT are presented. The influence of changing body position during CVT monitoring was evaluated on 24 patients with suspected acute coronary syndromes, i.e., unstable angina or acute myocardial infarction. Each patient performed a specific body positional schedule.

Results: We present three discrete clinical cases where CVT provided early and valuable evidence of ongoing myocardial ischemia. The consequences of different recumbent and ambulatory body positions on ST-VM during CVT monitoring appear to be limited.

Conclusion: Computerized vectorcardiography telemetry is a promising new tool for disclosing residual myocardial ischemic activity during the mobilization phase of patients with acute coronary syndromes. The clinical value of CVT needs further investigation in future trials.

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Continuous vectorcardiography ST-segment monitoring has become a well-established method in the surveillance of patients with acute myocardial ischemia during the last decade. This technique provides early prognostic information in patients admitted with acute coronary syndromes (ACS), i.e.,

unstable angina^{1–4} and acute myocardial infarction (AMI).^{3–5} Vectorcardiography monitoring can be used during coronary angioplasty,^{6,7} and it has become a valuable tool for evaluating the efficacy of pharmacological treatment in patients with ACS.^{8,9} However, immobility of the vectorcardiography

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technique prevents monitoring of patients during ambulatory activities. Computerized vectorcardiography telemetry (CVT) with the capacity of real-time ST-segment analysis has been developed in an attempt to overcome this shortcoming. Recent data, however, indicate that changes in body position occasionally lead to pseudo-ischemic ST-segment changes during continuous ST-segment monitoring.¹⁰⁻¹² Therefore, the purpose of this report is threefold: 1. to describe the on-line features of the CVT system, 2. to present discrete clinical examples using CVT, and 3. to estimate the influence of changes in body position on ST-vector magnitude (ST-VM) during CVT monitoring.

METHODS

Computerized Vectorcardiography Telemetry

The TELEGUARD telemetry system (Danica Biomedical AS, Copenhagen, Denmark) offers wireless on-line, multilead ST-segment as well as conventional arrhythmia monitoring, employing a central IBM-compatible personal computer. Electrocardiographic signals are continuously collected from eight conventional body surface electrodes positioned according to Frank¹³ via a transmitter (16 × 6 × 3.5 centimeters in size, weight 320 grams) carried by the patient. The electrocardiogram (ECG)s from the seven ECG-amplifiers are weighted to three orthogonal leads X, Y, and Z, conveyed via an aerial system to the receivers built into the central computer. A space diversity receiving system is used in order to ensure that data is not lost due to radiofrequency signal fading, i.e., all patients are monitored by two telemetry receivers in parallel, each receiving individual signals from the twin antenna. Transmitted data are protected by an interlacing technique together with a number of cyclical redundancy check bits. The ECG is analyzed with regard to baseline shift and high frequency noise before the ST-segment analysis takes place. A technical alarm appears if too much noise or artefacts are detected. A template matching procedure based on feature extraction is performed in order to separate normal from ectopic beats. Normal and analogous X, Y, and Z QRS complexes are used for ischemia analysis. QRS complexes in a 60-second window are averaged, and ST values calculated at an adjustable measuring point, for instance J + 60 msec. The ST-VM,

which is the summated deviation of the ST segment from the isoelectric level in the three orthogonal leads X, Y, and Z [$ST-VM = (ST-X^2 + ST-Y^2 + ST-Z^2)^{1/2}$, μV],^{1-10,12} is calculated following each averaging period. ST-vector magnitude is displayed as a trend curve continuously updated during the whole recording period on the central computer along with the patient's one-lead ECG. The corresponding orthogonal leads or a derived 12-lead ECG¹⁴ may be examined at any time. Reference X, Y, and Z as well as ST-VM complexes are defined in order of subsequent comparisons. An alternative reference complex can be selected at any time. A superimposed technique is used in order to display the difference between the reference and the current complexes. Data may be studied on-line on a color screen or from laser print-outs. All data from the last 72 hours are automatically stored. In addition, data may be stored for subsequent analysis, e.g., on floppy disks. The sensitivity of the system is 10 μV . The sampling rate for the telemetry transmitter is 100 Hz. The overall band-width of the system is 0.14–40 Hz.

Study Subjects

The influence of changing body position during CVT monitoring was evaluated in 24 consecutive patients suspected of ACS. Sinus rhythm and absence of conduction disturbances were required in a 12-lead ECG taken prior to the monitoring period. Moreover, patients were clinically stable, i.e., without uncontrolled cardiac pain and/or failure, as well as without significant ST-VM fluctuations during at least 2 hours prior to the investigation. Each patient performed a specific body positional schedule during the monitoring period: Supine, right lateral, left lateral, upright 80°, and slow walking position. The protocol was preceded by 5–10 minutes of rest in the supine position. The monitoring time was approximately 10 minutes in each position; thus, the positional protocol lasted approximately 60 minutes for each patient.

Data Analysis

Unstable angina and AMI were defined according to established criteria.^{15,16} A reproducible ST-VM deviation ≥ 0.05 mV during the body positional schedule relative to the ST-VM level in the supine position was termed positional. An ischemic ST-VM episode was defined as a transient deviation ≥ 0.05 mV after establishment (ST-eleva-

tion AMI) of and relative to the ST-VM baseline level, irrespective of body position. ST-vector magnitude was calculated at the J + 60 msec. level. Positional ST-VM calculations were based on values measured from minute 3 to 9 after changing body position during the positional protocol. Data are presented as means and medians (interquartile range, range). Comparisons of categorical response variables were carried out using the chi-square or Fischers exact tests as appropriate, and group comparisons of continuous variables were made by the Mann-Whitney U test. A P value < 0.05 was considered statistically significant.

Clinical Cases

Three cases of patients with unstable angina (Figs. 1 and 2) and AMI (Fig. 3), respectively, all early and fully mobilized, in whom CVT revealed valuable early information are presented.

RESULTS

Positional Changes During Computerized Vectorcardiography Telemetry Monitoring

One patient was excluded from analysis due to evolution of bundle branch block, and another was referred for coronary angiography due to clinical instability (Fig. 1). Characteristics of the final study group are shown in Table 1. Four patients with other diagnoses were retrospectively categorized as having stable angina, vasospastic angina, gastric reflux syndrome, and an unknown diagnosis, respectively. Mean (median, range) CVT monitoring time was 22 (21, 12–26) hours. The influence of different body positions on ST-VM are presented in Table 2. Mean (median, range) ST-VM level in the supine (reference) position was 0.101 (0.08, 0.03–0.21) mV. Four patients with ST-elevation AMI (two with antero-septal and two with inferior involvement) showed no signs of ST-segment resolu-

Figure 1. A 60-year-old male with stable angina after CABG performed 9 years earlier, presented with 1 week of atypical chest pain. A 12-lead ECG on admission showed no signs of myocardial ischemia. During the first hour of CVT monitoring a specific body positional schedule was performed in order to determine whether pseudo-ischemic positional ST-VM changes could be expected. No significant ST-VM (dotted trend curve) alterations occurred when changing from supine (Ref.) to the other nonambulatory body positions; however, a significant (but asymptomatic) ST-VM increase (≥ 0.05 mV from the ST-VM baseline value) evolved while walking slowly (1). It was impossible at that time to determine whether the ST-VM change was caused by shift in body position, by the simultaneously occurring tachycardia (solid line trend curve), or by myocardial ischemia. The recumbent position was reassumed and intravenous nitroglycerin infusion initiated. A subsequent walk (2) resulted in the same level of tachycardia as during the body position schedule, however, without a concomitant change in ST-VM. The corresponding ST-segment changes in lead-X (10 mm/mV and 100 mm/sec.) from Ref. to 1 and 2, respectively, are shown. Therefore, the ST-VM changes were believed to be of myocardial ischemic origin. A coronary angiogram revealed occlusion of venous grafts to the circumflex and right coronary arteries. The patient was transferred for subacute re-CABG. CABG = coronary artery bypass grafting, HR = heart rate, ST-VM = ST-vector magnitude.

Figure 2. A 61-year-old male with stable angina pectoris for 15 years presented with 2 weeks of crescendo angina. A 12-lead ECG on admission showed no signs of myocardial ischemia. No pseudo-ischemic ST-VM changes could be demonstrated during a body positional schedule performed at the beginning of the CVT monitoring period. Significant ST-VM changes occurred at 14:00 hours during slow walking activities, revealing asymptomatic ischemia in the anterolateral myocardium. Medical treatment was intensified. However, significant and asymptomatic ischemic ST-VM changes reoccurred during new ambulatory activities at 19:20 hours. The patient experienced slight to moderate anginal pain with concomitant extensive ST-changes in the same leads (lead X: 1.0 mm/mV and 100 mm/sec, V₆: 1.0 mm/mV and 50 mm/sec) at 21:30 and 23:00 hours during rest as indicated by the thick-line cursor and ECGs. An acute coronary angiogram revealed significant two-vessel disease (involving the left anterior descending and circumflex arteries). The patient was transferred to acute CABG. The "hole" in the ST-VM trend curve from 09:00 to 10:30 was caused by skin-electrode problems. ECG = electrocardiogram, CABG = coronary artery bypass grafting, ST-VM = ST-vector magnitude.

tion following thrombolytic therapy; thus a rather high baseline ST-VM value (range, 0.17–0.21 mV) was present during the body position schedule in these patients. The heart rate changed from a mean (range) of 71 (43–88) beats per minute in the supine position to 72 (42–93) ($P = \text{NS}$), 70 (43–90) ($P = \text{NS}$), 73 (46–98) ($P < 0.05$), 83 (53–112) ($P < 0.01$) beats per minute in the right lateral, left lateral, upright 80°, and walking positions, respectively. In Table 1, various clinical variables are presented according to whether positional ST-VM episodes were present. No statistically significant differences could be demonstrated in those with as compared to those without positional ST-VM episodes.

DISCUSSION

The goal of pharmacological and catheter-based interventions in patients with ACS is to reverse ongoing myocardial ischemia and to stabilize the culprit lesion. Therefore, continuous monitoring of the status of the culprit artery is important in order

to allocate treatment resources appropriately. Electrocardiographical monitoring is currently the most practical noninvasive approach in detecting myocardial ischemia over time. Evaluation of the ST-segment changes in a continuous, rather than a static, mode has increased the accuracy in detecting myocardial ischemia.^{17,18} Electrocardiographical monitoring should be performed by a multi-, rather than a single or dual, lead system because there is an inherent risk of reduced sensitivity in detecting myocardial ischemia of the latter.^{2,7,19} In order to timely identify ischemic changes (warranting prompt relevant and tailored therapy) as well as technical or skin-electrode impedance problems (potentially limiting loss of data), an ECG monitoring method should offer the capacity of real-time analysis. The technique of real-time, multi-lead ST-segment monitoring by continuous vectorcardiography has been comprehensively evaluated on patients with ACS.^{1–9} The occurrence of transient ST-VM episodes indicate a poor prognosis in pa-

Figure 3. A 74-year-old male without known cardiac disease presented after 4 hours of chest pain with a high ST-VM level and corresponding ST-segment elevation in the inferior leads as shown in the ECG's (Ref.) (lead Y: 10 mm/mV and 100 mm/sec, III: 10 mm/mV and 50 mm/sec). The patient was immediately treated with thrombolysis, followed by pain relief and rapid decline in ST-VM (1). Although the patient was free from cardiac complaints, the ST-VM trend curve revealed significant changes indicating residual inferior myocardial ischemia (2). The ST-segment changes seen were not consistently related to ambulatory activity. A myocardial stress scintigraphy indicated asymptomatic inferior wall reversible ischemia. A coronary angiogram showed two significant stenoses in the right coronary artery, and the patient was transferred for coronary angioplasty. The "hole" in the ST-VM trend curve around 13:00 hours was caused by skin-electrode problems. ECG = electrocardiogram, ST-VM = ST-vector magnitude.

tients with unstable angina and nonST-elevation AMI.¹⁻⁴ Furthermore, lack of reperfusion (as indicated by no or slow ST-VM decline) as well as the occurrence of residual ischemia (as indicated by

the presence of recurrent and transient ST-VM episodes) indicate a poor prognosis in patients with ST-elevation AMI.⁵ Continuous vectorcardiography ST-segment monitoring has hitherto

Table 1. Characteristics of Study Patients According to Occurrence of Positional ST-Vector Magnitude Changes

	Positional ST-VM Change, ^a n = 2	No Positional ST-VM Change, ^a n = 20
Men, n	2	16
Mean (range) age, years	61 (53-68)	60 (37-78)
Mean (range) height, m	1.71 (1.65-1.76)	1.76 (1.70-1.86)
Mean (range) supine ST-VM level, mV	0.182 (0.170-0.190)	0.092 (0.03-0.21)
Patients with $\geq$ one ischemic ST-VM episodes, ^a n:	1	5
Final diagnosis, n:		
ST-elevation AMI	2	7
Unstable angina/nonST-elevation AMI	0	9
Other	0	4
Occurrence of Q-wave, ^b n	2	7
Mean (range) change in heart rate, ^c bpm	-0.5 (-4+3)	-0.9 (-8+6)

^a For definitions of positional and ischemic ST-VM episodes, see text. ^b Q-wave in one of the respective orthogonal leads.

^c Alterations in heart rate after changing from the supine to the left lateral lying position. AMI = acute myocardial infarction; ST-VM = ST-vector magnitude.

Table 2. Influence of Different Body Positions on ST-Vector Magnitude

	Mean, Median (mV)	Interquartile Range (mV)	Range (mV)
Supine position	0.101, 0.080	0.060 – 0.130	0.030 – 0.210
Right lateral position	0.109, 0.090	0.070 – 0.150	0.040 – 0.220
Left lateral position	0.112, 0.090	0.060 – 0.138	0.040 – 0.270
80° upright position	0.103, 0.090	0.060 – 0.130	0.040 – 0.240
Walking position	0.111, 0.090	0.070 – 0.140	0.050 – 0.230

been limited to bed-ridden patients due to the wire-dependency and immobility of the system. However, current medical practice encourages early mobilization of patients with ACS. This report presents, for the first time, preliminary data regarding the use of a newly available ST-segment monitoring telemetry system, CVT. When compared to previously available multilead monitoring systems it adds the dimension of wireless ST-segment monitoring, thus, enabling real-time, multilead, ST-segment monitoring of patients during ambulatory activities.

We have presented three clinical examples using CVT monitoring (Figs. 1–3). Even the low level of activity produced by ambulation in a hospital setting was sufficient in at least two patients (Figs. 1 and 2) to generate myocardial ischemic ST-segment changes which were picked up by CVT. In another patient with a ST-segment elevation AMI (Fig. 3), in whom reperfusion therapy seemed to be successful and without subsequent cardiac complaints, CVT revealed both significant spontaneous and ambulatory residual myocardial ischemia. Significant coronary artery lesions was subsequently confirmed in the latter patient. Thus, in these patients CVT provided early evidence of ongoing ischemia which probably would have been missed by discrete ECG taking in the event of clinical complaint.

Previous studies have demonstrated that changes in body posture as well as increasing the heart rate, may lead to significant ST segment changes in the 12-lead ECG or ST-VM.^{10–12} The majority of positional shifts in the present study led to changes in ST-VM, however, these mean changes were small (≥ 0.011 mV). In particular, we found that the influence on ST-VM of changing from the supine to the walking position, and the resultant moderate change in heart rate, to be limited. The generally accepted criterion for myocardial ischemia during "recumbent" continuous vectorcardiography ST-segment monitoring among

patients suspected of ACS is one or more transient increases in ST-VM ≥ 0.05 mV from the individual baseline > 1 minute.^{2–4,9,12,18} Therefore, it appears that there is a wide margin between the level of ST-VM fluctuations due to myocardial ischemia and to those expected following changes in body posture. However, two patients reached ST-VM changes of ≥ 0.05 mV in the left lateral position in the present study. The fact that positional pseudo-ischemic ST-segment changes occur most often in the left lateral position during ST-segment monitoring is in accordance with previous studies.^{11,12} In the present study the impact on ST-VM following changes in body position was limited according to presently accepted ischemia criteria. However, the specificity of CVT, as for other vectorcardiographical monitoring techniques, may possibly be improved by algorithms automatically correcting for positional ST-VM changes.¹²

Compared to conventional "recumbent" ST-segment monitoring, CVT enables ST-segment monitoring during ambulatory activities. Therefore, CVT may improve early triage and evaluation of the efficacy of pharmacological and catheter-based interventions in patients with ACS, as well as the clinical applicability of ST-segment surveillance. In the present report, positional ST-VM changes during CVT monitoring of patients suspected of ACS were sparse. Although previous data have indicated that positional ST segment changes may be more pronounced and frequent in patients with coronary heart disease as compared to healthy subjects,¹¹ further delineation of positional (and spontaneous) ST-segment activity involving both healthy and patient controls are needed in order to test the accuracy of CVT in detecting myocardial ischemia. Moreover, cost benefit and safety in patients with ACS triaged to invasive or aggressive medical treatment regimens or early referral to a low cost facility (or even discharge) according to the information derived from CVT alone and in

combination with other risk stratification strategies require investigation in future prospective trials.

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