**Comparison of Signal Quality Between EASI and Mason-Likar 12-Lead Electrocardiograms During Physical Activity**

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**Background**  Myoelectric noise and baseline wander, artifacts that appear when patients move during electrocardiographic monitoring, can cause false alarms. This problem can be addressed by using a reduced lead set and placing electrodes on the anterior part of the torso only. The Mason-Likar modification of the standard 12-lead electrocardiogram and the EASI lead system are 2 alternative systems for lead placement.

**Objectives**  To test the hypothesis that the EASI lead system is less susceptible to artifacts than is the Mason-Likar modification of the standard 12-lead electrocardiogram.

**Methods**  Baseline wander and myoelectric noise amplitudes of EASI and Mason-Likar 12-lead electrocardiograms were compared. Twenty healthy volunteers participated. Both lead systems were recorded simultaneously for different types of physical activities. For each lead in each subject, baseline wander and myoelectric noise were measured for both systems, at rest and during each physical activity.

**Results**  The outcome for baseline wander was mixed. For myoelectric noise content, the EASI system performed better for the limb leads in the different physical activities. In the precordial leads, the differences were minimal or mixed. However, for supine-to-right turning, EASI performed worse than the Mason-Likar system.

**Conclusions**  The 2 systems have similar susceptibilities to baseline wander. The EASI system is, however, less susceptible to myoelectric noise than is the Mason-Likar system. EASI performed worse than Mason-Likar for turning supine to right, because only the EASI system uses an electrode in the right-midaxillary line. (American Journal of Critical Care. 2004;13:228-234)

Monitoring electrocardiograms (ECGs) is useful in many in-hospital clinical situations as well as in everyday activities (Holter monitoring). One problem with ECG monitoring is its susceptibility to artifacts due to such problems as poor electrode contact or disturbances from skeletal muscle. Excessive artifacts have made it impractical to use the standard 12-lead ECG with distal limb leads (standard-limb) when monitoring. The Mason-Likar modification (ML) of the standard 12-lead ECG is commonly used for ECG monitoring. ML uses all the conventional precordial electrode sites, but the limb electrodes are connected to sites on the anterior part of the torso instead of to distal limb sites. Repositioning the recording electrodes to only torso sites achieves the goal of reducing artifacts but requires the same number of electrodes (10) as does the standard-limb system. An alternative to ML is to use only 3 to 5 electrodes. This number is sufficient for rhythm detection but provides limited information on waveform morphology.

ECG signals from a few well-defined torso positions, in combination with mathematical transformations, however, may provide a “derived” 12-lead ECG,
which is useful also for analysis of morphology. The EASI system,\textsuperscript{2-4} introduced by Dower et al\textsuperscript{5} in the 1980s, uses 4 electrodes on easily located positions on the torso plus a fifth, ground electrode. Previous studies compared waveforms\textsuperscript{6} and diagnostic capability\textsuperscript{3,7-9} of 12-lead ECGs derived from EASI leads versus standard (proximal or distal limb lead placement) 12-lead ECGs. These comparisons were done with particular reference to monitoring patients in the intensive care environment. Studies\textsuperscript{4,7} suggest that the EASI system is less susceptible to artifacts than is the standard 12-lead ECG. To test this hypothesis, we designed a study to systematically compare baseline wander and myoelectric noise amplitudes in controlled situations between simultaneously recorded EASI-derived 12-lead ECGs and ML 12-lead ECGs.

**Methods**

**Study Population**

Twenty ostensibly healthy volunteers participated in this study at the Department of Clinical Physiology, Lund University Hospital, Lund, Sweden. The local investigational review board approved the study.

**Standardized Physical Activities**

We chose a range of physical activities known to cause baseline wander, myoelectric noise, or both. During a single 1-hour study, each subject had ECGs recorded at rest and during performance of the following physical activities:

- holding a 3-kg load with both arms at a 45° angle when supine ("arms up"),
- walking on a treadmill,
- turning slowly from supine to the left side,
- turning slowly from supine to the right side, and
- cycling on an ergometer.

**ECG Acquisition**

For each subject, 2 simultaneous recordings of the ML 12-lead ECG and the EASI ECG were made for each type of physical activity. The electrode type used was Niko\textsuperscript{®}UNI\textsuperscript{®}4 silver/silver-chloride electrodes (Niko Medical Products, Rodovre, Denmark); a Page Writer XLi (Philips Medical, Oxnard, Calif) acquired the ECG signal for 10 seconds and stored it digitally for later offline processing.

Figure 1A shows the 4 recording electrode positions of the EASI system. Positions A, E, and I are those of the Frank vectorcardiographic system.\textsuperscript{10} E is placed on the lower extreme of the body of the sternum. A and I are placed on the left and right midaxillary lines, respectively, in the same transverse plane as E. S is placed on the sternal manubrium. We used the same ground electrode for both the ML and the EASI system in our study.

**Figure 1** Lead placement for the EASI system (A) and the Mason-Likar (B) 12-lead electrocardiogram.

**12-Lead ECGs with limb leads are particularly susceptible to muscle movement artifact.**

The 3 bipolar quasi-orthogonal leads of the EASI system were generated offline by pairwise subtraction of signals recorded at the E, A, S, and I sites. Lead AI views the electrical activity of the heart in a left-to-right direction. Lead AS views the electrical activity of the heart both in left-to-right and caudal-cranial directions but also contains a small anterior-posterior component. Lead ES views the electrical activity of the heart in a caudal-cranial direction and also contains a considerable anterior-posterior component.
Optimal algebraic transfer coefficients have been determined for generating a derived 12-lead ECG from the ECG recorded at the EASI positions.\textsuperscript{11}

Figure 1B shows the lead placement for the ML modification of the standard 12-lead ECG. The right arm and the left arm electrodes are positioned in the right infraclavicular fossa and left infraclavicular fossa, respectively, medial to the border of the deltoid muscle and 2 cm below the lower border of the clavicle. The left leg electrode is positioned in the anterior axillary line, halfway between the costal margin and the crest of the ilium.

Noise Measurements

Two types of noise measurements were computed for each of the leads in both ECGs (Figure 2). These measures reflect the level of baseline wander and myoelectric noise, respectively. Computation of these measurements requires software detection of the QRS complexes.\textsuperscript{12}

Baseline wander is due to variations in electrode impedance caused by perspiration, respiration, and physical activity. Such low-frequency noise was quantified by fitting a regression model to the original ECG signal by using a regularized least-squares criterion.\textsuperscript{13} The method has time-varying properties that are essential in avoiding distortion at the signal end points; such distortion is otherwise a serious problem when time-invariant, linear filtering is used on short-duration signals. Baseline wander was defined as the peak-to-peak amplitude of the estimated baseline during the 10-second recording (Figure 2B).

Noise due to myoelectric activity primarily contains frequency components greater than 15 Hz. This type of activity was quantified from a signal that had been subjected to high-pass filtering (by using a filter cutoff frequency of 15 Hz) and subsequent blanking of the QRS complexes in an interval of 200 ms centered on the R wave. Finally, the root mean square value was computed in each R-R interval of the processed signal, and the largest value was taken as the final measurement of myoelectric noise (Figure 2C).

The length of the R-R interval for noise measurements is sufficient for all physiological heart rates. The influence of large-amplitude T waves in the measurement interval is avoided by using high-pass filtering.

Data Analysis

For each lead in each subject, we calculated the noise measurements at rest and during each physical activity for both the ML and the EASI-derived 12-lead ECGs. If these measures were within 25 µV for the myoelectric noise or within 300 µV for the baseline
wander, results were declared “equal” for the 2 systems. If the difference was greater than these respective thresholds, a “winner” was declared. These 2 threshold values were selected with reference to a signal amplitude at which the noise begins to have a clinical impact on the ECG interpretation. We used the $\chi^2$ statistic to compare the proportion of winners in the EASI and ML lead placement groups. In situations in which no winners occurred in 1 of the 2 groups, the Fisher exact test was used. One $P$ value was determined for the summed limb leads and the summed precordial leads for each physical activity separately.

**Results**

**Characteristics of the Sample**

In 1 of the 20 subjects, 4 of the 6 recordings had such excessive noise that analysis with our method was not meaningful, and therefore that subject was excluded from the study. Table 1 gives demographic descriptions of the remaining 19 study subjects, all of whom were white. The ages ranged from 30 to 64 years (mean, 46 years) and the heights and weights ranged from 1.61 to 1.77 m (mean 1.69 m) and from 54 to 95 kg (mean, 71 kg).

**Table 1** Demographic descriptions of the subjects included in the study

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<th>Height, m</th>
<th>Weight, kg</th>
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<td>21.0</td>
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*Calculated as weight in kilograms divided by the square of the height in meters.

The EASI system uses 5 torso electrodes and mathematical transformations to derive a 12-lead ECG.

Figure 4 and Table 3 present the outcome of comparisons of myoelectric noise content in the 2 recording systems. We found few differences either at rest or during physical activities required for arms up or cycling. For treadmill exercise and turning supine to left, the EASI-derived 12-lead ECG is superior; attaining a significantly higher number of “wins” in the limb leads. However, the ML ECG attained a significantly higher number of wins for turning supine to right in the precordial leads.

**Discussion**

Real-time ST monitoring is feasible and accurate and can be useful for supporting clinical decisions. However, false alarms are an important issue that must be addressed. Changes in body position may cause ST-T and QRS changes and may trigger false alarms.
The lower the susceptibility of a method to artifacts, the higher is the quality of the signal and the lower the prevalence of false alarms. A previous study 18 confirmed that ECG monitors in intensive care units generate a great number of false alarms. As indicated in the literature (and corroborated by vast clinical experience), abrupt changes in the appearance of the ECG due to a change in body position can be erroneously interpreted as an acute ischemic event 19 or an episode of arrhythmia. If false alarms occur frequently, staff might disable the alarm, potentially jeopardizing patients’ safety.

The ML system for placement of electrodes allows high-quality recording of 12-lead ECGs during exercise as well as at rest, and the precordial leads of the 12-lead ECGs closely resemble the standard 12-lead ECGs with distal positions for the limb electrodes.

Figure 3 Comparison of the outcomes for baseline wander at rest (A) and all 5 physical activities (B-F). On the horizontal axis, the zero indicates equivalent performance of the Mason-Likar (ML) 12-lead and EASI-derived 12-lead electrocardiograms. A longer bar to the right than to the left indicates superiority of the EASI-derived 12-lead electrocardiogram and vice versa. The numbers on the horizontal axis indicate the frequency of these occurrences.
However, in many clinical situations, an ECG-recording system that has the same advantages as ML but also has a reduced electrode set would be valuable. Fewer electrodes on more easily located sites would make data acquisition simpler and more rapid for both patients and staff members. The electrode positions of the E, A, S, and I electrodes are easily located, potentially reducing the risk of improperly placed electrodes.

Figure 4  Comparison of the outcomes for myoelectric noise at rest (A) and all 5 physical activities (B-F). On the horizontal axis, the zero indicates equivalent performance of the Mason-Likar (ML) 12-lead and EASI-derived 12-lead electrocardiograms. A longer bar to the right than to the left indicates superiority of the EASI-derived 12-lead electrocardiogram and vice versa. The numbers on the horizontal axis indicate the frequency of these occurrences.

With fewer electrodes, the interference with other clinical procedures would be lessened, movement artifacts would be lessened, and patients’ comfort would be increased.

We found no large differences between the ML and EASI systems in susceptibility to baseline wander, most likely because variations in electrode impedance, the primary cause of baseline wander, are due primar-
Influenced by age and infirmity.

Another limitation of our study is that some artifact-generating movements such as combing hair, brushing teeth, and shaving, which consequently may cause false alarms, were not included in the protocol. Another limitation is that the subjects were all relatively young (30-64 years old) and healthy, characteristics not generally representative of the population monitored in hospitals. The myoelectric noise and baseline wander might be influenced by age and infirmity.

Conclusion

The EASI system is less susceptible to myoelectric noise than is the ML system. However, the systems did not differ significantly with respect to susceptibility to baseline wander. These results, together with those of previous studies, make the EASI system an alternative to the ML system for both in-hospital and ambulatory 12-lead ECG monitoring.

References

13. Tarvainen MP, Ranta-aho PO, Karjalainen PA. An advanced detrending alternative to the ML system for both in-hospital and ambulatory 12-lead ECG monitoring.

Table 3 Comparison of myoelectric noise with EASI versus Mason-Likar (ML) lead placement

<table>
<thead>
<tr>
<th>Lead/setting</th>
<th>EASI winner</th>
<th>ML winner</th>
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<tr>
<td>Limb</td>
<td>%*</td>
<td>No.</td>
</tr>
<tr>
<td>Treadmill</td>
<td>3.5</td>
<td>4</td>
</tr>
<tr>
<td>Supine to right</td>
<td>25.4</td>
<td>29</td>
</tr>
<tr>
<td>Arms up</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Supine to left</td>
<td>23.7</td>
<td>27</td>
</tr>
<tr>
<td>Cycling</td>
<td>7.0</td>
<td>8</td>
</tr>
<tr>
<td>Precordial</td>
<td>0.9</td>
<td>1</td>
</tr>
<tr>
<td>Treadmill</td>
<td>2.6</td>
<td>3</td>
</tr>
<tr>
<td>Supine to right</td>
<td>1.8</td>
<td>2</td>
</tr>
<tr>
<td>Arms up</td>
<td>1.8</td>
<td>2</td>
</tr>
<tr>
<td>Supine to left</td>
<td>0</td>
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</tr>
</tbody>
</table>

Abbreviation: NA, not applicable.
*Percentages are based on a total of 114 comparisons, 6 limb leads in 19 patients or 6 precordial leads in 19 patients.
†By the Fisher exact test.
‡By χ² test.

Acknowledgment

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