Heart Failure

Early Repolarization in an Ambulatory Clinical Population

Abhimanyu Uberoi, MD, MS; Nikhil A. Jain, BS; Marco Perez, MD; Anthony Weinkopff, BS; Euan Ashley, MRCP, Dphil; David Hadley, PhD; Mintu P. Turakhia, MD, MAS; Victor Froelicher, MD

Background—The significance of early repolarization, particularly regarding the morphology of the R-wave downslope, has come under question.

Methods and Results—We evaluated 29,281 resting ambulatory ECGs from the VA Palo Alto Health Care System. With PR interval as the isoelectric line and amplitude criteria ≥0.1 mV, ST-segment elevation is defined at the end of the QRS, J wave as an upward deflection, and slur as a conduction delay on the QRS downstroke. Associations of ST-segment elevation patterns, J waves, and slurs with cardiovascular mortality were analyzed with Cox analysis. With a median follow-up of 7.6 years, there were 1995 cardiac deaths. Of 29,281 subjects, 87% were male (55±14 years) and 13% were female (56±17 years); 13% were black, 6% were Hispanic, and 81% were white or other. Six hundred sixty-four (2.3%) had inferior or lateral ST-segment elevation: 185 (0.6%) in inferior leads and 479 (1.6%) in lateral leads, 163 (0.6%) in both, and 0.4% had global elevation. A total of 4041 ECGs were analyzed with enhanced display, and 583 (14%) had J waves or slurring, which were more prevalent in those with than in those without ST-segment elevation (61% versus 13%; Pr<0.001). ST-segment elevation occurred more in those with than in those without J waves or slurs (12% versus 1.3%; P<0.001). Except when involving only inferior leads, all components of early repolarization were more common in young individuals, male subjects, blacks, and those with bradycardia. All patterns and components of early repolarization were associated with decreased cardiovascular mortality, but this was not significant after adjustment for age.

Conclusions—We found no significant association between any components of early repolarization and cardiovascular mortality. (Circulation. 2011;124:2208-2214.)

Key Words: electrocardiography □ death □ follow-up studies

ST-segment elevation in the absence of acute infarction was first reported in the ECGs of healthy individuals in 1947 and called early repolarization in 1951. This “normal RS-T segment elevation variant” was characterized as ST-segment elevation at the end of the QRS complex with a distinct notch (J wave) or slur on the downslope of the R wave by Wasserburger and Alt in 1961. In 1976, Kambara and Phillips reported that early repolarization was more common in young male individuals and blacks, and appeared typically in lateral leads and less frequently in inferior leads. Whereas the key feature of early repolarization has been ST-segment elevation because of its critical association with myocardial infarction or ischemia and pericarditis, morphology of the downslope of the R wave has long been noted and thought to be benign.

Recent studies that suggested an association between early repolarization and cardiovascular death did not use the traditionally characteristic ST-segment elevation in their definition; rather, they focused on the morphology of the downslope of the R wave. The seminal article by Haissaguerre and colleagues was based on a retrospective analysis of 206 individuals with idiopathic ventricular fibrillation (VF) with structurally normal hearts. The subjects were found to have a higher prevalence of J waves or slurring of the QRS downstroke compared with age-matched control subjects. Subsequently, a community epidemiological study reported that only J waves or slurring in the inferior leads had an adjusted hazard of 2 for association with cardiac death. Together, these studies were contrary to the previously held notion that early repolarization in healthy athletes and a general clinical population was a benign finding. On the basis of these 2 studies, cellular physiologists hypothesized that early repolarization should be included in the pathological categories of J-wave syndromes and ST-segment elevation channelopathies.

If these new observations and hypotheses were confirmed, they could have a profound impact on the preparticipation examination and on ECG screening in general, because athletes, blacks, and young male individuals often exhibit a

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higher prevalence of early repolarization than the general population.\textsuperscript{4,10} The burden of requiring further testing of this potentially large cohort with early repolarization would be prohibitive.

In an attempt to clarify this controversy, we evaluated the prevalence and prognosis of early repolarization, defined by ST-segment elevation and the morphology of the downslope of the R wave, in a large outpatient population.

**Methods**

**Clinical Population**

We performed a retrospective study of 45,829 inpatient and outpatient ECGs from March 1987 to December 1999 at the VA Palo Alto Health Care System. Since 1987, the VA Palo Alto Health Care System has used a centralized, computerized ECG system for the collection, storage, and analysis of ECGs (GE Healthcare, Wauwatosa, WI). This system has been approved by the US Food and Drug Administration and the European Union and is widely used around the world. All patients were seen at the main VA facility or its satellite clinics, and ECGs were ordered by healthcare providers for standard clinical indications, usually to screen for occult disease and to obtain a baseline when care is initiated. For patients with multiple ECGs, only the first ECG was considered because serial ECGs were obtained only for clinical indications, not as part of routine protocol. Because clinical diagnostic codes were not available, we excluded those with inpatient status (n=12,319) to eliminate ECGs possibly associated with acute coronary syndromes and other acute processes. Furthermore, ECGs exhibiting a trial fibrillation or flutter (n=12,553), ventricular rates >100 bpm (n=27,999), QRS durations >120 milliseconds (n=3,141), paced rhythms (n=290), ventricular preexcitation (n=42), and acute myocardial infarction (n=29) were excluded, leaving 29,281 patients for analysis. Race was determined by self-report at the time of ECG acquisition. Race was determined by self-report at the time of ECG acquisition. Unfortunately, incorporating the concurrent clinical data was beyond the scope of this project because that would have required manually reviewing all records, coding the clinical variables, and adding them to the database. Furthermore, the inclusion of additional variables would be inconsistent because a protocol was not in place for gathering the data.

**ECG Interpretation**

With the PR interval as the isoelectric line and the amplitude criteria as \( \geq 0.1 \) mV, J waves were defined as an upward deflection, slurs as a conduction delay beginning on the QRS downstroke, and ST-segment elevation at the end of the QRS complex. All ECGs exhibiting ST-segment elevation as determined by the computer measurements were reread by 3 observers (blinded to outcomes) and corrected when necessary (4.5%). In general, the criterion requiring ST-segment elevation in 2 contiguous leads in any lead group (inferior: II, III, and AVF; lateral: I, aVL, and V\(_4\)–V\(_6\); anterior: V\(_1\)–V\(_3\)) was applied. However, if an ST-segment elevation classification resulted in a group size <1% of the total population, then only 1 lead with ST-segment elevation in the territory was considered sufficient for classification. This way, visual inaccuracy was accounted for without losing computer accuracy. As in prior studies,\textsuperscript{5,6} anterior lead elevation was not considered separately but was included in the global ST-segment elevation pattern. The ECGs were also coded for left ventricular hypertrophy, ST-segment depression, diagnostic Q waves, and Minnesota Codes consistent with coronary artery disease. Figure 1 provides examples of slurs and J waves with and without ST-segment elevation.

A subset of the population (n=4,041) were in a data structure in which the ECGs could be displayed on a 24-in computer screen in multiple formats, enabling careful classification of slurring on the downslope of the R and J waves. These patients were visually coded for \( \geq 0.1 \)-mV slurs on the downslope of the R and J waves by an experienced interpreter. A random sample of 100 (half with and half without J waves or slurring) were reread, and the agreement was 95% owing to slight differences in amplitude measurements.

To determine the natural history of early repolarization, 250 patients with ECGs exhibiting the greatest amplitude of early repolarization were reviewed to see if they had another ECG >1 year later. Their serial ECGs, obtained for clinical indications and not by protocol, were then reviewed and manually coded.

**Outcomes**

The primary outcome variable was time to cardiovascular mortality. The California Health Department Service and Social Security Death Indexes were used to ascertain the vital status of each patient as of December 31, 2002, for the total population and, as of December 31, 2010, for the digital data subset. Accuracy of causes of deaths was reviewed by 2 clinicians blinded to ECG results and confirmed with the Veterans Affairs computerized medical records. Sufficient data...
Table 1. Population Characteristics of the Total Population for Comparison Between the Patterns of ST-Segment Elevation

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>All Subjects</th>
<th>No ST-Segment Elevation in Lateral or Inferior Leads</th>
<th>ST Elevation Inferior Leads</th>
<th>ST-Segment Elevation Lateral or Inferior Leads</th>
<th>ST-Segment Elevation Both Inferior and Lateral (Any)</th>
<th>ST-Segment Elevation Global (Any)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n (%)</td>
<td>29,281</td>
<td>28,617 (97.7)</td>
<td>185 (0.6)</td>
<td>1479 (1.6)</td>
<td>864 (2.3)</td>
<td>119 (0.4)</td>
</tr>
<tr>
<td>Age, y</td>
<td>25 ±15</td>
<td>25 ±15</td>
<td>52 ±16</td>
<td>0.005</td>
<td>42 ±13</td>
<td>0.001</td>
</tr>
<tr>
<td>Male, n (%)</td>
<td>25,544</td>
<td>24,904 (97.0)</td>
<td>168 (0.6)</td>
<td>0.001</td>
<td>42 (96.4)</td>
<td>0.001</td>
</tr>
<tr>
<td>Black, n (%)</td>
<td>3885</td>
<td>3644 (97.7)</td>
<td>185 (4.8)</td>
<td>0.001</td>
<td>42 (34.8)</td>
<td>0.001</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>27.3 ±5.5</td>
<td>27.3 ±5.5</td>
<td>25.8 ±5.4</td>
<td>0.002</td>
<td>26.0 ±4.1</td>
<td>0.001</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>70.6 ±12.6</td>
<td>70.7 ±12.6</td>
<td>69.8 ±13.1</td>
<td>0.3</td>
<td>63.2 ±12.3</td>
<td>0.001</td>
</tr>
<tr>
<td>QTc duration, ms</td>
<td>418 ±22</td>
<td>418 ±22</td>
<td>413 ±30</td>
<td>0.005</td>
<td>408 ±19</td>
<td>0.001</td>
</tr>
<tr>
<td>Coronary artery disease on ECG, n (%)</td>
<td>7796 (26.8)</td>
<td>7684 (26.9)</td>
<td>51 (27.6)</td>
<td>0.77</td>
<td>61 (12.7)</td>
<td>0.001</td>
</tr>
<tr>
<td>Romhilt-Estes LVH score &gt;3, n (%)</td>
<td>1241 (4.2)</td>
<td>1155 (4.0)</td>
<td>6 (3.2)</td>
<td>0.5</td>
<td>80 (16.7)</td>
<td>0.001</td>
</tr>
<tr>
<td>ST-segment depression (V_e &lt; 0.5 mm), n (%)</td>
<td>1974 (6.7)</td>
<td>1963 (6.9)</td>
<td>10 (0.4)</td>
<td>0.47</td>
<td>1 (0.2)</td>
<td>0.001</td>
</tr>
<tr>
<td>Inferior Q waves, n (%)</td>
<td>2079 (7.1)</td>
<td>2044 (7.1)</td>
<td>25 (13.5)</td>
<td>0.001</td>
<td>10 (2.1)</td>
<td>0.001</td>
</tr>
<tr>
<td>Anterior Q waves, n (%)</td>
<td>593 (2.0)</td>
<td>588 (2.1)</td>
<td>3 (1.6)</td>
<td>0.7</td>
<td>2 (0.4)</td>
<td>0.012</td>
</tr>
<tr>
<td>CV deaths, n (%)</td>
<td>1995 (6.8)</td>
<td>1966 (6.9)</td>
<td>14 (7.6)</td>
<td>0.68</td>
<td>15 (3.1)</td>
<td>0.001</td>
</tr>
<tr>
<td>Annual CV mortality, %</td>
<td>0.86</td>
<td>0.87</td>
<td>0.92</td>
<td>0.33</td>
<td>0.49</td>
<td>0.16</td>
</tr>
</tbody>
</table>

LVH indicates left ventricular hypertrophy; CV, cardiovascular.

were not available to classify arrhythmic deaths. Follow-up was complete.

Statistical Analysis

NCSS software 2007 (Kaysville, UT) and SAS version 9.1 were used for all statistical analyses. Unpaired t tests were used for comparisons of continuous variables, and χ² tests were used to compare dichotomous variables between patient groups. Survival analysis was performed with the Kaplan-Meier method. The Kaplan-Meier method also was used to estimate the survival rates. The log-rank test was used to compare the estimated survival rates of the patient groups. The hazard ratio estimated from the Cox proportional hazards model was used to determine the associations between ST-segment elevation patterns and outcome. This hazard ratio was adjusted for age, sex, and ethnicity.

Results

Of the 29,281 patients, 25,544 (87.2%) were male and were on average 55±14 years of age. The remaining 3737 patients (12.8%) were female and on average 56±17 years of age. The ethnic distribution was as follows: black, 13%; Hispanic, 6%; and white (and other), 81%. There were 6739 deaths (1995 cardiovascular, 30%) over a mean follow-up of 7.6±3.8 years.

The cohort was stratified into subgroups based on presence and location of ST-segment elevation: no ST-segment elevation, inferior lead only, lateral lead only, inferior or lateral lead, inferior and lateral leads, and global elevation (inferior, lateral, and anterior elevation). There were no significant differences in the baseline characteristics between those without ST-segment elevation and patients with ST-segment elevation except for those with isolated inferior lead elevation. The isolated inferior lead elevation group was older, had a higher heart rate, were less likely to be male, and exhibited more ECG abnormalities, particularly inferior Q waves (13.5%), than the other groups.

Table 1 provides the demographics, ECG findings, and annual cardiovascular mortality of the total population and its subgroups according to patterns of ST-segment elevation. Patients with lateral ST-segment elevation, isolated or as part of a more global pattern, were significantly younger and had a lower heart rate, a lower prevalence of any ECG abnormality other than left ventricular hypertrophy, and a higher prevalence of black race.

The early repolarization pattern in ≥2 contiguous leads was present in 664 subjects (2.3%): 185 (0.6%) in inferior leads and 479 (1.6%) in lateral leads, with elevation in both territories in 43 subjects (0.1%). Because of the small number of patients with contiguous lead elevation in inferior and lateral leads (n=43), we instead considered those with elevation in 1 lead per territory (n=163 patients, 0.6%). The same was done for global elevation (n=30 when requiring contiguous elevation but 119 [0.4%] when using 1 lead per territory). No patients exhibited ST-segment elevation ≥0.2 mV in either the inferior or lateral lead. Figures 2 through 5 exhibit the Kaplan-Meier curves of freedom from cardiovascular death in the different ST-segment elevation patterns. The hazard ratio estimated from the Cox proportional hazards model was used to determine the associations between ST-segment elevation patterns and outcome. This hazard ratio was adjusted for age, sex, and ethnicity. They showed that ST-segment elevations ≥0.1 mV in lateral leads (Figure 2), in inferior or lateral leads with J waves or slurs (Figure 4), or with global ST-segment elevation (Figure 5) were associated with a trend to decreased mortality, although not statistically significantly. ST-segment elevations of ≥1 mm in inferior leads (Figure 3) did not demonstrate such trends. They appeared to be of no consequence in terms of mortality.

Table 2 presents the demographics of the subset of 4041 that were available for enhanced visualization, enabling...
coding for J waves and slurring on the downslope of the R wave in addition to the ST level measurements. Only minor differences were found between them and the entire population. There were 1082 deaths (245 cardiovascular, 23%) over a mean follow-up of 9.1±3 years. J waves or slurring occurred in 583 (14%), more commonly in those with ST-segment elevation than those without ST-segment elevation (61% versus 13%; \( P<0.001 \)). ST-segment elevation occurred more frequently in those with J waves or slurs (12% versus 1.3%; \( P<0.001 \)). J waves or slurring was more common than ST-segment elevation (14% versus 2.9%; \( P<0.001 \)), with 1.8% having both ST-segment elevation and a J wave or a slur. Patients with lateral lead early repolarization were significantly younger and had a lower heart rate, a lower prevalence of any ECG abnormality, and a higher prevalence of black race.

Table 3 provides unadjusted and adjusted hazard ratios for the subgroups according to patterns of ST-segment elevation for cardiovascular mortality. The most striking finding is the decreased risk associated with ST-segment elevation, either isolated or as part of any other more global pattern. Although the significance disappears with covariate adjustment, these trends remain. This was also found in the group with global elevation. No significant adjusted or unadjusted hazard associated with inferior lead elevation was found in the overall group. Multivariate models were created to adjust for age, sex, and black ethnicity; a second model also adjusted for resting heart rate, body mass index, and other ECG abnormalities. When included in the multivariate models, all of the covariates were associated with cardiovascular mortality except race and body mass index.

Table 4 provides unadjusted and adjusted hazard ratios for the association between J waves, slurs, ST-segment elevation, and cardiovascular mortality in the 4041 coded for the R-wave downslope patterns. All of the patterns except those with a small sample size were significantly associated with a lowered risk for cardiovascular death. The significance for protection disappeared with adjustment, but the trend remained, and no pattern was associated with an increased risk.

Of the 250 patients with the greatest amplitude of early repolarization, 122 were found to have a repeat ECG 1 year later. After an average of 7 years, 35 still reached the
Table 3. Cox Hazard Analysis of the Total Population of 29,281 Ambulatory Clinic Patients With Cardiovascular Death as Outcome

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Unadjusted Relative Risk (95% CI)</th>
<th>P</th>
<th>Age-Adjusted Relative Risk (95% CI)</th>
<th>P</th>
<th>Adjusted Relative Risk (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST-segment elevation in inferior leads only</td>
<td>1.29 (0.76–2.18)</td>
<td>0.34</td>
<td>1.77 (1.05–2.99)</td>
<td>0.03</td>
<td>1.73 (0.93–3.3)</td>
<td>0.08</td>
</tr>
<tr>
<td>ST-segment elevation in lateral leads only</td>
<td>0.39 (0.23–0.64)</td>
<td>&lt;0.001</td>
<td>0.84 (0.50–1.4)</td>
<td>0.5</td>
<td>0.83 (0.50–1.50)</td>
<td>0.52</td>
</tr>
<tr>
<td>Global elevation</td>
<td>0.23 (0.06–0.90)</td>
<td>0.04</td>
<td>0.97 (0.62–1.5)</td>
<td>0.9</td>
<td>0.98 (0.6–1.5)</td>
<td>0.9</td>
</tr>
<tr>
<td>ST-segment in inferior and lateral leads</td>
<td>0.34 (0.13–0.90)</td>
<td>0.03</td>
<td>0.89 (0.34–2.39)</td>
<td>0.82</td>
<td>0.69 (0.17–2.76)</td>
<td>0.76</td>
</tr>
</tbody>
</table>

CI indicates confidence interval. Multivariate-adjusted analysis includes age, sex, black race, body mass index, heart rate, and ECG abnormalities.
in control subjects (31% versus 5%). Rosso et al\textsuperscript{23} reported contradicting results in 45 patients with idiopathic ventricular fibrillation, 124 matched control subjects, and 121 athletes; they found that the prevalence of ST-segment elevation and QRS slurring was similar in all 3 groups. Merchant et al\textsuperscript{24} compared 39 patients with idiopathic ventricular tachycardia/VF, 23% of whom had 1-mm ST-segment elevation, with 200 normal patients with ST-segment elevation. They found notching (J wave) to be more prevalent in idiopathic VF (44% versus 5%). In these 2 articles, notching on the R-wave downslope, or a J wave, was considered early repolarization in the absence of ST-segment elevation.

These studies, concentrating on patients with idiopathic ventricular tachycardia/VF, were followed by a community-based epidemiological study that factored baseline characteristics and used visually interpreted ECGs, which included manual measurements of ST-segment elevation, notching, and slurring in the inferior and lateral leads, with cardiovascular death as the outcome.\textsuperscript{6} This study found no hazards associated with these patterns in the lateral leads but an adjusted hazard of roughly 2 for inferior lead ST-segment elevation. The subjects with inferior ST-segment elevation had a higher prevalence of Minnesota Code ECG findings, which are associated with coronary artery disease. The example this study provides for this group exhibited ST-segment elevation occurring over inferior Q waves, which is a pattern that has been associated with wall motion abnormalities of aneurysms after a myocardial infarction. In an earlier clinical population undergoing voluntary health screening, Klatsky and colleagues\textsuperscript{7} analyzed 2000 ECGs to find that 15% had 0.5-mm and 33% had 1.0-mm ST-segment elevation. Those with ST-segment elevation were more likely to be male, <40 years old, bradycardic, black, or physically active. No deaths were reported, and their hypothesis that ST-segment elevation would lead to hospitalizations or cardiac diagnoses was not supported. In a case-cohort study, Sinner et al\textsuperscript{25} considered noting on the QRS downslope, or a J wave, early repolarization in the absence of ST-segment elevation. They found these R-wave downslope patterns to be associated with a 2- to 4-fold increased risk of cardiac mortality in those between 35 and 54 years of age, particularly when located inferiorly.

On the basis of their cellular physiology experiments and the 2 recent key studies,\textsuperscript{5,6} Antzelevitch and Yan\textsuperscript{8} have proposed dividing early repolarization into 3 subtypes: type 1, which displays an ST-segment elevation pattern predominantly in the inferior lead; type 2, which displays an ST-segment elevation pattern predominantly in the inferior or inferolateral leads and is associated with a higher level of risk; and type 3, which displays an ST-segment elevation pattern in the inferior, lateral, and right precordial leads and is associated with the highest level of risk for development of malignant arrhythmias. They included the above types in a category of J-wave syndromes consisting of early repolarization, ischemia, Osborn waves, and Brugada patterns. Our results do not support a clinical utility for this typing or classification.

There are limitations to our study, including a predominantly male population and the use of computerized ECG technology. Whereas we focused on the traditional definition of early repolarization, only a 10% subset considered the independent prognostic value of terminal QRS slurring and J waves. Variation between studies regarding the prevalence of early repolarization may be explained by the wide variation in criteria and population selection. Although our results are more similar to the results of Tikkanen et al,\textsuperscript{6} who also showed no risk of death for lateral lead patterns, the differing results of Sinner et al\textsuperscript{23} could be due to the limitations of the case-cohort design. Our application of computerized measurements and display with visual confirmation are more consistent with current clinical practice. Development of algorithms to identify and quantify R-wave slurring and J waves should be a priority for future studies. Sufficient data were not available to classify arrhythmic deaths.

**Conclusions**

We have demonstrated that common patterns of ST-segment elevation, global ST-segment elevation, or J waves and slurring are not associated with cardiovascular death in an asymptomatic outpatient population. Decisions such as...
whether to perform additional diagnostic tests should be based on symptoms, family history, and all available clinical information and not the benign classic ECG patterns of early repolarization.

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Dr. Turakhia was supported by a VA Health Services Research Career Development Award (CDA09027–1) and AHA National Scientist Development Grant (09SDG2250647).

**Disclosures**

None.

**References**


**CLINICAL PERSPECTIVE**

A common interpretative statement from modern ECG machines, particularly when testing healthy, young male subjects, is early repolarization. Although these statements are based on the level of the ST segment, recent studies have created concern about variations on the downslope of the R wave, specifically J waves and slurs. Using a large ambulatory clinical population and computerized techniques, we were unable to demonstrate an association of any of these components of early repolarization to cardiovascular death. Although perhaps more prevalent in certain high-risk groups, early repolarization is a benign ECG pattern in apparently healthy individuals with no significant predictive value.
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심전도상의 조기 재분극은 심혈관질환 관련 사망률과 무관하다

강 석 민 교수 세브란스병원 심장내과

Summary

배경
심전도상 조기 재분극(early repolarization), 특히 R파의 downslope 형태에 관한 임상적 중요성이 대두되어 왔다.

방법 및 결과
본 연구자들은 VA Palo Alto Health Care System 병원 외래를 내원하는 환자 29,281명의 심전도를 분석하였다. ST 분절 상승(≥0.1mV) 유무는 QRS파의 종점에서 판단하였다. J파는 R파의 하강 곡선의 상승, slur는 QRS파의 하강 곡선의 전도 장애로 정의하였다. Cox analysis를 통해 ST 분절 상승 패턴, J파 유무, QRS파의 slur 유무 등이 심혈관질환의 사망률과 연관성이 있는지 알아보았다. 7.6년간의 추적관찰 기간 동안 1,995건의 심혈관 사망이 발생하였다. 29,281명의 대상자 중 87%가 남성(55±14세), 13%가 여성(56±17세)이었다. 664명(2.3%)이 하벽 혹은 측벽 ST 분절 상승을 보였고, 이 중 185명(0.6%)에서는 하벽 ST 분절 상승, 479명(1.6%)에서는 측벽 ST 분절 상승, 163명(0.6%)에서는 하벽과 측벽 ST 분절 상승, 0.4%에서는 전체적인 ST 분절 상승을 보였다. 이 중에서 4,041건의 심전도를 심층 분석하였는데, 583명(14%)명에서 J파 혹은 slur를 발견할 수 있었는데, 이는 ST 분절 상승을 보이지 않았던 군보다 ST 분절 상승을 동반한 군에서 유의하게 높게 관찰되었다(61% vs. 13%; P<0.001). ST 분절 상승은 J파나 slur를 동반하지 않는 군보다 동반한 군에서 유의하게 나타났다(12% vs. 1.3%; P<0.001). 단지 하벽 유도(inferior leads)에서만 조기 재분극을 보이는 군을 제외하면, 조기 재분극의 모든 요소는 젊은 연령, 남성, 흑인, 서맥 군에서 흔하다. 조기 재분극의 형태와 요소들은 심혈관질환의 사망률 감소와 연관성이 있었으나, 연령을 보정한 경우에는 통계적 의의가 없다.

결론
본 연구 결과에 의하면, 조기 재분극의 어떠한 요소들도 심혈관 사망률과 유의한 연관성이 없음을 알 수 있었다.
Commentary

심근경색증을 동반하지 않는 ST 분절의 상승을 가진 사람들은 주로 하벽 유도 부위보다는 측벽 유도에서는 젊은 연령(40세 미만), 남성, 흑인 등에서 흔하게 발견되며, 주로 하벽 유도 부위보다는 측벽 유도 상에서는 주로 젊은 연령(40세 미만), 남성, 흑인 등에서 흔하게 발견되며, 주로 하벽 유도 부위보다는 측벽 유도 (lateral leads) 부위에서 많이 관찰된다. 조기 재분극의 정의는 ST 분절의 상승, J파, R파의 slur 유무 등으로 구분할 수 있다. 일반적으로 건강한 사람에서 나타나는 이른 심전도상 조기 재분극은 임상적으로 양성(benign)으로 간주된다. 그러나 그동안 동물 실험에서 조기 재분극이 심장 환경을 유발할 가능성이 제시되어 왔으며, Brugada 증후군, 심근이상, 저체온 등에서 관찰되는 것

Table 1. Cox hazard analysis of the total population of 29,281 ambulatory clinic patients with cardiovascular death as outcome

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Unadjusted Relative Risk (95% CI)</th>
<th>P</th>
<th>Age-Adjusted Relative Risk (95% CI)</th>
<th>P</th>
<th>Adjusted Relative Risk (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST-segment elevation in inferior leads only</td>
<td>1.29(0.76–2.18)</td>
<td>0.34</td>
<td>1.77(1.05–2.99)</td>
<td>0.03</td>
<td>1.73(0.93–3.3)</td>
<td>0.08</td>
</tr>
<tr>
<td>ST-segment elevation in lateral leads only</td>
<td>0.39(0.23–0.64)</td>
<td>&lt;0.001</td>
<td>0.84(0.50–1.4)</td>
<td>0.5</td>
<td>0.83(0.50–1.50)</td>
<td>0.52</td>
</tr>
<tr>
<td>Global elevation</td>
<td>0.23(0.06–0.90)</td>
<td>0.04</td>
<td>0.97(0.62–1.5)</td>
<td>0.9</td>
<td>0.98(0.6–1.5)</td>
<td>0.9</td>
</tr>
<tr>
<td>ST-segment in inferior and lateral leads</td>
<td>0.34(0.13–0.90)</td>
<td>0.03</td>
<td>0.89(0.34–2.39)</td>
<td>0.82</td>
<td>0.69(0.17–2.76)</td>
<td>0.76</td>
</tr>
</tbody>
</table>

CI indicates confidence interval. Multivariate-adjusted analysis includes age, sex, black race, body mass index, heart rate, and ECG abnormalities.
으로 알려져 있고, 구조적으로 정상인 심장에서 발생하는 특발성 심실세동 환자들에서는 조기 재분극의 유병률이 높고 심혈관 사망과 관련이 있다는 보고도 있다. 특히, 심실세동을 경험한 환자들에서 조기 재분극을 동반한 경우는 남자이거나, 실신의 과거력이 있거나, 수면 중 심장시가 발생한 환자들이 많다. 본 논문에서는 관상동맥 질환 환자(26.6%, 7,796명)를 포함해 외래에서 측정한 총 29,281명의 심전도를 분석한 결과, 조기 재분극의 어떠한 요소들도 심혈관 사망률과 유의한 연관이 없음을 알 수 있었다. 조기 재분극이 나타나는 유도 부위 혹은 형태에 따라 심혈관 사망률과의 약간의 연관성을 보이기도 하였으나, 통계적으로 의미있는 결과를 산출하지는 못했다. 본 연구는 대상 환자군이 주로 남성(87.2%)이었으며, 부정맥에 의한 급사 등에 대한 분석자료가 없어 아쉬움이 있지만, 무증상의 대규모 외래 환자들을 장기간의 추적 관찰(7.6년)을 통해 조기 재분극의 임상적 의미를 알아본 연구였다. 따라서 임상에서 단순히 심전도의 소견만으로 환자의 예후를 예측하기보다는 증상, 가족력 및 다양한 임상 정보를 종합하여 판단하여야 할 것이다.

References
Early Repolarization in an Ambulatory Clinical Population

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Background—The significance of early repolarization, particularly regarding the morphology of the R-wave downslope, has come under question.

Methods and Results—We evaluated 29,281 resting ambulatory ECGs from the VA Palo Alto Health Care System. With PR interval as the isoelectric line and amplitude criteria =0.1 mV, ST-segment elevation is defined at the end of the QRS, J wave as an upward deflection, and slur as a conduction delay on the QRS downstroke. Associations of ST-segment elevation patterns, J waves, and slurs with cardiovascular mortality were analyzed with Cox analysis. With a median follow-up of 7.6 years, there were 1954 cardiac deaths. Of 29,281 subjects, 87% were male (55±14 years) and 13% were female (56±17 years); 13% were black, 6% were Hispanic, and 81% were white or other. Six hundred sixty-four (2.3%) had inferior or lateral ST-segment elevation: 185 (0.6%) in inferior leads and 479 (1.6%) in lateral leads, 163 (0.6%) in both, and 0.4% had global elevation. A total of 4041 ECGs were analyzed with enhanced display, and 583 (14%) had J waves or slurring, which were more prevalent in those with than in those without ST-segment elevation (61% versus 13%; P<0.001). ST-segment elevation occurred more in those with than in those without J waves or slurs (12% versus 1.3%; P<0.001). Except when involving only inferior leads, all components of early repolarization were more common in young individuals, male subjects, blacks, and those with bradycardia. All patterns and components of early repolarization were associated with decreased cardiovascular mortality, but this was not significant after adjustment for age.

Conclusions—We found no significant association between any components of early repolarization and cardiac mortality. (Circulation. 2011;124:2208–2214.)

Key Words: electrocardiography • death • follow-up studies

ST-segment elevation in the absence of acute infarction was first reported in the ECGs of healthy individuals in 1947 and called early repolarization in 1951. This “normal RS-T segment elevation variant” was characterized as ST-segment elevation at the end of the QRS complex with a distinct notch (J wave) or slur on the downslope of the R wave by Wasserburger and Alt in 1961. In 1976, Kambara and Phillips reported that early repolarization was more common in young male individuals and blacks, and appeared typically in lateral leads and less frequently in inferior leads. Whereas the key feature of early repolarization has been ST-segment elevation because of its critical association with myocardial infarction or ischemia and pericarditis, morphology of the downslope of the R wave has long been noted and thought to be benign.

Clinical Perspective on p 119

Recent studies that suggested an association between early repolarization and cardiovascular death did not use the traditionally characteristic ST-segment elevation in their definition; rather, they focused on the morphology of the downslope of the R wave. The seminal article by Haissaguerre and colleagues was based on a retrospective analysis of 206 individuals with idiopathic ventricular fibrillation (VF) with structurally normal hearts. The subjects were found to have a higher prevalence of J waves or slurring of the QRS downstroke compared with age-matched control subjects. Subsequently, a community epidemiological study reported that only J waves or slurring in the inferior leads had an adjusted hazard of 2 for association with cardiac death. Together, these studies were contrary to the previously held notion that early repolarization in healthy athletes and a general clinical population was a benign finding. On the basis of these 2 studies, cellular physiologists hypothesized that early repolarization should be included in the pathological categories of J-wave syndromes and ST-segment elevation channelopathies.

If these new observations and hypotheses were confirmed, they could have a profound impact on the preparticipation examination and on ECG screening in general, because athletes, blacks, and young male individuals often exhibit a...
higher prevalence of early repolarization than the general population.\textsuperscript{4,10} The burden of requiring further testing of this potentially large cohort with early repolarization would be prohibitive.

In an attempt to clarify this controversy, we evaluated the prevalence and prognosis of early repolarization, defined by ST-segment elevation and the morphology of the downslope of the R wave, in a large outpatient population.

**Methods**

**Clinical Population**

We performed a retrospective study of 45,829 inpatient and outpatient ECGs from March 1987 to December 1999 at the VA Palo Alto Health Care System. Since 1987, the VA Palo Alto Health Care System has used a centralized, computerized ECG system for the collection, storage, and analysis of ECGs (GE Healthcare, Wauwatosa, WI). This system has been approved by the US Food and Drug Administration and the European Union and is widely used around the world. All patients were seen at the main VA facility or its satellite clinics, and ECGs were ordered by healthcare providers for standard clinical indications, usually to screen for occult disease and to obtain a baseline when care is initiated. For patients with multiple ECGs, only the first ECG was considered because serial ECGs were obtained only for clinical indications, not as part of routine protocol. Because clinical diagnostic codes were not available, we excluded those with inpatient status (n=12,319) to eliminate ECGs possibly associated with acute coronary syndromes and other acute processes. Furthermore, ECGs exhibiting atrial fibrillation or flutter (n=12,314), paced rhythms (n=290), ventricular preexcitation (n=42), and acute myocardial infarction (n=29) were excluded, leaving 29,281 patients for analysis. Race was determined by self-report at the time of ECG acquisition. Unfortunately, incorporating the concurrent clinical data was beyond the scope of this project because that would have required manually reviewing all records, coding the clinical variables, and adding them to the database. Furthermore, the inclusion of additional variables would be inconsistent because a protocol was not in place for gathering the data.

**ECG Interpretation**

With the PR interval as the isoelectric line and the amplitude criteria as $\geq 0.1$ mV, $J$ waves were defined as an upward deflection, slurs as a conduction delay beginning on the QRS downstroke, and ST-segment elevation at the end of the QRS complex. All ECGs exhibiting ST-segment elevation as determined by the computer measurements were reread by 3 observers (blinded to outcomes) and corrected when necessary (4.5%). In general, the criterion requiring ST-segment elevation in 2 contiguous leads in any lead group (inferior: II, III, and AVF; lateral: I, aVL, and V$_4$–V$_6$; anterior: V$_1$–V$_3$) was applied. However, if an ST-segment elevation classification resulted in a group size $<1\%$ of the total population, then only 1 lead with ST-segment elevation in the territory was considered sufficient for classification. This way, visual inaccuracy was accounted for without losing computer accuracy. As in prior studies,\textsuperscript{5,6} anterior lead elevation was not considered separately but was included in the global ST-segment elevation pattern. The ECGs were also coded for left ventricular hypertrophy, ST-segment depression, diagnostic Q waves, and Minnesota Codes consistent with coronary artery disease. Figure 1 provides examples of slurs and $J$ waves with and without ST-segment elevation.

A subset of the population (n=4041) were in a data structure in which the ECGs could be displayed on a 24-in computer screen in multiple formats, enabling careful classification of slurring on the downslope of the R and $J$ waves. These patients were visually coded for $\geq 0.1$-mV slurs on the downslope of the R and $J$ waves by an experienced interpreter. A random sample of 100 (half with and half without $J$ waves or slurring) were reread, and the agreement was 95% owing to slight differences in amplitude measurements.

To determine the natural history of early repolarization, 250 patients with ECGs exhibiting the greatest amplitude of early repolarization were reviewed to see if they had another ECG >1 year later. Their serial ECGs, obtained for clinical indications and not by protocol, were then reviewed and manually coded.

**Outcomes**

The primary outcome variable was time to cardiovascular mortality. The California Health Department Service and Social Security Death Indexes were used to ascertain the vital status of each patient as of December 31, 2002, for the total population and, as of December 31, 2010, for the digital data subset. Accuracy of causes of deaths was reviewed by 2 clinicians blinded to ECG results and confirmed with the Veterans Affairs computerized medical records. Sufficient data

![Figure 1. Examples of slurs and J waves with and without ST-segment elevation (STE; [0.1 mm]). Arrow points to amplitude measurement point for the slur and J wave; hash line at the end of QRS is the computerized ST measurement point.](image-url)
Table 1. Population Characteristics of the Total Population for Comparison Between the Patterns of ST-Segment Elevation

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>All Subjects</th>
<th>No ST-Segment Elevation in Lateral or Inferior Leads</th>
<th>ST Elevation Inferior Only</th>
<th>P</th>
<th>ST-Segment Elevation Lateral Leads Only</th>
<th>P</th>
<th>ST-Segment Elevation Both Inferior and Lateral (Any)</th>
<th>P</th>
<th>ST-Segment Elevation Global (Any)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>n (%)</td>
<td>29,281</td>
<td>28,617 (97.7)</td>
<td>185 (0.6)</td>
<td></td>
<td>479 (1.6)</td>
<td></td>
<td>664 (2.3)</td>
<td></td>
<td>183 (0.6)</td>
<td></td>
</tr>
<tr>
<td>Age, y</td>
<td>55 ± 15</td>
<td>55 ± 15</td>
<td>52 ± 16</td>
<td>0.005</td>
<td>42 ± 13</td>
<td>0.001</td>
<td>45 ± 15</td>
<td>0.001</td>
<td>42 ± 14</td>
<td>0.001</td>
</tr>
<tr>
<td>Male, n (%)</td>
<td>25,544 (87.2)</td>
<td>24,904 (87.0)</td>
<td>168 (80.8)</td>
<td>0.14</td>
<td>472 (98.5)</td>
<td>0.001</td>
<td>640 (96.4)</td>
<td>0.001</td>
<td>158 (96.9)</td>
<td>0.001</td>
</tr>
<tr>
<td>Black, n (%)</td>
<td>3,885 (13.3)</td>
<td>3,644 (12.7)</td>
<td>31 (16.8)</td>
<td>0.1</td>
<td>210 (43.8)</td>
<td>0.001</td>
<td>231 (34.8)</td>
<td>0.001</td>
<td>62 (38.0)</td>
<td>0.001</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>27.3 ± 5.5</td>
<td>27.3 ± 5.5</td>
<td>25.8 ± 5.4</td>
<td>0.002</td>
<td>26.0 ± 4.1</td>
<td>0.001</td>
<td>26.0 ± 4.5</td>
<td>0.001</td>
<td>24.5 ± 3.4</td>
<td>0.001</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>70.6 ± 12.6</td>
<td>70.7 ± 12.6</td>
<td>69.6 ± 13.1</td>
<td>0.3</td>
<td>63.2 ± 12.3</td>
<td>0.001</td>
<td>65.0 ± 12.9</td>
<td>0.001</td>
<td>66.0 ± 12.4</td>
<td>0.001</td>
</tr>
<tr>
<td>QTc duration, ms</td>
<td>418 ± 22</td>
<td>418 ± 22</td>
<td>413 ± 30</td>
<td>0.005</td>
<td>408 ± 19</td>
<td>0.001</td>
<td>409 ± 23</td>
<td>0.001</td>
<td>407 ± 22</td>
<td>0.001</td>
</tr>
<tr>
<td>GRS duration, ms</td>
<td>92 ± 10</td>
<td>92 ± 10</td>
<td>90 ± 11</td>
<td>0.002</td>
<td>91 ± 9</td>
<td>0.001</td>
<td>90 ± 10</td>
<td>0.001</td>
<td>90 ± 9</td>
<td>0.001</td>
</tr>
<tr>
<td>coronary artery disease n (%)</td>
<td>7,796 (26.9)</td>
<td>7,684 (26.9)</td>
<td>51 (27.6)</td>
<td>0.77</td>
<td>61 (12.7)</td>
<td>0.001</td>
<td>112 (16.9)</td>
<td>0.001</td>
<td>12 (7.4)</td>
<td>0.001</td>
</tr>
<tr>
<td>Romhilt-Estes LVH score ≥3, n (%)</td>
<td>1,241 (4.2)</td>
<td>1,155 (4.0)</td>
<td>6 (3.2)</td>
<td>0.5</td>
<td>80 (16.7)</td>
<td>0.001</td>
<td>86 (13.0)</td>
<td>0.001</td>
<td>21 (12.9)</td>
<td>0.001</td>
</tr>
<tr>
<td>ST-segment depression (V&lt;sub&gt;5&lt;/sub&gt; &lt; -0.5 mV), n (%)</td>
<td>1,974 (6.7)</td>
<td>1,963 (6.9)</td>
<td>10 (5.4)</td>
<td>0.47</td>
<td>1 (0.2)</td>
<td>0.001</td>
<td>11 (1.7)</td>
<td>0.001</td>
<td>1 (2.3)</td>
<td>0.002</td>
</tr>
<tr>
<td>Inferior Q waves, n (%)</td>
<td>2,079 (7.1)</td>
<td>2,044 (7.1)</td>
<td>25 (13.5)</td>
<td>≤0.001</td>
<td>10 (2.1)</td>
<td>≤0.001</td>
<td>35 (5.3)</td>
<td>0.06</td>
<td>4 (9.3)</td>
<td>0.021</td>
</tr>
<tr>
<td>Anterior Q waves, n (%)</td>
<td>593 (2.0)</td>
<td>588 (2.1)</td>
<td>3 (1.6)</td>
<td>0.7</td>
<td>2 (0.4)</td>
<td>0.012</td>
<td>5 (0.8)</td>
<td>0.019</td>
<td>4 (9.3)</td>
<td>0.7</td>
</tr>
<tr>
<td>CV deaths, n (%)</td>
<td>1,995 (6.8)</td>
<td>1,966 (6.9)</td>
<td>14 (7.6)</td>
<td>0.68</td>
<td>15 (3.1)</td>
<td>≤0.001</td>
<td>29 (4.4)</td>
<td>0.011</td>
<td>4 (2.5)</td>
<td>0.027</td>
</tr>
<tr>
<td>Annual CV mortality, %</td>
<td>0.86</td>
<td>0.87</td>
<td>0.92</td>
<td>0.33</td>
<td>0.49</td>
<td>0.16</td>
<td>0.11</td>
<td></td>
<td></td>
<td>0.11</td>
</tr>
</tbody>
</table>

LVH indicates left ventricular hypertrophy; CV, cardiovascular.

were not available to classify arrhythmic deaths. Follow-up was complete.

Statistical Analysis

NCSS software 2007 (Kaysville, UT) and SAS version 9.1 were used for all statistical analyses. Unpaired t tests were used for comparisons of continuous variables, and χ² tests were used to compare dichotomous variables between patient groups. Survival analysis was performed with the Kaplan-Meier method. The Kaplan-Meier method also was used to estimate the survival rates. The log-rank test was used to compare the estimated survival rates of the patient groups. The hazard ratio estimated from the Cox proportional hazards model was used to determine the associations between ST-segment elevation patterns and outcome. This hazard ratio was adjusted for age, sex, and ethnicity.

Results

Of the 29,281 patients, 25,544 (87.2%) were male and were on average 55 ± 14 years of age. The remaining 3,737 patients (12.8%) were female and on average 56 ± 17 years of age. The ethnic distribution was as follows: black, 13%; Hispanic, 6%; and white (and other), 81%. There were 6,739 deaths (19.5%) over a mean follow-up of 7.6 ± 3.8 years.

The cohort was stratified into subgroups based on presence and location of ST-segment elevation: no ST-segment elevation, inferior lead only, lateral lead only, inferior or lateral lead, and global elevation (inferior, lateral, and anterior elevation). There were no significant differences in the baseline characteristics between those without ST-segment elevation and patients with ST-segment elevation except for those with isolated inferior lead elevation. The isolated inferior lead elevation group was older, had a higher heart rate, was less likely to be male, and exhibited more ECG abnormalities, particularly inferior Q waves (13.5%), than the other groups.

Table 1 provides the demographics, ECG findings, and annual cardiovascular mortality of the total population and its subgroups according to patterns of ST-segment elevation. Patients with lateral ST-segment elevation, isolated or as part of a more global pattern, were significantly younger and had a lower heart rate, a lower prevalence of any ECG abnormality other than left ventricular hypertrophy, and a higher prevalence of black race.

The early repolarization pattern in ≥2 contiguous leads was present in 664 subjects (2.3%); 185 (0.6%) in inferior leads and 479 (1.6%) in lateral leads, with elevation in both territories in 43 subjects (0.1%). Because of the small number of patients with contiguous lead elevation in inferior and lateral leads (n = 43), we instead considered those with elevation in 1 lead per territory (n = 163 patients, 0.6%). The same was done for global elevation (n = 30) when requiring contiguous elevation but 119 (0.4%) when using 1 lead per territory. No patients exhibited ST-segment elevation >0.2 mV in either the inferior or lateral lead. Figures 2 through 5 exhibit the Kaplan-Meier curves of freedom from cardiovascular death in the different ST-segment elevation patterns. The hazard ratio estimated from the Cox proportional hazards model was used to determine the associations between ST-segment elevation patterns and outcome. This hazard ratio was adjusted for age, sex, and ethnicity. They showed that ST-segment elevations ≥0.1 mm in lateral leads (Figure 2), in inferior or lateral leads with J waves or slurs (Figure 4), or with global ST-segment elevation (Figure 5) were associated with a trend to decreased mortality, although not statistically significantly. ST-segment elevations of ≥1 mm in inferior leads (Figure 3) did not demonstrate such trends. They appeared to be of no consequence in terms of mortality.

Table 2 presents the demographics of the subset of 4041 that were available for enhanced visualization, enabling
coding for J waves and slurring on the downslope of the R wave in addition to the ST level measurements. Only minor differences were found between them and the entire population. There were 1082 deaths (245 cardiovascular, 23%) over a mean follow-up of 9.1 ± 3 years. J waves or slurring occurred in 583 (14%), more commonly in those with ST-segment elevation than those without ST-segment elevation (61% versus 13%; P < 0.001). ST-segment elevation occurred more frequently in those with than in those without J waves or slurs (12% versus 1.3%; P < 0.001). J waves or slurring was more common than ST-segment elevation (14% versus 2.9%; P < 0.001), with 1.8% having both ST-segment elevation and a J wave or a slur. Patients with lateral lead early repolarization were significantly younger and had a lower heart rate, a lower prevalence of any ECG abnormality, and a higher prevalence of black race.

Table 3 provides unadjusted and adjusted hazard ratios for the subgroups according to patterns of ST-segment elevation for cardiovascular mortality. The most striking finding is the decreased risk associated with ST-segment elevation, either isolated or as part of any other more global pattern. Although the significance disappears with covariate adjustment, these trends remain. This was also found in the group with global elevation. No significant adjusted or unadjusted hazard associated with inferior lead elevation was found in the overall group. Multivariate models were created to adjust for age, sex, and black ethnicity; a second model also adjusted for resting heart rate, body mass index, and other ECG abnormalities. When included in the multivariate models, all of the covariates were associated with cardiovascular mortality except race and body mass index.

Table 4 provides unadjusted and adjusted hazard ratios for the association between J waves, slurs, ST-segment elevation, and cardiovascular mortality in the 4041 coded for the R-wave downslope patterns. All of the patterns except those with a small sample size were significantly associated with a lowered risk for cardiovascular death. The significance for protection disappeared with adjustment, but the trend remained, and no pattern was associated with an increased risk.

Of the 250 patients with the greatest amplitude of early repolarization, 122 were found to have a repeat ECG >1 year later. After an average of 7 years, 35 still reached the
Table 2. Population Characteristics of the Subset of the Population That Could Be Coded for Patterns of R-Wave Morphology for Comparison With the Total Population

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>All Subjects (n=29,281)</th>
<th>R-Wave Morphology Subset (n=4,041)</th>
<th>Any Lateral Slur/J Wave (n=256 [6.3%])</th>
<th>Any Inferior Slur/J Wave (n=386 [9.6%])</th>
<th>Any Slur/J Wave and ST-Segment Elevation (n=72 [1.8%])</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>55±15</td>
<td>57±14</td>
<td>0.01</td>
<td>&lt;0.001</td>
<td>55±13</td>
<td>0.001</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>27.3±5.5</td>
<td>28.5±6.2</td>
<td>0.02</td>
<td>27±5</td>
<td>0.05</td>
<td>27.9±5</td>
</tr>
<tr>
<td>Male, n (%)</td>
<td>25,544 (87)</td>
<td>3634 (90)</td>
<td>0.03</td>
<td>245 (96)</td>
<td>0.001</td>
<td>347 (90)</td>
</tr>
<tr>
<td>Black, n (%)</td>
<td>3,885 (13.3)</td>
<td>506 (12.5)</td>
<td>0.1</td>
<td>78 (30)</td>
<td>&lt;0.001</td>
<td>50 (13)</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>70.6±12.6</td>
<td>73±16.6</td>
<td>&lt;0.01</td>
<td>67±14</td>
<td>0.01</td>
<td>73±16</td>
</tr>
<tr>
<td>QTc duration, ms</td>
<td>418±22</td>
<td>416±26</td>
<td>0.2</td>
<td>407±17</td>
<td>0.008</td>
<td>413±19</td>
</tr>
<tr>
<td>QRS duration, ms</td>
<td>92±10</td>
<td>91±12</td>
<td>0.3</td>
<td>88±8</td>
<td>0.008</td>
<td>90.5±9</td>
</tr>
<tr>
<td>Coronary artery disease on ECG, n (%)</td>
<td>7796 (26.6)</td>
<td>1012 (25)</td>
<td>0.09</td>
<td>31 (12)</td>
<td>&lt;0.001</td>
<td>77 (20)</td>
</tr>
<tr>
<td>Romhilt-Estes LVH score &gt;3, n (%)</td>
<td>1241 (4.2)</td>
<td>116 (2.9)</td>
<td>&lt;0.01</td>
<td>2 (1)</td>
<td>0.005</td>
<td>14 (3.6)</td>
</tr>
<tr>
<td>ST depression (V_7 &lt; -0.5 \text{ mV}), n (%)</td>
<td>1974 (6.7)</td>
<td>342 (8.5)</td>
<td>&lt;0.01</td>
<td>0 (0)</td>
<td>&lt;0.001</td>
<td>15 (4)</td>
</tr>
<tr>
<td>ST-segment elevation, inferior or lateral, n (%)</td>
<td>664 (2.3)</td>
<td>118 (3)</td>
<td>0.06</td>
<td>58 (23)</td>
<td>&lt;0.001</td>
<td>29 (8)</td>
</tr>
<tr>
<td>Inferior Q waves</td>
<td>2079 (7.1)</td>
<td>351 (8.7)</td>
<td>&lt;0.01</td>
<td>11 (4)</td>
<td>&lt;0.001</td>
<td>16 (4)</td>
</tr>
<tr>
<td>Anterior Q waves</td>
<td>593 (2.0)</td>
<td>90 (2.2)</td>
<td>0.07</td>
<td>3 (1)</td>
<td>0.02</td>
<td>6 (1.6)</td>
</tr>
</tbody>
</table>

LVH indicates left ventricular hypertrophy.

amplitude criteria for early repolarization, but most no longer exhibited early repolarization, and in another 29, no sign of a slur or J wave was present. Thus, the majority did not exhibit early repolarization on the second ECG. Chart review revealed that 5 patients developed heart disease between ECGs, but all of the second ECGs were obtained as part of routine follow-up.

Discussion

To the best of our knowledge, this is the largest multiethnic, long-term population study of the association between ST-segment elevation and cardiovascular death. The subset is equivalent in size to the 2 previous population studies of J waves and slurs and the only such study to consider ST-segment elevation also. We found no statistically significant associations between the components of early repolarization (ie, ST-segment elevation, J waves, or slurs) and cardiovascular death in this ambulatory clinical population.

In an apparently asymptomatic, healthy population, early repolarization has been considered to be a benign finding. However, ST-segment elevation patterns, with or without J waves, can also be found in hypothermia, ischemia, and the Brugada syndrome.11–17 The J waves of hypothermia, also called Osborn waves, are usually more marked than those seen routinely. The ST-segment elevation seen in Brugada syndrome is isolated to the right precordial leads, often with right ventricular conduction delays, which result in an R' with the same timing of a J wave. Elegant cellular physiology studies have associated both ECG patterns with channelopathies, which has led to concerns that their presence, even in apparently healthy individuals, could be markers of cardiac events.12,18,19,21 Several recent clinical articles have supported this hypothesis.5,8,13,22 The results of our study challenge this hypothesis, supporting the long-held clinical belief that early repolarization is primarily a benign phenomenon.

The seminal paper by Haissaguerre and colleagues5 was based on a unique, high-risk population of 202 individuals with ventricular tachycardia or fibrillation and no other evidence for heart disease. Two surprising observations were made in this important study: In 18 subjects with ECG tracings at the time before VF or tachycardia, dynamic ST-segment elevation similar to that seen with coronary spasm was noted, and there was a higher prevalence of slurring and notching, or J waves, on their resting ECGs than

Table 3. Cox Hazard Analysis of the Total Population of 29,281 Ambulatory Clinic Patients With Cardiovascular Death as Outcome

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Unadjusted Relative Risk (95% CI)</th>
<th>P</th>
<th>Age-Adjusted Relative Risk (95% CI)</th>
<th>P</th>
<th>Adjusted Relative Risk (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST-segment elevation in inferior leads only</td>
<td>1.29 (0.76–2.18)</td>
<td>0.34</td>
<td>1.77 (1.05–2.99)</td>
<td>0.03</td>
<td>1.73 (0.93–3.3)</td>
<td>0.08</td>
</tr>
<tr>
<td>ST-segment elevation in lateral leads only</td>
<td>0.39 (0.23–0.64)</td>
<td>&lt;0.001</td>
<td>0.84 (0.50–1.4)</td>
<td>0.5</td>
<td>0.83 (0.50–1.50)</td>
<td>0.52</td>
</tr>
<tr>
<td>Global elevation</td>
<td>0.23 (0.06–0.90)</td>
<td>0.04</td>
<td>0.97 (0.62–1.5)</td>
<td>0.9</td>
<td>0.98 (0.61–1.5)</td>
<td>0.9</td>
</tr>
<tr>
<td>ST-segment in inferior and lateral leads</td>
<td>0.34 (0.13–0.90)</td>
<td>0.03</td>
<td>0.89 (0.34–2.39)</td>
<td>0.82</td>
<td>0.69 (0.17–2.76)</td>
<td>0.76</td>
</tr>
</tbody>
</table>

CI indicates confidence interval. Multivariate-adjusted analysis includes age, sex, black race, body mass index, heart rate, and ECG abnormalities.
These studies, concentrating on patients with idiopathic ventricular tachycardia/VF, were followed by a community-based epidemiological study that factored baseline characteristics and used visually interpreted ECGs, which included manual measurements of ST-segment elevation, notching, and slurring in the inferior and lateral leads, with cardiovascular death as the outcome.\(^6\) This study found no hazards associated with these patterns in the lateral leads but an adjusted hazard of roughly 2 for inferior lead ST-segment elevation. The subjects with inferior ST-segment elevation had a higher prevalence of Minnesota Code ECG findings, which are associated with coronary artery disease. The example this study provides for this group exhibited ST-segment elevation occurring over inferior Q waves, which is a pattern that has been associated with wall motion abnormalities of aneurysms after a myocardial infarction. In an earlier clinical population undergoing voluntary health screening, Klatsky and colleagues\(^1\) analyzed 2000 ECGs for ST-segment elevation and reported that 15% had 0.5-mm and 33% had 1.0-mm ST-segment elevation. Those with ST-segment elevation were more likely to be male, <40 years old, bradycardic, black, or physically active. No deaths were reported, and their hypothesis that ST-segment elevation would lead to hospitalizations or cardiac diagnoses was not supported. In a case-cohort study, Sinner et al\(^2\) considered notching on the QRS downslope, or a J wave, early repolarization in the absence of ST-segment elevation. They found these R-wave downslope patterns to be associated with a 2- to 4-fold increased risk of cardiac mortality in those between 35 and 54 years of age, particularly when located inferiorly.

On the basis of their cellular physiology experiments and the 2 recent key studies,\(^5,6\) Antzelevitch and Yan\(^8\) have proposed dividing early repolarization into 3 subtypes: type 1, which displays an ST-segment elevation pattern predominantly in the lateral precordial leads; type 2, which displays an ST-segment elevation pattern predominantly in the inferior or inferolateral leads and is associated with a higher level of risk; and type 3, which displays an ST-segment elevation pattern in the inferior, lateral, and right precordial leads and is associated with the highest level of risk for development of malignant arrhythmias. They included the above types in a category of J-wave syndromes consisting of early repolarization, ischemia, Osborn waves, and Brugada patterns. Our results do not support a clinical utility for this typing or classification.

There are limitations to our study, including a predominately male population and the use of computerized ECG technology. Whereas we focused on the traditional definition of early repolarization, only a 10% subset considered the independent prognostic value of terminal QRS slurring and J waves. Variation between studies regarding the prevalence of early repolarization may be explained by the wide variation in criteria and population selection. Although our results are more similar to the results of Tikkanen et al,\(^6\) who also showed no risk of death for lateral lead patterns, the differing results of Sinner et al\(^2\) could be due to the limitations of the case-cohort design. Our application of computerized measurements and display with visual confirmation are more consistent with current clinical practice. Development of algorithms to identify and quantify R-wave slurring and J waves should be a priority for future studies. Sufficient data were not available to classify arrhythmic deaths.

### Conclusions

We have demonstrated that common patterns of ST-segment elevation, global ST-segment elevation, or J waves and slurring are not associated with cardiovascular death in an asymptomatic outpatient population. Decisions such as

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**Table 4. Cox Proportional Hazard Analysis of Population Subset (n=4041) That Could Be Coded for Morphology of the R-Wave Downslope With Cardiovascular Death as the Outcome**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n (%)</th>
<th>Unadjusted Relative Risk (95% CI)</th>
<th>(P)</th>
<th>Age-Adjusted Relative Risk (95% CI)</th>
<th>(P)</th>
<th>Adjusted Relative Risk (95% CI)</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inferior slurs</td>
<td>234 (5.8)</td>
<td>0.5 (0.3–1.1)</td>
<td>0.08</td>
<td>0.7 (0.4–1.5)</td>
<td>0.4</td>
<td>0.8 (0.4–1.7)</td>
<td>0.6</td>
</tr>
<tr>
<td>Lateral slurs</td>
<td>104 (2.6)</td>
<td>0.6 (0.2–1.6)</td>
<td>0.3</td>
<td>0.7 (0.3–1.8)</td>
<td>0.4</td>
<td>0.8 (0.3–2.2)</td>
<td>0.7</td>
</tr>
<tr>
<td>Inferior J waves</td>
<td>152 (3.8)</td>
<td>0.5 (0.2–1.2)</td>
<td>0.1</td>
<td>0.5 (0.2–1.3)</td>
<td>0.2</td>
<td>0.6 (0.3–1.6)</td>
<td>0.3</td>
</tr>
<tr>
<td>Lateral J waves</td>
<td>152 (3.8)</td>
<td>0.2 (0.05–0.8)</td>
<td>0.02</td>
<td>0.4 (0.1–1.8)</td>
<td>0.2</td>
<td>0.5 (0.1–2.1)</td>
<td>0.3</td>
</tr>
<tr>
<td>Any slur or J wave</td>
<td>583 (14.4)</td>
<td>0.5 (0.3–0.8)</td>
<td>0.002</td>
<td>0.6 (0.4–1.0)</td>
<td>0.05</td>
<td>0.7 (0.5–1.2)</td>
<td>0.2</td>
</tr>
<tr>
<td>Any J wave</td>
<td>292 (7.2)</td>
<td>0.3 (0.2–0.7)</td>
<td>0.006</td>
<td>0.5 (0.2–1.1)</td>
<td>0.08</td>
<td>0.6 (0.3–1.3)</td>
<td>0.2</td>
</tr>
<tr>
<td>Any slur</td>
<td>319 (7.9)</td>
<td>0.6 (0.3–1.0)</td>
<td>0.06</td>
<td>0.7 (0.4–1.3)</td>
<td>0.3</td>
<td>0.9 (0.5–1.5)</td>
<td>0.6</td>
</tr>
<tr>
<td>Any lateral slur/J wave</td>
<td>256 (6.3)</td>
<td>0.3 (0.2–0.8)</td>
<td>0.009</td>
<td>0.6 (0.2–1.2)</td>
<td>0.2</td>
<td>0.7 (0.3–1.5)</td>
<td>0.4</td>
</tr>
<tr>
<td>Any inferior slur/J wave</td>
<td>386 (9.6)</td>
<td>0.5 (0.3–0.9)</td>
<td>0.02</td>
<td>0.6 (0.4–1.1)</td>
<td>0.1</td>
<td>0.7 (0.4–1.3)</td>
<td>0.3</td>
</tr>
<tr>
<td>Any slur/J wave and lateral/inferior elevation</td>
<td>72 (1.8)</td>
<td>0.4 (0.1–1.6)</td>
<td>0.2</td>
<td>0.9 (0.2–3.8)</td>
<td>0.9</td>
<td>1.2 (0.3–4.7)</td>
<td>0.8</td>
</tr>
</tbody>
</table>

CI indicates confidence interval. Slur or J wave indicates R-wave downslope J wave or slur ≥0.1 mV adjusted for age, sex, and abnormal ECG.
whether to perform additional diagnostic tests should be based on symptoms, family history, and all available clinical information and not the benign classic ECG patterns of early repolarization.

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Dr Turakhia was supported by a VA Health Services Research Career Development Award (CDA09027-1) and AHA National Scientist Development Grant (09SDG2250647).

Disclosures
None.

References

CLINICAL PERSPECTIVE
A common interpretative statement from modern ECG machines, particularly when testing healthy, young male subjects, is early repolarization. Although these statements are based on the level of the ST segment, recent studies have created concern about variations on the downslope of the R wave, specifically J waves and slurs. Using a large ambulatory clinical population and computerized techniques, we were unable to demonstrate an association of any of these components of early repolarization and cardiovascular death. Although perhaps more prevalent in certain high-risk groups, early repolarization is a benign ECG pattern in apparently healthy individuals with no significant predictive value.