Use of the Acute Cardiac Ischemia Time-Insensitive Predictive Instrument (ACI-TIPI) To Assist with Triage of Patients with Chest Pain or Other Symptoms Suggestive of Acute Cardiac Ischemia

A Multicenter, Controlled Clinical Trial

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Background: Approximately 6 million U.S. patients present to emergency departments annually with symptoms suggesting acute cardiac ischemia. Triage decisions for these patients are important but remain difficult.

Objective: To test whether computerized prediction of the probability of acute ischemia, used with electrocardiography, improves the accuracy of triage decisions.

Design: Controlled clinical trial.

Setting: 10 hospital emergency departments in the midwestern, southeastern, and northeastern United States.

Patients: 10,689 patients with chest pain or other symptoms suggestive of acute cardiac ischemia.

Intervention: The probability of acute ischemia predicted by the acute cardiac ischemia time-insensitive predictive instrument (ACI-TIPI), either automatically printed or not printed on patients' electrocardiograms.

Measurements: Emergency department triage to a coronary care unit (CCU), telemetry unit, ward, or home. Other measurements were the bed capacity of the CCU relative to that of the telemetry unit; training or supervision status of the triaging physician; and patient diagnoses and outcomes based on clinical, electrocardiographic, and creatine kinase data.

Results: For patients without cardiac ischemia, in hospitals with high-capacity CCUs and relatively low-capacity cardiac telemetry units, use of ACI-TIPI was associated with a reduction in CCU admissions from 15% to 12%, a change of -16% (95% CI, -30% to 0%), and an increase in emergency department discharges to home from 45% to 56%, a change of 25% (CI, 8% to 45%; overall P = 0.008).

Among patients with stable angina, in hospitals with high-capacity CCUs, use of ACI-TIPI was associated with a reduction in CCU admissions from 26% to 13%, a change of -50% (CI, -70% to -17%), and an increase in emergency department discharges to home from 20% to 22%, a change of 10% (CI, -29% to 71%; overall P = 0.02). At hospitals with high-capacity telemetry units, use of ACI-TIPI was associated with a reduction in telemetry unit admissions from 68% to 59%, a change of -14% (CI, -27% to 1%), and an increase in emergency department discharges to home from 10% to 21%, a change of 100% (CI, 22% to 230%; overall P = 0.02).

Conclusions: Use of ACI-TIPI was associated with reduced hospitalization among emergency department patients without acute cardiac ischemia. This result varied as expected according to the CCU and cardiac telemetry unit capacities and physician supervision at individual hospitals. Appropriate admission for unstable angina or acute infarction was not affected. If ACI-TIPI is used widely in the United States, its potential incremental impact may be more than 200,000 fewer unnecessary hospitalizations and more than 100,000 fewer unnecessary CCU admissions.

This paper is also available at http://www.acponline.org.


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More than half of emergency department diagnoses of acute cardiac ischemia (acute myocardial infarction or unstable angina pectoris) prove to be incorrect (1), leading to approximately 2 million unnecessary hospitalizations associated with $8 billion in costs annually in the United States (2). Underdiagnosis of acute ischemia also occurs: Approximately 2% of emergency department patients with acute infarction are sent home (3, 4). Unnecessary hospitalization for patients incorrectly presumed to have acute ischemia must be reduced without increasing inadvertent discharges of those with acute ischemia (5, 6).

To address this problem, we developed an acute cardiac ischemia predictive instrument to provide real-time guidance for triage decisions in the emergency department (1). Programmed initially into a hand-held calculator, a logistic regression formula computed a patient's probability (0% to 100%) of having acute ischemia on the basis of seven yes/no questions, including the presence of chest pain, chest pain as the chief symptom, a history of heart attack or nitroglycerine use, and electrocardiogram ST-segment or T-wave abnormalities. In a 2300-patient controlled clinical trial done in urban and rural hospitals in 1980–1981, providing patients' probability values of acute ischemia to emergency department physicians improved triage decisions: Admissions to the coronary care unit (CCU) for patients without acute ischemia were reduced by 30% and missed cases of acute ischemia did not increase (1).

Unfortunately, the calculator-based instrument was not user-friendly for busy emergency department physicians and found limited use. In addition, it required physician interpretation of the ST segment and T waves, which may be incorrect 25% of the time (7), introducing error into predictions. To address these issues, a new version of the instrument was developed for incorporation into conventional computerized electrocardiograph (8–12). It was designed to compute the probability value either by using data obtained during real-time emergency department care or retrospective review; thus, we called it an acute cardiac ischemia time-insensitive predictive instrument (ACI-TIPI) (8, 13). This was accomplished primarily by replacing the variables from the medical history with age, sex, and the presence of Q waves on electrocardiography. More detailed data on ST and T waves were also added. Diagnostic performance was equivalent to that of the original version, and no further variables were needed. Of note, classic long-term coronary risk factors, such as hypercholesterolemia and smoking, were not important predictors of acute ischemia in the emergency department compared with the variables used in ACI-TIPI (8, 14). To acquire the ACI-TIPI probability in clinical use, the user enters the patient's age and sex and indicates whether chest or left arm pain is the primary symptom; the electrocardiograph then directly measures the waveforms and computes and prints the probability of acute ischemia on the electrocardiogram header for the physician's immediate use (Figure 1).

We report the results of a clinical trial to test the effect of electrocardiogram-based ACI-TIPI on emergency department triage of patients with chest pain or other symptoms suggestive of acute cardiac ischemia. We sought to determine whether its use would reduce unnecessary hospital and CCU admission for emergency department patients without cardiac ischemic disease or with stable angina pectoris while not reducing hospitalization of emergency department patients with acute ischemia (unstable angina or acute infarction). Because our previous work showed that the bed capacity of the hospital CCU influences emergency department triage (15) and that the effects of ACI-TIPI vary with the training level of residents (9), we hypothesized that the effect of ACI-TIPI would differ according to the bed capacities of CCUs and physician training status. Thus, we included hospitals with a wide range of CCU bed capacities and emergency department training programs.

**Methods**

**Sites**

The study was conducted at 10 hospitals, including public, private, community, and tertiary hospitals with urban, suburban, and semi-rural catchment areas (Baystate Medical Center [Springfield, Massachusetts]; Boston City Hospital, Boston University...
Medical Center, and New England Medical Center [Boston, Massachusetts]; Medical College of Virginia [Richmond, Virginia]; Medical College of Wisconsin [Milwaukee, Wisconsin]; Newton-Wellesley Hospital [Newton, Massachusetts]; Rhode Island Hospital [Providence, Rhode Island]; University of Cincinnati Medical Center [Cincinnati, Ohio]; and University of North Carolina Hospitals [Chapel Hill, North Carolina]. All emergency departments had internal medicine residents; four had emergency medicine residents.

Patients

We included all consenting emergency department patients who 1) were at least 30 years of age or at least 18 years of age if they were suspected of using or were reported to have used cocaine recently and 2) had a chief symptom of chest, left arm, jaw, or epigastric pain or discomfort; shortness of breath; dizziness; palpitations; or other symptoms suggestive of acute ischemia.

Intervention

The ACI-TIPI was installed in each emergency department’s “native” brand electrocardiographs by using software and necessary equipment upgrades provided by the manufacturer. Both brands used (Hewlett-Packard [Palo Alto, California] and Marquette [Milwaukee, Wisconsin]) generated equivalent predictions in the same format (Figure 1). Manufacturers had no input in the design or conduct of the study, data analysis, or reporting of results.

The trial was carried out over 7 alternating months of control and intervention periods starting in May 1993. On presentation to the emergency department, each patient’s ACI-TIPI probability of acute ischemia was automatically computed by the electrocardiograph. During intervention periods, the probability was automatically printed on the electrocardiogram header, with an indication that it was “to supplement, not replace physician judgment,” along with the standard electrocardiogram interpretive header text. During control periods, only the standard header text was printed.

Data Collection

Sociodemographic information, initial and follow-up clinical features, electrocardiographic information, creatine kinase–MB test results, training level and supervision of the triaging physician, and hospital bed capacities were recorded at presentation.
Table 3. Effect of the Acute Cardiac Ischemia Time-insensitive Predictive Instrument Electrocardiograph on Emergency Department Triage of 8150 Patients without Cardiac Ischemia*

<table>
<thead>
<tr>
<th>ED Triage Disposition</th>
<th>ED Triage at Hospitals with Low-Capacity Telemetry Units (High-Capacity CCUs)†</th>
<th>Disposition-Specific Change</th>
<th>ED Triage at Hospitals with High-Capacity Telemetry Units (Low-Capacity CCUs)‡</th>
<th>Disposition-Specific Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control Group ACI-TIPI Group Absolute Difference (95% CI) Relative Difference (95% CI)</td>
<td>Control Group ACI-TIPI Group Absolute Difference (95% CI) Relative Difference (95% CI)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>% percentage points %</td>
<td>% percentage points %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCU</td>
<td>15 12 -2 (-5 to 0) -16 (-30 to 0)</td>
<td>7 8 1 (0 to 3) 21 (0 to 47)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telemetry unit</td>
<td>30 31 1 (-3 to 3) 0 (-9 to 11)</td>
<td>32 52 0 (-3 to 3) 0 (-5 to 6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ward</td>
<td>5 5 -1 (-2 to 1) 6 (-17 to 13)</td>
<td>6 5 -1 (-2 to 1) 11 (-29 to 13)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Home</td>
<td>49 52 3 (0 to 7) 6 (0 to 14)</td>
<td>35 34 -1 (-4 to 2) -3 (-10 to 5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall P value</td>
<td>0.09</td>
<td>&gt;0.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* ACI-TIPI = acute cardiac ischemia time-insensitive predictive instrument; CCU = coronary care unit; ED = emergency department.
† 3335 patients.
‡ 4815 patients.

Table 4. Effect of the Acute Cardiac Ischemia Time-insensitive Predictive Instrument Electrocardiograph Relative to Trainee Supervision of Emergency Department Triage of 7996 Patients without Cardiac Ischemia*

<table>
<thead>
<tr>
<th>ED Triage Disposition</th>
<th>ED Triage for Patients Seen Only by Attending Physicians (n = 2717)</th>
<th>Disposition-Specific Change</th>
<th>ED Triage for Patients Seen by Attending-Supervised Residents (n = 4556)</th>
<th>Disposition-Specific Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control Group ACI-TIPI Group Absolute Difference (95% CI) Relative Difference (95% CI)</td>
<td>Control Group ACI-TIPI Group Absolute Difference (95% CI) Relative Difference (95% CI)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>% percentage points %</td>
<td>% percentage points %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCU</td>
<td>10 10</td>
<td>10 10</td>
<td>0 (-2 to 2) 2 (-14 to 22)</td>
<td></td>
</tr>
<tr>
<td>Telemetry unit</td>
<td>46 49</td>
<td>43 43</td>
<td>0 (-3 to 0) 7 (-7 to 7)</td>
<td></td>
</tr>
<tr>
<td>Ward</td>
<td>7 6</td>
<td>6 5</td>
<td>0 (-3 to 0) 7 (-7 to 7)</td>
<td></td>
</tr>
<tr>
<td>Home</td>
<td>38 35</td>
<td>42 43</td>
<td>1 (-2 to 4) 2 (-5 to 9)</td>
<td></td>
</tr>
<tr>
<td>Overall P value</td>
<td>0.2</td>
<td>&gt;0.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* ACI-TIPI = acute cardiac ischemia time-insensitive predictive instrument; CCU = coronary care unit; ED = emergency department.
metry units (low-capacity CCUs) had telemetry-to-
CCU bed ratios at least double the ratios of hospi-
tals with low-capacity telemetry units.

A priori, we elected to consider physicians who
signed the official medical record as the responsible
physicians. Thus, each patient was classified as hav­
ing been triaged by an attending physician (single
signature), a resident supervised by an attending
(both signatures), or an unsupervised resident (sin­
gle signature).

Statistical Analysis

Baseline comparisons of patient characteristics
between control and intervention months were done
by using t-tests for continuous variables and chi-
square tests for categorical variables, including emer-
gency department triage dispositions. Using Cochran–
Mantel–Haenszel adjustments for individual hospitals
did not change significance levels. When few pa­
patients were sent to wards (≤3%), emergency depart­
ment dispositions to ward and telemetry units were
combined for statistical testing in the tables (but were
kept separate for presentation in the text). Apparent
discrepancies between emergency department triage
disposition rates and computer disposition-specific
changes are due to the effects of rounding.

The possibility of changes over the course of the
trial in differences between control and intervention
periods (“learning”) was checked by testing for
trends over time with multivariable regression analy­
sis of variance and spline curves for graphical analy­
sis. The SAS statistical software c-index (SAS, Inc.,
Cary, North Carolina) was used to calculate receiver-
operating characteristic (ROC) curve areas. Calibra­
tion of ACI-TIPI predictions with actual proportions
of patients with acute cardiac ischemia was tested
by ranking patients by their predicted values and
creating equal-sized deciles.

Table 4—Continued

**Table 2**

<table>
<thead>
<tr>
<th>ED Triage for</th>
<th>Disposition-Specific</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients Seen by</td>
<td>Absolute Difference (95% CI)</td>
</tr>
<tr>
<td>Unsupervised Residents (n = 723)</td>
<td>%</td>
</tr>
<tr>
<td>Control Group</td>
<td>ACI-TIPI Group</td>
</tr>
<tr>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>39</td>
<td>31</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>45</td>
<td>56</td>
</tr>
</tbody>
</table>

Results

Of all potential participants, 92% were asked to
participate; 94% (10 689) of these consented and
were included in the trial. Inclusion did not differ by
sex or ethnicity. The 5951 controls and 4738 inter­
vention group patients were similar in terms of age,
sex, ethnicity, presenting symptoms, history of dia­
betes, previous coronary disease, and confirmed di­
agnosis of acute ischemia (Table 1).

Hospital and 30-day mortality data were com­
plete for 95% of enrolled participants (97% of those
admitted to the hospital and 90% of those
sent home); no differences were observed among
diagnostic groups or between the control and inter­
vention groups. Of patients sent home for whom
30-day mortality data were missing, eight controls
and three intervention group patients had confirmed
nonischemic diagnoses and two controls and three
intervention group patients had acute infarction or
unstable or stable angina. Data on 30-day mortality
were missing for 7 hospitalized controls and 11 hospi­
talized intervention group patients without con­
firmed nonischemic diagnoses and 44 hospitalized
controls and 25 hospitalized intervention group pa­
tients with acute ischemic diagnoses. Thus, the rate
of missing data on 30-day mortality was 0.45% for
patients sent home (no excess was seen among inter­
vention group patients) and 1.12% for hospi­
talized patients.

Table 2 shows the telemetry unit and CCU bed
capacities of the study hospitals and the propor­
tions of patients for whom CCU beds were not available
at the time of emergency department triage. Hospi­
tals in the two groups were similar in overall size,
but for 13% of patients who went to hospitals with
low ratios of CCU beds to telemetry unit beds, no
CCU beds were open at the time of emergency
department triage. In contrast, the CCU was full at
the time of triage for only 2% of patients presenting
to hospitals with high-capacity CCU units (P <
0.001). Thus, the a priori designation of these
groups seems to correspond to the previously re­
ported “full CCU” effect (15).

Both manufacturers’ ACI-TIPI electrocardiographs
had ROC areas of 0.78. Calibration—the match be­
tween the predicted and the actual proportions
of patients with acute ischemia over the entire predic­
tive range of ACI-TIPI—was very good (Figure 2).

For patients without cardiac ischemia (Table 3)
admitted to hospitals with high-capacity CCUs (rela­
tive to telemetry unit capacity), the admission rate
to the CCU decreased from 15% to 12%, a change
of -16% (95% CI, -30% to 0%), and discharges to
home increased from 49% to 52%, a change of 6%
(CI, 0% to 14%), with the use of ACI-TIPI. These
results were of borderline statistical signification
Figure 2. Comparison of the acute cardiac ischemia time-insensitive predictive instrument's predicted rates of acute cardiac ischemia with proportions of patients with acute ischemia. Data are displayed in equal size-ordered deciles of predicted risk over a probability range of 0% to 100%. White bars represent observed proportion of patients with acute cardiac ischemia; striped bars represent predicted proportion of patients with acute cardiac ischemia.

The use of ACI-TIPI did not affect patients without cardiac ischemia (Table 4) cared for by attending physicians or supervised residents, but it reduced CCU admission from 14% to 10%, a change of -32% (CI, -55% to 3%), and telemetry unit admission from 39% to 31%, a change of -20% (CI, -34% to -2%), among those seen by unsupervised residents. Correspondingly, the rate of emergency department discharge to home increased from 45% to 56%, a change of 25% (CI, 8% to 45%; overall \( P = 0.008 \)). The reductions in admissions were greater among patients for whom the ACI-TIPI predicted lower probabilities of acute ischemia. Thus, on the basis of previously defined ACI-TIPI risk groups (8), patients with low ACI-TIPI-predicted probabilities of having acute ischemia (<10%) experienced greater reductions in hospitalization (odds ratio, 0.51 [CI, 0.28 to 0.91]) than those in higher-risk groups (odds ratio, 0.74 [CI, 0.52 to 1.05]).

For patients with stable angina pectoris (Table 5), the use of ACI-TIPI in hospitals with high-capacity CCUs was associated with a decrease in CCU admission from 26% to 13%, a change of -50% (CI, -70% to -17%), and, correspondingly, an increase in telemetry unit admission from 51% to 63%, a change of 25% (CI, 2% to 52%) and an increase in emergency department discharges to home from 20% to 22%, a change of 10% (CI, -29% to 71%) (overall \( P = 0.02 \)). Patients in the low or low-mid ACI-TIPI probability groups (≤25%) experienced greater reductions in CCU admission (odds ratio, 0.36 [CI, 0.13 to 0.999]) than those in the high-mid or high probability groups (>25%) (odds ratio, 0.73 [CI, 0.34 to 1.58]). In hospitals with relatively high-capacity telemetry units (relatively low CCU capacity), more patients (68%) were admitted to telemetry unit beds under the control condition than in those with relatively low-capacity telemetry units. Accordingly, although not reducing CCU admissions, use of ACI-TIPI reduced telemetry unit admissions in hospitals with high-capacity telemetry units from 68% to 59%, a change of -14% (CI, -27% to 1%), and increased emergency department discharges home from 10% to 21%, a change of 100% (CI, 22% to 230%) (overall \( P = 0.02 \)). Patients in the low or low-mid ACI-TIPI probability groups experienced greater reductions in telemetry unit admission (odds ratio, 0.48 [CI, 0.20 to 1.15]) than the high-mid and high risk groups (odds ratio, 0.67 [CI, 0.39 to 1.13]). After all hospitals were pooled, CCU admissions for patients with stable angina decreased from 22% to 16%, a change of -26% (CI, -47% to 2%), and emergency department discharges to home increased from 15% to 21%, a change of 47% (CI, 6% to 85%)

### Table 5. Effect of the Acute Cardiac Ischemia Time-Insensitive Predictive Instrument Electrocardiograph on Emergency Department Triage of 673 Patients with Stable Angina Pectoris*

<table>
<thead>
<tr>
<th>ED Triage Disposition</th>
<th>ED Triage at Hospitals with Low-Capacity Telemetry (High-Capacity CCUs)*</th>
<th>Disposition-Specific Change</th>
<th>ED Triage at Hospitals with High-Capacity Telemetry Units (Low-Capacity CCUs)*</th>
<th>Disposition-Specific Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control Group</td>
<td>ACI-TIPI Group</td>
<td>Absolute Difference (95% CI)</td>
<td>Relative Difference (95% CI)</td>
</tr>
<tr>
<td>CCU</td>
<td></td>
<td></td>
<td>%</td>
<td>percentage</td>
</tr>
<tr>
<td>26</td>
<td>13</td>
<td>-13 (-22 to -4)</td>
<td>-50 (-70 to -17)</td>
<td></td>
</tr>
<tr>
<td>Telemetry unit</td>
<td>51</td>
<td>63</td>
<td>12 (1 to 24)</td>
<td>25 (2 to 52)</td>
</tr>
<tr>
<td>Ward</td>
<td>3</td>
<td>2</td>
<td>-1 (-5 to 2)</td>
<td>-48 (-90 to 162)</td>
</tr>
<tr>
<td>Home</td>
<td>20</td>
<td>22</td>
<td>2 (-7 to 11)</td>
<td>-10 (-29 to 71)</td>
</tr>
<tr>
<td>Overall P value</td>
<td></td>
<td></td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

* ACI-TIPI = acute cardiac ischemia time-insensitive predictive instrument; CCU = coronary care unit; ED = emergency department. 
* 300 patients. 
* 373 patients.
Table 6. Effect of Acute Cardiac Ischemia Time-Insensitive Predictive Instrument Electrocardiograph on Emergency Department Triage of 1866 Patients with Acute Myocardial Infarction or Unstable Angina Pectoris*

<table>
<thead>
<tr>
<th>ED Triage Disposition</th>
<th>ED Triage at Hospitals with Low-Capacity Telemetry Units (High-Capacity CCUs)*</th>
<th>Disposition-Specific Change</th>
<th>ED Triage of Patients at Hospitals with High-Capacity Telemetry Units (Low-Capacity CCUs)#</th>
<th>Disposition-Specific Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control Group</td>
<td>ACI-TIPI Group</td>
<td>Absolute Difference (95% CI)</td>
<td>Relative Difference (95% CI)</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>percentage points</td>
<td>%</td>
<td>percentage points</td>
</tr>
<tr>
<td>CCU</td>
<td>62</td>
<td>62</td>
<td>0 (-7 to 8)</td>
<td>1 (-11 to 13)</td>
</tr>
<tr>
<td>Telemetry unit</td>
<td>34</td>
<td>34</td>
<td>0 (-8 to 7)</td>
<td>-1 (-26 to 23)</td>
</tr>
<tr>
<td>Ward</td>
<td>1</td>
<td>1</td>
<td>0 (-1 to 1)</td>
<td>11 (-84 to 681)</td>
</tr>
<tr>
<td>Home</td>
<td>3</td>
<td>3</td>
<td>0 (-3 to 3)</td>
<td>0 (-59 to 142)</td>
</tr>
<tr>
<td>Overall P value</td>
<td>&gt;0.2</td>
<td>&gt;0.2</td>
<td>&gt;0.2</td>
<td>&gt;0.2</td>
</tr>
</tbody>
</table>

* ACI-TIPI = acute cardiac ischemia time-insensitive predictive instrument; CCU = coronary care unit; ED = emergency department.
† 634 patients.
‡ 1232 patients.

104%) (overall P = 0.03). The effect on triage was similar for attending physicians, supervised residents, and unsupervised residents.

For patients with acute infarction or unstable angina (Table 6), use of ACI-TIPI was not associated with a change in the 96% admission rate to telemetry units or CCUs for all physician types.

For all groups in which ACI-TIPI had an effect, the differences between the intervention and control periods over the course of the trial did not decrease; that is, no "learning" of the ACI-TIPI triage strategy occurred in the absence of its actual use (data not shown; P > 0.2 for all comparisons between first and second half of the trial for effect of ACI-TIPI).

To see whether the use of ACI-TIPI caused emergency department triage to less-intensive care with the result that subsequent transfer to more-intensive care was required, we compared transfer rates to the CCU of controls and intervention group patients initially admitted to ward or telemetry unit beds and found no clinically or statistically significant difference. Among patients without cardiac ischemia given less-intensive initial triage dispositions, 5.3% were transferred to the CCU during control periods and 5.4% were transferred during ACI-TIPI periods. Among patients with stable angina pectoris, 8.5% were transferred to the CCU during control periods and 8.7% were transferred during ACI-TIPI periods. Among patients with unstable angina or acute infarction, 22.2% were transferred during control periods and 22.0% were transferred during ACI-TIPI periods.

Rates of in-hospital complications, rehospitalization among patients discharged to home, and 30-day mortality (Tables 7 and 8) did not differ between the control and intervention groups for patients who were hospitalized or those who were sent home. Mortality rates fell within expected ranges: 1.8% for patients without cardiac ischemia, 1.4% for those with stable angina, and 6.0% for those with unstable angina or acute infarction.

Discussion

In this clinical trial of 10,689 patients conducted in a range of hospitals, the use of ACI-TIPI improved emergency department triage of patients with chest pain or other symptoms suggestive of acute ischemia in several circumstances. Its use was associated with improved triage, which varied, as expected, depending on whether a patient had acute cardiac ischemia and whether the hospital had a high- or low-capacity CCU relative to the capacity of its cardiac telemetry unit and whether the triaging physician was an unsupervised resident. Reductions in admissions for patients without acute cardiac ischemia were greater among patients with ACI-TIPI-predicted ischemia probabilities in the lower ranges, reflecting a greater effect with stronger probabilistic advice not to admit (that is, a dose-response effect). Of note, in settings in which use of the ACI-TIPI reduced unnecessary admissions, appropriate hospital and CCU admission did not deteriorate for patients with true acute ischemia (unstable angina or acute infarction). Given these results of this "effectiveness" trial (that is, how ACI-TIPI works in usual care in contradistinction to only its "efficacy," how it works under ideal conditions [18]), ACI-TIPI seems to be safe and effective for general use.

At hospitals with high-capacity CCUs, about half of patients without cardiac ischemia were hospitalized (including 15% in the CCU), whereas at hospitals with high-capacity telemetry units (relatively
Table 7. In-hospital Complications and Rehospitalization for 10,689 Participants in the Acute Cardiac Ischemia Time-Insensitive Predictive Instrument Trial*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hospitals with Low-Capacity Telemetry Units</th>
<th>Hospitals with High-Capacity Telemetry Units</th>
<th>All Hospitals Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(High-Capacity CCUs)*</td>
<td>(Low-Capacity CCUs)#</td>
<td>§ 10,689 patients</td>
</tr>
<tr>
<td></td>
<td>Control Group</td>
<td>ACI-TIPI Group</td>
<td>P Value</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>In-hospital complications among admitted patients</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic blood pressure &lt;100 mm Hg</td>
<td>22.8</td>
<td>21.1</td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>Ventricular tachycardia</td>
<td>5.1</td>
<td>4.6</td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>Ventricular fibrillation</td>
<td>0.9</td>
<td>1.2</td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>Cardiac arrest</td>
<td>1.4</td>
<td>1.7</td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>Cardiopulmonary resuscitation given</td>
<td>0.9</td>
<td>1.5</td>
<td>0.2</td>
</tr>
<tr>
<td>Reinfarction</td>
<td>0.4</td>
<td>0.8</td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>Intravenous nitroglycerine</td>
<td>17.9</td>
<td>18.9</td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>Defibrillation</td>
<td>0.9</td>
<td>1.1</td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>Intra-aortic balloon pump</td>
<td>0.3</td>
<td>0.5</td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>30-day rehospitalization among nonadmitted patients</td>
<td>9.2</td>
<td>10.0</td>
<td>&gt;0.2</td>
</tr>
</tbody>
</table>

* ACI-TIPI = acute cardiac ischemia time-insensitive predictive instrument; CCU = coronary care unit.
† 4269 patients.
‡ 6420 patients.
§ 10,689 patients.
low CCU capacity), two thirds of patients without cardiac ischemia were hospitalized (primarily in the telemetry unit, with only 7% in the CCU) (Table 5). Of note, in both cases, CCU admission rates under control conditions for emergency department patients who proved not to have ischemic disease were only half the rates found in our analogous trial conducted 12 years earlier. In the earlier trial, which included several of the same hospitals (as well as rural hospitals), use of the calculator version of the predictive instrument reduced CCU admission by 30% (1). Given the low overall rates of hospitalization and low baseline CCU admission rates in the present study, it is not surprising that the use of ACI-TIPI had a more modest effect among patients without acute ischemia. In fact, use of ACI-TIPI reduced admission rates in hospitals in which use of CCU beds was higher relative to the number of telemetry unit beds available and among patients cared for by unsupervised resident physicians, who more often admitted these patients to the CCU (Table 4).

This trial included no rural hospitals and none that lacked on-site emergency physicians. We surmise that the substantial effects seen for unsupervised residents and the results found in our earlier trial, which included rural hospitals, might also be found among less-trained or less-specialized physicians in smaller and rural hospitals. In general, the higher a hospital's baseline admission rate for patients without cardiac ischemia, especially to the CCU, the more likely it is that the use of ACI-TIPI will reduce unnecessary admissions. At the other end of the spectrum, our study included hospitals with explicit protocols for patients with chest pain, including one with a highly developed "chest pain unit"; nonetheless, the effect of ACI-TIPI was the same in those hospitals as in the overall study. As noted by the National Institutes of Health Working Group on Diagnostic Technologies for Acute Ischemia (5), ACI-TIPI may be particularly useful when combined with other diagnostic methods into integrated strategies for chest pain evaluation.

For patients with stable angina pectoris, a group increasingly targeted for outpatient management (19), the effect of ACI-TIPI depended on the capacity-related admission practices of the hospitals (Table 5). In hospitals with high-capacity CCUs (low-capacity telemetry units), use of ACI-TIPI halved CCU admissions, increased telemetry unit admissions by 25%, and increased the proportion of discharges to home from the emergency department by 10%. At hospitals with low-capacity CCUs (relative to high-capacity telemetry units), baseline CCU admissions were lower, presumably because of greater bed availability in the telemetry unit, and did not decrease further. Instead, use of ACI-TIPI reduced admissions to the telemetry unit by 14% and doubled the proportion of discharges to home from the emergency department, bringing the latter figure up to the proportion found in hospitals with low-capacity telemetry units.

As would be desired for patients with acute cardiac ischemia (unstable angina or acute infarction), use of ACI-TIPI was not associated with reduced admissions to either the CCU or the telemetry unit, regardless of the capacity of the units or whether ACI-TIPI was used by attending physicians, supervised residents, or unsupervised residents (Table 6). Moreover, it did not increase emergency depart-
ment triage to less-intensive care that led to later transfer to the CCU. However, among patients with unstable angina or acute infarction initially admitted to ward or telemetry unit beds, 22% (in both the control and ACI-TIPI groups) subsequently required transfer to the CCU. This raises the question of whether the recent trend to not always admit such patients to the CCU has gone too far; further investigation is warranted.

This study extends our earlier finding that physicians selectively reduce CCU admission for patients without acute ischemia when fewer CCU beds are available (15). In this study, we found that different allocation of beds to telemetry units or CCUs (Table 2) corresponded to different admission patterns for patients without cardiac ischemia, those with stable angina, and those with unstable angina or acute infarction. That the ACI-TIPI had different but desirable influences on emergency department triage in settings with such different resources supports its generalizability for a wide range of hospitals.

Although physician triage decisions improved when ACI-TIPI predictions were provided, the improvement was not “learned”: When ACI-TIPI predictions were not made available, triage performance returned to baseline. This was the case even after repeated use; differences between control and intervention months did not diminish during the trial. This finding, like that in our earlier trial of the calculator-based version (1), suggests that the instrument’s patient-specific predictions continue to add information to the decision-making process beyond merely reminding clinicians that its variables (age; sex; presence of chest pain; and presence of QRS, ST, and T waves on the electrocardiogram) are key predictors of acute ischemia.

We observed no adverse influence on emergency department triage with use of ACI-TIPI. In addition, we found no potentially deleterious effects on in-hospital complications, rehospitalization of patients who were not admitted, and 30-day mortality (Tables 7 and 8). The 99% follow-up rate for diagnostic data, including patients sent home, and the low rate (0.45%) of missing mortality data for patients triaged directly to home suggest nominal potential for ascertainment error. Thus, on the basis of emergency department triage and clinical outcomes, use of ACI-TIPI seems to be safe.

In this study, the patient’s probability of having acute ischemia was automatically printed as part of the familiar electrocardiogram text header (Figure 1) by conventional computerized electrocardiographs. In this implementation, the diagnostic performance of ACI-TIPI seemed to be accurate across its entire probability range of 0% to 100% (Figure 2). This approach to providing decision support in the emergency department illustrates the potential for this use of computerized equipment already found in clinical practice. This computerized approach can also take advantage of the time-insensitive aspect of ACI-TIPI, which makes it suitable for retrospective as well as real-time use (8). For example, probabilities generated by ACI-TIPI can be stored in a database for feedback reports for clinicians, hospitals, and others (8, 13).

Although further study is needed to understand the cognitive processes involved, the selective and appropriate use of ACI-TIPI for patients who prove to have different diagnoses in a wide range of settings may be facilitated by the availability of diagnostic information as a 0% to 100% probability scale rather than as specific risk categories. This observation is consistent with findings for interpretation of exercise test electrocardiography (18) and may explain the lack of impact of decision aids with other formats for patients with chest pain (20, 21).

A limitation of our study is that identification of the responsible physicians was based on the emergency department record signatory; physicians found in that record might not have been the only or the principal decision makers. However, the physician who signs the record assumes medical and legal responsibility for clinical care, a standard that is widely accepted (including at the hospitals in our study). Moreover, because some supervision may have occurred without an attending physician signature, our findings may underestimate the true difference in the effect of ACI-TIPI when it is used by truly unsupervised residents. In addition, to the extent

Table 8. 30-Day Mortality for Participants in the Acute Cardiac Ischemia Time-Insensitive Predictive Instrument Trial

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hospitals with Low-Capacity Telemetry Units (High-Capacity CCUs)</th>
<th>Hospitals with High-Capacity Telemetry Units (Low-Capacity CCUs)</th>
<th>All Hospitals Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Deaths in the Control Group</td>
<td>Deaths in the ACI-TIPI Group</td>
<td>Deaths in the Control Group</td>
</tr>
<tr>
<td></td>
<td>n/n (%)</td>
<td>n/n (%)</td>
<td>n/n (%)</td>
</tr>
<tr>
<td>All patients</td>
<td>47/2092 (2.2)</td>
<td>39/1647 (2.4)</td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>Patients hospitalized</td>
<td>46/1282 (3.6)</td>
<td>37/1005 (3.7)</td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>Patients discharged home</td>
<td>1/869 (0.1)</td>
<td>2/642 (0.3)</td>
<td>&gt;0.2</td>
</tr>
</tbody>
</table>
that all decision-making physicians did not personally review ACI-TIPI predictions, this trial may have underestimated the instrument’s potential impact.

Another limitation is that we tested ACI-TIPI in only two manufacturers’ electrocardiographs. However, these are probably representative; the ACI-TIPI formula (8) and its electrocardiographic implementation (1, 9, 10) are in the public domain and are available to any manufacturer. In addition, U.S. Food and Drug Administration requirements for electrocardiographs should ensure performance close to that found in our study.

Finally, a trial design involving on/off months rather than patient-by-patient randomization might be considered a limitation. However, because in actual practice physicians would expect the ACI-TIPI electrocardiograph to operate for all patients, we believed that this trial design, rather than the surprise of random appearance, better emulated actual use. Moreover, because the month of a given patient’s presentation to the emergency department is presumably random, the overall study effect should be equivalent to that of traditional patient-by-patient randomization.

The potential national impact of the ACI-TIPI is hard to calculate but could be substantial, especially given that most U.S. hospitals have fewer on-site emergency physicians than those included in this study and half are in rural settings. For patients without cardiac ischemia, approximately 192,000 hospitalizations and 78,000 CCU admissions per year could be avoided. These estimates assume that the impact would be less than that seen in rural hospitals in 1980–1981 but similar to that seen with unsupervised residents in the current trial and that, as seen in this study, approximately 76% of the 6 million patients with chest pain seen yearly in emergency departments prove not to have acute ischemia. On the basis of one participating hospital’s cost (not charges) accounting system, average costs for an uncomplicated “rule-out infarction” admission for a study patient without acute ischemia was $2997 in the telemetry unit and $4309 in the CCU, yielding an estimated national total yearly savings of $650 million.

For patients with stable angina, reductions similar to those seen in this trial would correspond nationally each year to approximately 34,000 fewer CCU admissions and 12,000 fewer hospitalizations, assuming (as seen in this study) that 6% of all patients presenting to the emergency department with symptoms suggestive of acute ischemia prove to have stable angina. By using the cost assumptions outlined above, such reductions would translate into savings on the order of $45 million for CCU admissions and $33 million for hospitalizations, for a total yearly savings of $78 million.

Combining these projections for patients without cardiac ischemia and those with stable angina, the potential yearly impact of use of ACI-TIPI in the United States could be 204,000 fewer hospitalizations and 112,000 fewer CCU admissions, for a total savings of $728 million. Aside from its potential national impact, the use of ACI-TIPI should help clinicians in settings with apparent excess hospitalization, in which improved cost-effectiveness is particularly desirable.

In conclusion, the use of the ACI-TIPI programmed into an electrocardiograph seemed to assist emergency department triage effectively and safely in different types of hospitals. Its use may be associated with substantial reductions in admissions to the CCU, telemetry unit, and hospital, particularly in settings in which overuse is greatest, without adversely affecting care. The degree of further improvement that could be obtained by using ACI-TIPI simultaneously as a real-time decision aid in the emergency department and for retrospective feedback reports on emergency department triage to physicians, hospitals, and health plans (8) deserves investigation. In addition, the use of ACI-TIPI in prehospital emergency medical service settings (12) and nonacute clinic settings and its continuous use over time to monitor patients suspected of having acute ischemia need further evaluation. Finally, to understand its strengths and limitations better, the TIPI approach would benefit from application in other clinical domains (13).

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