PREDICT: A Simple Risk Score for Clinical Severity and Long-Term Prognosis After Hospitalization for Acute Myocardial Infarction or Unstable Angina

The Minnesota Heart Survey

David R. Jacobs, Jr, PhD; Candyce Kroenke, MPH; Richard Crow, MD; Mahesh Deshpande, MS; Dong Feng Gu, MD; Lael Gatewood, PhD; Henry Blackburn, MD

Background—We evaluated short- and long-term mortality risks in 30- to 74-year-old patients hospitalized for acute myocardial infarction or unstable angina and developed a new score called PREDICT.

Methods and Results—PREDICT was based on information routinely collected in hospital. Predictors abstracted from hospital record items pertaining to the admission day, including shock, heart failure, ECG findings, cardiovascular disease history, kidney function, and age. Comorbidity was assessed from discharge diagnoses, and mortality was determined from death certificates. For 1985 and 1990 hospitalizations, the 6-year death rate in 6134 patients with 0 to 1 score points was 4%, increasing stepwise to 89% for ≥16 points. Score validity was established by only slightly attenuated mortality prediction in 3570 admissions in 1970 and 1980. When case severity was controlled for, 6-year risk declined 32% between 1970 and 1990. When PREDICT was held constant, 24% of those treated with thrombolysis died in 6 years compared with 31% of those not treated.

Conclusions—The simple PREDICT risk score was a powerful prognosticator of 6-year mortality after hospitalization. (Circulation. 1999;100:599-607.)

Key Words: myocardial infarction ■ angina ■ cardiovascular diseases ■ thrombolysis
Records of such patients were obtained from 35 of 36 Twin Cities hospitals in 1970, 30 of 31 hospitals in 1980 and 1985, and all 25 hospitals in 1990.

In 1980, when abstraction forms were created for 1970 and 1980 admissions, MHS cardiologists identified variables that they believed would reflect event severity. Abstracted information pertaining to the day of admission included history of disease, blood pressure, heart rate, ECG (by the Minnesota Code20), digitalis use, and chest x-ray findings. Comorbidity, much of which is apparent on the day of admission, was assessed by use of the Charlson Comorbidity Score,21,22 which is based on discharge diagnoses. Data obtained after the day of admission were not included in these analyses because a downward clinical course might reflect, rather than predict, in-hospital mortality. Abstraction was done by trained nurses under physician supervision. If no information was found in a hospital chart concerning a particular item, “not recorded” was checked.

Follow-Up and End Points
The vital status at the time of hospital discharge was ascertained from medical records and subsequently by computerized linkage with the Minnesota death certificate database (MINNDEX). MINNDEX had 98% agreement with the National Death Index for death certificates for 1980 through 1983.23 All-cause death was the study end point. Underlying cause based on nosologic coding of the death certificate diagnoses was also examined. Follow-up started at...
the hospital admission date and went out 6 years from each hospitalization year.

**Statistical Analysis**

The analytic goal was to form a predictive score, PREDICT (Predicting Risk of Death in Cardiac Disease Tool), from noninvasive markers available in the MHS database that was based on information routinely collected in hospital and was available on the day of admission. Development of PREDICT was based on 1985 and 1990 hospitalizations for precision in current data, with validation based on an independent sample of hospitalizations from 1970 or 1980. Mortality within 30 days, 2 years, and 6 years of the day of admission was related to 35 single items; both “yes” and “not recorded” responses connoted higher risk among many variables (data not shown). The average number of items not recorded decreased from 8 to 3 from 1970 to 1990 ($P<0.0001$). Information not recorded was predictive of excess mortality in 1985 and 1990; we used the number of not recorded items as a covariate in subsequent analyses.

In the first stage of development, for simplicity, the score was assigned 1 point for a “yes” for each item. However, the data confirmed that indicators such as shock and congestive heart failure were far more predictive than other indicators such as history and age, so we considered other weightings, forming PREDICT components by equal weighting of clinically related items. The first 4 components were specifically CHD related (shock, congestive heart failure, ECG, and clinical cardiovascular disease [CVD] history), and 3 others were not (comorbidity, kidney function, and age). Specific items used in each component are listed in Figure 1. We evaluated each component by linear regression of mortality on each potential PREDICT component, adjusting for age and sex. We ran multiple linear regressions with death in different follow-up intervals as the dependent variable and potential components as the independent variables, adjusting for sex, age, and the number of not recorded items to determine optimal weights. Because adjustment had little effect on regression coefficients for PREDICT components, we returned to the unadjusted model. For simplicity, the final score assigns integer points and adds them across components. Thus, PREDICT includes 7 clinically understandable factors measured on the day of admission (except discharge comorbidity codes) and thought a priori to indicate clinical severity and to predict long-term mortality after hospital admission for an acute coronary event.

![Table](https://example.com/table.png)

**Figure 1.** Continued.
To evaluate goodness of fit, we used logistic regression to regress mortality on PREDICT with SAS PROC LOGISTIC. We report the C-statistic (area under the receiver-operating characteristic curve) and the Hosmer-Lemeshow \( \chi^2 \) statistic for goodness of fit (high probability value corresponds to good fit).

**Epidemiological Applications**

To analyze time trends in mortality rates from 1970 to 1990, we interpreted PREDICT as a measure of severity, using linear regression analysis to regress mortality on year of death, and computed mortality rates adjusted for age and sex; for age, sex, and severity; and for age, sex, severity, and count of not recorded items. We similarly evaluated mortality rates according to use of thrombolytic agents.

**Results**

**Potential PREDICT Components**

The components in Figure 2 generally showed a consistent gradient of mortality risk in short- and long-term follow-up. However, clinical history was inversely associated with short-term mortality. Shock was most predictive in the short term. The relative mortality risk of those with \( \geq 3 \) shock points versus those with 0 points was 11.7 in the first 30 days, whereas in 30-day survivors, relative risk from 31 days to 6 years dropped to 2.3. Moderately reduced kidney function, defined as blood urea nitrogen of 18 to 29 mg/dL, became predictive only after 2 years. Left bundle-branch block, intraventricular block, and right bundle-branch block accompanied by Q waves were the most predictive ECG abnormalities. Risks for anterior or anterolateral Q-wave infarction or for anterior, anterolateral, or inferior non–Q-wave infarction were similar to each other and less than risk for ventricular conduction defect. No excess risk was noted for inferior Q-wave infarction. Given the Q/ST score defined in Figure 1, no excess risk was noted for negative T wave, ST elevation, or reciprocal changes (data not shown). The ECG severity score defined in Figure 1 is based on location, extent, and severity of Q-wave or non–Q-wave infarction and viability of the electrical conduction system. Risk generally increased as the ECG severity score increased.

Figure 3 presents age- and sex-adjusted mortality rates for several additional variables not included in PREDICT that added little to prediction of 6-year mortality after adjustment for PREDICT: sex, any elevated enzyme, transport to the hospital in an ambulance, the presence of cardiomegaly among those who had an x-ray, race, medical insurance, and marital status. High systolic blood pressure was inversely related to mortality, although this effect largely disappeared by 6 years. Diagnosis of MI (ICD 9, discharge diagnosis code 410) had a 36% 6-year risk compared with 23% for unstable...
angina (ICD 9, code 411); the same was true for MI defined by a standardized diagnostic algorithm. However, this diagnostic category added little to prediction of 6-year mortality, given knowledge of PREDICT (data not shown).

**PREDICT Score**

PREDICT was formed by adding points over components (Figure 1) and assigning the risk observed in MHS (Table 1). The mean±SD of PREDICT was 6.8±4.0. Distribution (Figure 4) peaked at 4 points and was skewed to the right; only 4% had ≥16 points. PREDICT showed a 22-fold, graded, monotonic increase in 6-year mortality (Figure 5); 30-day and 2-year mortality rates were also graded and nearly monotonic. Each point corresponds to an ~5% increase in 6-year death rate. In logistic regression of mortality on PREDICT, the C-statistic was 0.79 for 30-day mortality, 0.81 for 2-year mortality, and 0.81 for 6-year mortality. The Hosmer-Lemeshow goodness-of-fit statistic indicated relatively poor fit for 30-day mortality ($\chi^2$ with 8 df=23.4, $P=0.003$), better fit for 2-year mortality ($\chi^2$ with 8 df=18.1, $P=0.02$), and excellent fit for 6-year mortality ($\chi^2$ with 8 df=3.7, $P=0.88$).

In 1985 and 1990 admissions, 52% of deaths were attributed to CHD, and 74% were attributed to CVD. The higher the PREDICT score was, the more likely was the cause of death to be attributable to CVD. Generally, early deaths were attributed to CHD or CVD (74% and 88%). Among deaths occurring 2 to 6 years after hospital admission, 42% were CHD deaths, and 65% were attributable to CVD. Conversely, other non-CVD causes increased 3-fold, and cancer mortality increased 7-fold, from 2% in the first 30 days after admission to 12% and 15% in 31 days to 2 years and in 2 to 6 years, respectively.

**Prediction of Mortality in Those Discharged Alive**

The PREDICT score estimated a strong gradient of risk among the 5709 hospital survivors. Mortality risk in 6 years ranged from 4% for the 6% who had a PREDICT score of 0 to 1 to 85% for the 3% who had a PREDICT score ≥16 ($P<0.0001$).

**Validation of PREDICT in 1970 and 1980 Hospitalizations**

PREDICT performed nearly as well in 1970 and 1980 admissions as in 1985 and 1990 admissions. The relative 6-year mortality risk was 9-fold, graded, and nearly monotonic over its range (10% to 85% dead). As in 1985 and 1990, the distribution peaked at 4 points and was skewed to the right.
TABLE 1. Percent Mortality Rates Predicted Through Logistic Regression After Hospitalization for Acute MI or Unstable Angina in 1985 or 1990: MHS

<table>
<thead>
<tr>
<th>PREDICT Score</th>
<th>No. At Risk</th>
<th>Predicted Mortality Rates, %</th>
<th>30 d</th>
<th>2 y</th>
<th>6 y</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>54</td>
<td>1</td>
<td>2</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>262</td>
<td>1</td>
<td>3</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>436</td>
<td>2</td>
<td>4</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>645</td>
<td>2</td>
<td>5</td>
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<td>9</td>
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<tr>
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<td>6</td>
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<td>0</td>
<td>75</td>
<td>95</td>
<td></td>
<td>99</td>
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</table>

(Figures 6 and 7). In logistic regression, the C-statistic was 0.76 for 30-day mortality, 0.77 for 2-year mortality, and 0.77 for 6-year mortality. The Hosmer-Lemeshow goodness-of-fit statistic indicated relatively poor fit for 30-day mortality ($\chi^2$ with 8 $df=22.1$, $P=0.002$), better fit for 2-year mortality ($\chi^2$ with 8 $df=15.1$, $P=0.03$), and excellent fit for 6-year mortality ($\chi^2$ with 8 $df=8.2$, $P=0.31$).

Comparison to Killip Score

For comparison with existing scores, we computed the Killip score, approximated as closely as possible by use of MHS abstracted data from the day of admission. We formed subcategories, given in Table 2, to illustrate ambiguities in recreating the original definition. Maximal 30-day death rate with use of the Killip score was 24%; in a Killip score subcategory, the death rate was 34% (data not shown). A broad range of 6-year death rates is seen across levels of the Killip score. There is also substantial variation across the subcategories within each Killip class (Table 2). In logistic regression of mortality on the Killip score, the C-statistic was $\approx 0.70$ for 30-day, 2-year, and 6-year mortality.

**Epidemiological Applications of PREDICT**

**Mortality Time Trends**

The mean age- and sex-adjusted PREDICT score increased from 6.3 in 1970 to 7.0 in 1990 (Table 3), whereas the number of not recorded items decreased. Age- and sex-adjusted mortality decreased 43% from 1970 to 1990, with the largest drop occurring between 1980 and 1985 (Table 3). Adjusting for PREDICT and the number of items not recorded attenuated the decrease to 32%. A decrease of $\approx 32\%$ was consistently seen for each individual PREDICT score (data not shown).

**Risk Differential According to Use of Thrombolytic Agents**

Although 30-day mortality rates were similar in the 669 patients treated with thrombolytic agents versus the 5450 not treated (8.5% versus 8.2%, respectively; $P=0.8$), those treated had reduced 2-year mortality (13.1% versus 18.8%, respectively; $P=0.0002$). The risk difference expanded during years 2 through 6 of follow-up (Table 4), even after controlling for PREDICT score. After further adjustment for both severity and number of items not recorded, those treated with thrombolytic agents had a 25.3% 6-year mortality rate versus 30.8% in those not treated ($P=0.0006$).

**Discussion**

PREDICT has epidemiological utility both for evaluating trends of disease severity and for examining whether other factors in diagnosis and care are predictive of mortality risk, controlling for severity. Although the mean PREDICT score changed little across study years of 1970, 1980, 1985, and 1990, we are mindful that severity may have been underestimated in the earlier years when hospital charts were less complete. Six-year mortality rates after hospital admission declined 32% between 1970 and 1990, controlling for severity and improvements in hospital chart record keeping. In
Figure 5. Short- and long-term mortality rates after day of hospital admission in 1985 or 1990 for MI or unstable angina (ICD 9, code 410 or 411) by PREDICT (n=6134).

Figure 6. Percent frequency distribution of PREDICT: day of hospital admission in 1970 and 1980 (validation sample, n=3570).

Figure 7. Short- and long-term mortality rates after day of hospital admission in 1970 or 1980 for MI or unstable angina (ICD 9, code 410 or 411) by PREDICT (validation sample, n=3570).
agreement with clinical trials, we observed that use of thrombolytic agents was associated with improved long-term survival, even though those who received thrombolysis had less severe disease and more complete hospital charts. Because the factors used in PREDICT have been shown to be predictive in other settings,5–18 it is reasonable to believe that the PREDICT score would perform well if formed by the physician’s assignment of clinical severity levels, with the sense of the rules we used in MHS. For example, elevated serum creatinine can be substituted for blood urea nitrogen in determining the kidney score, and other signs of congestive heart failure, such as auscultatory findings, may help to classify the level of severity. Clinically, PREDICT may be useful in reassuring those patients with low scores, whose long-term risk is little different from people who have neither MI nor unstable angina. It also can help to identify those patients with intermediate levels of risk for whom additional clinical watchfulness may be appropriate.

Although PREDICT was designed to estimate long-term mortality risk, it did reasonably well in short-term prediction. A score more predictive of short-term risk would have reversed the weighting of clinical history and admission systolic blood pressure and increased the weighting of shock. Other clinical and invasive measures would be useful in a score designed to predict in-hospital or other short-term outcome.

We found 5 long-term noninvasive scores in the literature that included factors known to be predictive of mortality. Scores such as those developed by Norris et al14 or Killip and Kimball9 focused on subsets of variables well known to be directly related to CHD, most of which are included in PREDICT. Differences in prognostic scores depend on the particular combination of factors included (limited by data availability in a particular study) and by the way factors are defined and implemented. This ambiguity is illustrated in our implementation of the Killip score. The PREDICT score has a broader range of values and provides a finer gradation of outcome probabilities than existing clinical severity scores; PREDICT specifically adds renal function and comorbidity as predictors. One score, the Myocardial Infarction Severity Score,18 has a great deal in common with PREDICT and adds 3 factors not abstracted in MHS: state of consciousness, heart murmur, and respiratory rate. These scores are applicable to prediction in those patients who survive hospital; PREDICT is applicable from the day of admission.

We were hampered in our evaluation of other clinical severity scores5–8,10,14 because we did not abstract predictors in the specific form required to implement each score. We did estimate Killip score9 and found PREDICT to perform better, even after 30 days of follow-up. Furthermore, therapeutic success was far greater in 1985 and 1990 than in 1965, when the Killip score was created. The sample of 250 patients presented by Killip and Kimball9 included 19% judged to be in cardiogenic shock compared with <6% of MHS patients with shock and congestive heart failure recorded. The patients in cardiogenic shock suffered 78% in-hospital mortality in 1965 compared with only 24% 30-day mortality in the MHS patients and 58% in the GUSTO-I trial.25 Thus, the probabilities associated with the Killip score9 may be high, given present-day therapeutics.

### TABLE 3. Standardized 6-Year Mortality Rates for Study Year

<table>
<thead>
<tr>
<th>Year</th>
<th>n</th>
<th>Mean (SEM)</th>
<th>PREDICT Items Not Recorded (n)</th>
<th>Mean (SEM)</th>
<th>Age and Sex Adjusted (6-Year Mortality Rates, %)</th>
<th>Age, Sex, Predicted Adjusted (6-Year Mortality Rates, %)</th>
<th>Age, Sex, Predicted, NR* Adjusted (6-Year Mortality Rates, %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>1816</td>
<td>6.3 (0.094)</td>
<td>7.2 (0.052)</td>
<td>44.0</td>
<td>46.2</td>
<td>42.9</td>
<td></td>
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<tr>
<td>1980</td>
<td>1754</td>
<td>6.6 (0.096)</td>
<td>5.5 (0.053)</td>
<td>40.1</td>
<td>40.2</td>
<td>38.6</td>
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<tr>
<td>1985</td>
<td>2483</td>
<td>6.9 (0.081)</td>
<td>3.1 (0.045)</td>
<td>32.7</td>
<td>31.6</td>
<td>32.5</td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>3651</td>
<td>7.0 (0.067)</td>
<td>2.4 (0.037)</td>
<td>27.9</td>
<td>27.5</td>
<td>29.2</td>
<td></td>
</tr>
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</table>

n=9704.

*Information not recorded.
TABLE 4  Standardized 6-Year Mortality Rates by Thrombolytic Treatment in 1985 or 1990

<table>
<thead>
<tr>
<th>Thrombolysis</th>
<th>Items Not Recorded, %</th>
<th>6-Year Mortality Rates, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age, and Sex Adjusted</td>
<td>Age, Sex, and PREDICT Adjusted</td>
</tr>
<tr>
<td>No</td>
<td>5450  7.1  0.057  2.8  0.026</td>
<td>31.3</td>
</tr>
<tr>
<td>Yes</td>
<td>669   6.2  0.163  1.8  0.073</td>
<td>22.6</td>
</tr>
</tbody>
</table>

n=6134.

*Information not recorded.

Conclusions

PREDICT is a risk score for acute coronary patients that uses information routinely obtained on the day of hospital admission for acute MI or unstable angina. It is a simple and powerful discriminator of 30-day, 2-year, and 6-year total mortality risk and is largely independent of sex and CHD manifestation. It reflects severity of the event. In an independent validation, there was little loss of power. Because the hospital samples selected are representative of the Twin Cities metropolitan statistical area, it has broad generalizability among white men and women. PREDICT expands on predictors used in earlier scores and updates risk assessment for particular conditions by use of recent information. Further evaluation of the score in other clinical settings and among ethnic minorities would be useful.

References

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