may have a protective effect at a time that a large proportion of heart attacks normally take place.²⁰ The effects on the fibrinolytic system were observed at blood alcohol concentrations below the 10.85 mmol/l (0.5 g/l), the Dutch legal limit for drinking and driving. This indicates that even at the low levels of alcohol consumption (5–25 g/day) shown to reduce coronary heart disease risk in epidemiological studies an effect on the fibrinolytic system might be expected. This effect seems to be mediated by the endothelium.

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Early identification of patients at low risk of death after myocardial infarction and potentially suitable for early hospital discharge

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Abstract

Objectives—To find (a) whether data available shortly after admission for acute myocardial infarction can provide a reliable prognostic indicator of survival at 28 days, and (b) whether such an indicator might be used to identify patients at low risk of death and suitable for early discharge.

Design—Retrospective analysis of data collected on patients admitted to a coronary care unit for acute myocardial infarction. A validation sample was selected at random from these patients.

Setting—Coronary care units in Perth, Western Australia.

Subjects—6746 patients aged under 65 and resident in the Perth Statistical Division who during 1984–92 were admitted to a coronary care unit with symptoms of myocardial infarction.

Main outcome measures—Sensitivity and specificity of several models for predicting survival at 28 days after myocardial infarction, and detailed performance characteristics of a particular model.

Results—Patients with a pulse rate of 100 beats/min or less, aged 60 or under, and with symptoms typical of myocardial infarction, no past history of myocardial infarction or diabetes, and no significant Q wave in the admission electrocardiogram had a very high chance of survival at 28 days (99.2%). These patients made up one third of all patients studied.

Conclusion—The prognostic index identifies patients very soon after admission who are at low risk of death and potentially eligible for early discharge from hospital or the coronary care unit. Computing the index does not need complex cardiac investigations.

Introduction

Recommendations for hospital stay after myocardial infarction have shortened progressively over the past 30 years. In the 1950s around six weeks of bed rest was recommended, as studies had shown that this was the time required for healing of the myocardial scar.¹ The potential danger of this prolonged bed rest was recognised by Levine and Lown in 1952, when they proposed the “armchair treatment” of coronary thrombosis.² They reported that a large proportion of patients could sit in a bedside chair by the third day after infarction without adverse consequences.

Over the subsequent 20 years the duration of hospital care for patients with myocardial infarction decreased steadily. A survey of American physicians by Wenger *et al* in 1973 showed that a hospital stay of three weeks was accepted as normal.³ From the late 1960s and into the 1970s a series of controlled clinical trials with progressively shorter durations of hospital stay all showed that patients with uncomplicated acute myocardial infarction could be discharged early without adverse effect on mortality or other complications.^{4–15} That series of studies set the pattern for practice in the 1980s, and in the United States a hospital stay of seven to 10 days became routine.¹⁶

In recent years there have been suggestions that an even shorter hospital stay may be feasible for some patients. A randomised trial of early discharge by Topol *et al* showed the feasibility of discharge on the third day after infarction in selected patients.¹⁷ The rate of return to work was marginally better in the early discharge group and the overall care costs of the group were substantially less.

A main difficulty in introducing early discharge after myocardial infarction is the identification of patients

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who have uncomplicated disease or are at low risk of death. This assessment is needed very early after admission so that the patients can be given appropriate treatment and health education in the few days that they spend in hospital.

This study compared several models for their prognostic value and aimed at identifying the simplest that had adequate (as determined by specificity and sensitivity) prognostic ability. Factors included in the models were chosen from those available shortly after admission. The model was then applied to a test set of patients to check its performance.

Patients and methods

Patients included in the study were part of the population based MONICA project (an international study conducted under the auspices of the World Health Organisation to monitor trends and determinants of mortality from cardiovascular disease over 10 years).¹⁸ The MONICA project register in Perth holds information on all people between the ages of 25 and 64 who are resident in the Perth Statistical Division and have had an acute myocardial infarction since the beginning of 1984. MONICA project staff monitor all death registrations in Western Australia for fatal cases and hospital discharge diagnoses for cases of acute myocardial infarction admitted to hospital. Any patient given an ICD-9 (*International Classification of Diseases*, ninth revision) diagnostic code of 410.0 to 411.9 (but not 411.1, which is for unstable angina) is registered.

For this study we selected that subset of MONICA project events for which the patient was admitted to a coronary care unit in Western Australia during the nine years 1984-92. There had to be an admission electrocardiogram and a creatine kinase estimation. In addition, the patient had to show symptoms of myocardial infarction which were either typical or atypical according to MONICA project criteria.¹⁹ "Typical" symptoms required chest pain for more than 20 minutes and no definite non-cardiac or cardiac non-atherosclerotic cause. "Atypical" symptoms needed one or more of atypical pain, acute left ventricular failure, shock, or syncope, together with the absence of cardiac disease other than ischaemic heart disease, and no definite non-cardiac or cardiac non-atherosclerotic cause.

Data collected on each patient as part of the MONICA project are extensive.¹⁹ In accordance with the MONICA project protocol, episodes of infarction beginning less than 28 days apart were counted only once, and survival of the patient was determined from vital status 28 days after the onset of infarction.

Vital status was assessed by examining the official register of deaths within Western Australia. Patients who were discharged alive and not found on the register were presumed to have been alive 28 days after the event.

STATISTICAL ANALYSIS

A sample of records was selected at random from the whole database to serve as a "test" set of patients. These were thus separated from the remainder (the "training" set), who were used to develop the prognostic models. Forward stepwise logistic regression was used to determine factors predictive of death within 28 days of the onset of symptoms by using the computer program EGRET.²⁰ Variables included in the model were chosen only from those available shortly after admission. Most variables recorded simply the presence or absence of a factor. For example, a past history of acute myocardial infarction was recorded if the medical records for the current event included evidence of a previous admission with a clinical diagnosis of myocardial infarction. Otherwise, a history of myocardial infarction was recorded as negative.

The two continuous variables—pulse rate (maximum recorded during the first 24 hours after admission) and ratio of peak creatine kinase activity to its upper limit of normal—were classified into low, medium, and high. The two cut points for pulse were 100 and 120 beats/min, and those for creatine kinase activity ratio were 5 and 10. The definition "significant Q wave" was taken from the Minnesota coding system as any abnormal 1 code on the first electrocardiogram taken after admission.²¹ Bundle branch block was defined from the same trace.

Defining the prognostic model

A hierarchy of models was obtained from the stepwise procedure, and the fitted coefficients for each of these were used to assign scores to each patient. In order to assess the prognostic value of each model we examined the distribution of the scores among survivors and among the patients who died. A useful prognostic model would be one that assigned a low score to patients who survived the 28 day period and a high score to those who died within 28 days.

For each model there was a choice of threshold score below which a patient might be considered at low risk of death. By calculating the sensitivity and specificity of a score below some threshold to predict survival at 28 days (for the full range of possible thresholds) the receiver operating characteristic²² curve was drawn for each model. The prognostic value of each model was compared by examining these curves. As the prognostic model was to be used to identify low risk patients, there had to be the least possible chance of wrongly classifying a person who ultimately died as being at low risk—that is, high specificity (rather than sensitivity) was of utmost importance. A suitable model would give the maximum sensitivity for a clinically acceptable specificity. Models capable of about 95% specificity or greater were considered in more detail, and the application of one such model is described as a particular example.

This selected model was applied to the test set of records to check its performance with patients who were not included in the derivation of the models. As well as survival to 28 days, the number of days spent in the coronary care unit, total days in hospital, and the

TABLE 1—Multivariate odds ratios for mortality within 28 days in 5746 patients (full model of 12 variables; model 12)

Variable	No of patients	Odds ratio	95% Confidence interval
Pulse (beats/min)			
≤ 100	4294	1.0	—
101-120	1010	2.7	2.0 to 3.7
> 120	442	7.5	5.4 to 10.3
Age (years)			
≤ 60	4238	1.0	—
> 60	1508	2.1	1.7 to 2.8
Symptoms			
Typical	5278	1.0	—
Atypical	468	2.8	2.0 to 4.0
History of acute myocardial infarction			
No	4150	1.0	—
Yes	1596	1.7	1.3 to 2.4
Diabetes			
No	5094	1.0	—
Yes	652	2.0	1.4 to 2.7
Significant Q wave			
No	4725	1.0	—
Yes	1021	1.6	1.2 to 2.1
Diuretics			
No	4861	1.0	—
Yes	885	1.6	1.2 to 2.2
Creatine kinase activity ratio†			
< 5	3246	1.0	—
5-10	1193	1.3	0.9 to 1.8
> 10	1307	1.9	1.4 to 2.6
Bundle branch block			
No	5490	1.0	—
Yes	256	1.9	1.2 to 2.9
Antiplatelet agent			
No	4729	1.0	—
Yes	1017	0.5	0.3 to 0.8
Digoxin			
No	5577	1.0	—
Yes	169	1.8	1.1 to 2.9
Nitrates			
No	4288	1.0	—
Yes	1458	1.5	1.1 to 2.0

†Ratio of peak activity to upper limit of normal.

TABLE II—Fitted coefficients for variables in 12 models. Each model is "best" for that number of variables. Coefficients are natural logarithms of odds ratios

Variable	Model No											
	1	2	3	4	5	6	7	8	9	10	11	12
Pulse 101-120 beats/min	1.2	1.2	1.2	1.3	1.2	1.1	1.1	1.0	1.0	1.0	1.0	1.0
Pulse > 120 beats/min	2.5	2.4	2.3	2.3	2.3	2.2	2.2	2.1	2.1	2.0	2.0	2.0
Age > 60 years		0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Atypical symptoms			1.0	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0
History of acute myocardial infarction				0.7	0.7	0.6	0.5	0.6	0.6	0.7	0.7	0.6
Diabetes					0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Significant Q wave						0.5	0.6	0.5	0.5	0.4	0.4	0.4
Diuretics							0.6	0.6	0.6	0.6	0.5	0.5
Creatine kinase activity ratio 5-10								0.2	0.2	0.2	0.2	0.2
Creatine kinase activity ratio > 10								0.6	0.6	0.6	0.6	0.6
Bundle branch block									0.6	0.6	0.6	0.6
Antiplatelet agent										-0.6	-0.6	-0.7
Digoxin											0.6	0.6
Nitrates												0.4

TABLE III—Calculation of specificity and sensitivity for all possible thresholds by using simplest model (model 1)

Score	Survival at 28 days	
	Yes	No
Scores for model 1		
0	4189	105
1.2	931	79
2.5	339	103
Threshold score = 0		
0	4189	105
> 0	1270	182
Threshold score = 1.2		
≤ 1.2	5120	184
> 1.2	339	103

various cardiac complications that occurred at some time during the hospital stay were examined for all patients. "Ventricular tachycardia" refers to any run of more than three extrasystoles, with the rate for such beats exceeding 100/min.

χ^2 statistics were used to test hypotheses that complications affected the non-fatal and fatal cases equally. Days spent in the hospital and coronary care unit were compared by *t* tests (mean number of days) with the SAS data analysis program.²³ For those patients who died within 28 days both the timing of death (in hospital or after discharge) and cause of death were also examined.

Results

During 1984-92, 7272 MONICA project registrations concerned admission of the patient to a coronary care unit with an illness satisfying the inclusion criteria (typical or atypical symptoms of myocardial infarction). Results of a creatine kinase assay, an admission electrocardiogram, and a maximum pulse rate greater than zero within the first 24 hours were available for 6746 of these episodes. There were 326 deaths (4.8%) among these patients during the 28 days after onset of the symptoms. The other 526 events had missing electrocardiograms (415), missing creatine kinase data (76), or missing pulse recordings (60), 25 events missing more than one of these. There were 71 deaths (13.5%) among these cases, and 39 of them occurred before the end of the second day in hospital. From the events with no missing data a test set of 1000 records was selected at random, so that the training set comprised 5746 patients. There were 39 (3.9%) deaths in the test set and 287 (5.0%) deaths in the training set.

The results of the final logistic regression model produced from the stepwise fitting procedure are shown in table I. The factors in order of inclusion in the model were maximum pulse rate in the first 24 hours, age, symptoms, history of myocardial infarction, history of diabetes, significant Q wave in the admission electrocardiogram, diuretics taken before onset, creatine kinase activity ratio, bundle branch block in

the admission electrocardiogram, antiplatelet agent taken before onset, digoxin taken before onset, and nitrates taken before onset. None of anterior site of infarction, sex, marital status, history of hypertension, cardiac arrest outside hospital, or taking β blockers or calcium channel blockers before admission was selected for inclusion by the stepwise fitting procedure with a threshold P value for inclusion set at 0.05.

The estimated coefficients in the logistic regression model (logarithms of the odds ratios) were used to create an index from which each patient's score was calculated. This was done by using each of the 12 models derived through the stepwise regression procedure. For example, the first (and simplest) model had a term only for the pulse; the second had terms for pulse and age; and so on. Table II shows the coefficients produced by the procedure for each of the models, numbered 1 to 12. Calculating a score for a patient by using a particular model was done by adding the scores for variables included in that model which were relevant to that patient. For example, with model 1 a patient having a pulse rate of 80/min would score zero, but a pulse rate of 110/min would yield a score of 1.2. Table II shows that as variables were added to the model the odds ratios for variables already in the model were remarkably stable, showing that these variables did not exhibit collinearity in this database.

The receiver operating characteristic curve for survival at 28 days was constructed for each model by calculating the specificity and sensitivity of scoring less than a threshold figure.

Table III shows calculation of the specificities and sensitivities required for constructing the curve by using the simplest model. The curves for the 12 models are shown in figure 1. The numbered points represent the maximum attainable specificity for each model. This increased with complexity of the model, and at the same time there was some improvement in sensitivity for a given specificity. Figure 2 shows an enlargement of figure 1 for those curves whose maximum attainable specificity was at least 94%.

FIG 1—Receiver operating characteristic curves for 12 models. Numbered points identify maximum attainable specificity for each model

FIG 2—Enlargement of receiver operating characteristic curves in figure 1 showing models that can attain specificity of at least 94%

Figure 2 shows that model 6 was the least complicated which could give a specificity of around 95%. At its minimum possible threshold (zero) the sensitivity was 33%—that is, one third of patients who ultimately survived the 28 days had a zero score. Its 95% specificity means that 95% of the patients who died had a score greater than zero. For model 7 a threshold could be selected to give 96% specificity and 31% sensitivity. Model 8 was the first which included the creatine kinase measurement and showed a maximum attainable specificity of over 98%, but the sensitivity at that threshold was only 17%.

For the training and test patients separately, table IV shows the distribution of survivors by the score calculated by using model 6 with a threshold of zero. For the test set of patients the specificity was 97% and sensitivity 36%—that is, 3% of deaths (one event) and 36% of the survivors (352 events) scored zero.

Table V shows the pattern of deaths (place, cause, and timing) and the duration of hospital stay for the survivors according to score for patients in the training and test sets combined. The median hospital stay was eight days for both groups and the median stay in the coronary care unit was two days for both groups. Various cardiac complications that occurred are listed in table VI for fatal and non-fatal events.

Discussion

This study aimed at identifying a low risk group of patients soon after myocardial infarction by using

TABLE IV—Distribution of scores based on model 6

	Survival at 28 days		
Score	Yes	No	Case fatality (%)
	<i>Training set of 5746 patients</i>		
0	1835	15	0.8
>0	3624	272	7.0
	<i>Test set of 1000 patients</i>		
0	352	1	0.3
>0	609	38	5.9

readily available data. The requirement that patients should have an admission electrocardiogram and pulse and creatine kinase measurements eliminated from consideration those who died too quickly for these data to be available and those who were recognised clinically as not having acute myocardial infarction. We believe that this selection process was relevant and appropriate, as it avoided including in the predictive model most patients who died before the question of early discharge would have arisen.

The method of comparing different models by using the receiver operating characteristic curve shows that the main difference between all the models was the maximum attainable specificity, which was poor (about 60%) for the simplest model and rose to almost 100% for the most complicated, but with a corresponding loss of sensitivity. For all models comprising six or more explanatory variables the maximum attainable specificities were over 94%, leading to case fatality rates in the low scoring groups of less than 1%.

OTHER PROGNOSTIC INDICES

Previous attempts at identifying low risk groups have not achieved such a degree of specificity. DuBois *et al* developed a prognostic index for short term risk of

TABLE V—Place, cause, and timing of death, and length of hospital stay for survivors among training and test sets combined, distributed by using score based on model 6 with threshold of zero. In deaths section, except for case fatalities, results expressed as numbers (percentages) of total deaths

	Score	
	0	>0
Total No of patients	2203	4543
<i>Deaths</i>		
Total No of deaths	16	310
Case fatality (%)	0.7	6.8
Place of death:		
In hospital	13 (81.3)	288 (92.9)
After discharge	3 (18.8)	22 (7.1)
Cause of death:		
Acute myocardial infarction	12 (75.0)	216 (69.7)
Other ischaemic heart disease	2 (12.5)	36 (11.6)
Other circulatory disease	2 (12.5)	7 (2.3)
Other	0	51 (16.5)
Days of survival after onset:		
0	3 (18.8)	54 (17.4)
1	1 (6.3)	47 (15.2)
2-8	8 (50.0)	134 (43.2)
>8	4 (25.0)	75 (24.2)
<i>Survivors</i>		
Mean (SD) days spent in hospital	8.7 (4.5)	9.6 (5.4)
Mean (SD) days spent in coronary care unit	2.9 (2.3)	3.2 (3.8)
		P < 0.001

TABLE VI—Distribution of cardiac complications among fatal and non-fatal events for all 6746 patients in training and test sets combined. Results expressed as numbers (percentages) of total patients in each column

	Non-fatal	Fatal	P value
Total No of patients	6420	326	
Pulmonary oedema	304 (4.7)	134 (41.1)	<0.001
Complete heart block	209 (3.3)	63 (19.3)	<0.001
Ventricular fibrillation	313 (4.9)	104 (31.9)	<0.001
Ventricular tachycardia	1693 (26.4)	155 (47.5)	<0.001
Reinfarction	222 (3.5)	16 (4.9)	<0.001

death based on simple clinical data available at admission from 536 patients in a coronary care unit.²⁴ Factors on which the index was based were age, site of infarction (anterior versus other), and grade of left ventricular function. With this index they identified a group of 62% of the patients whose risk of death was 4%, as compared with a risk of 24% in the remainder. In contrast with this and other similar findings²⁵⁻²⁸ we found site of infarction not to be predictive, though we included it as one of the candidate explanatory variables for the logistic regression.

One explanation may be that as patients in our study

Clinical implications

- Shortage of hospital beds indicates a need for identifying low risk patients after myocardial infarction
- Simple clinical data may be used that will not add to the cost of hospital care
- Up to one third of patients may be suitable for early discharge based on clinical indices
- A prospective study of early discharge based on these data is strongly recommended

had to survive long enough to have an admission electrocardiogram and creatine kinase measurements, many of those with anterior infarcts may have died too soon to be included. Those with anterior infarcts who survived to be included had no poorer prognosis than those without anterior infarcts after all the other variables had been adjusted for. Our subjects were under 65 at the time of infarction, and it is also possible that anterior infarcts are more life threatening for people over this age.

INTERPRETATION OF MAIN RESULT

One third of the patients in our study had none of the first six adverse factors named in the model—that is, they had a pulse rate of 100 beats/min or less, were aged 60 or under, and had symptoms typical of myocardial infarction, no past history of myocardial infarction or diabetes, and no significant Q wave in the admission electrocardiogram. This group of patients had a score of zero for model 6 and a very high chance of survival at 28 days after infarction (99.2%). We are tempted to suggest that patients in this group should be considered for early discharge from the coronary care unit or hospital, as their case fatality rate between days 2 and 28 was 0.5%. We remain cautious, however, because over half the patients in this group stayed in hospital for eight days or more. Their ultimate survival advantage, therefore, cannot necessarily be wholly ascribed to their lower risk profile, as it may have been due partly to medical treatment in the later days of their stay in hospital.

Patients who scored zero (the low risk group) had a similar length of stay in the coronary care unit to those with a positive score (around two or three days), though it was statistically significantly less. This shows that patients in the low risk group were still regarded as needing a similar degree of intensive care. The incidence of cardiac complications in patients who survived was much lower than in those who died, though ventricular tachycardia was common in the non-fatal group (26%). We did not include cardiac complications in the prognostic model because we do not know whether they occurred in the first hours after admission to the coronary care unit or later in the hospital stay. Probably, however, they would occur within the first two days, and in practice clinicians would use judgment to exclude such patients from early discharge even if they had a favourable score. This process of clinical selection would further reduce the risk of death out of hospital in those selected for early discharge.

In most of the deaths that occurred the official cause was recorded as myocardial infarction, though 51 (16%) of the deaths that occurred in the high risk group were due to causes other than myocardial infarction or ischaemic heart disease (ICD codes 410-414).

Conclusion

We conclude that by using the proposed prognostic

index patients may be stratified into an appropriate risk group soon after admission to a coronary care unit. The feasibility of early discharge of low risk patients identified by this method would need to be tested in a prospective study. The cost savings of early discharge—an estimated overall reduction in bed days of one fifth if patients with low scores were discharged after three days—would need to be balanced against several important factors. These would include the limited time available for patient education and risk factor modification, the need for readmission to hospital for complications, and the inconvenience of scheduling follow up visits and further investigations as an out-patient. We did not assess the value of adding other inpatient investigations to stratify risk further in the patients being considered for early discharge but this could be included in a prospective study.

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