The length of hospitalization after acute myocardial infarction determined by risk calculation

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ABSTRACT The feasibility of the use of a Cox model for risk assessment of individualized hospital discharge after myocardial infarction was evaluated. First, a previously developed prognostic index computed at the fifth day after admission was tested on a new population of 1140 patients. It was confirmed that after 5 days half of the patients (52%) could be discharged with low risk. Second, a new competing risk variant of the Cox model that updates prognosis according to the occurrence of complications was developed that describes the risk of death, cardiac arrest, and cardiogenic shock within 44 days after hospital admission. With a risk of one of these events being below 2% during a 14 day period after proposed discharge, 453 patients of 966 survivors (47%) could be discharged after only 5 days. A longer stay (of up to 30 days) was proposed for 338 patients (35%) to achieve the same level of risk. The savings in hospitalization days would be 15%. These results were confirmed in a new sample of 197 patients from the same institution who were discharged according to the proposed system. Of the 169 day 5 survivors, 67% were discharged on days 6 through 15 and this resulted in only two unexpected deaths and a 20% savings in hospitalization days. We conclude that individually determined discharge time is feasible without increased risk of death of severe complications after early discharge.

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THE RISK of severe complications and death is high in the first few days after the onset of symptoms in patients with acute myocardial infarctions (MIs). Therefore, the risk decreases, the actual risk depending on important prognostic factors in the individual patient.

The slight but definite risk that exists, even many days after admission, has required that all patients with MIs stay in the hospital about the same length of time, often up to 3 weeks. The monitored stay in the coronary care unit has usually been only a few days followed by admission to either intermediate care units or general medical wards in which patients are not monitored.

A shorter hospitalization period has been proposed for patients with uncomplicated MIs. It has been suggested that about 50% of the survivors could be discharged after 8 days, 10 to 12 days, or 9 to 14 days. A longer hospitalization period has also been suggested for certain high-risk patients. A recent survey of physicians treating patients with uncomplicated MIs showed that the median length of total hospital stay decreased from 21 days in 1970 to 14 days in 1979. It is considered relatively safe to discharge patients with uncomplicated MIs after approximately 10 days, but this policy requires further examination and clarification. More information is needed to help identify subgroups of patients with uncomplicated disease who are candidates for early discharge. Furthermore, precise measures of the benefits or disadvantages of early discharge for these subgroups of patients are needed.

Ideally, a patient should be hospitalized only until the benefits of hospitalization no longer justify the expense. At some point the risk of complications requiring immediate detection and treatment will be so low that continued hospitalization cannot be justified. Also, once this point has been reached, a patient is likely to benefit emotionally by returning to his family and physically by resuming his normal activities. The only reasonable basis for deciding the appropriate dis-
charge time is estimation of the risk of death and severe complications for the individual patient. Several previous studies have shown the feasibility of this approach.11–22

The purpose of this study was to show that it is possible to determine individual hospital discharge times with the use of multivariate statistical techniques for estimating the risk to the individual. The proposed system will result in shorter hospital stays for many low-risk patients and longer stays for some high-risk patients.

Material and methods

Patients. The feasibility of early discharge has been evaluated previously in Glostrup Hospital in a consecutive population of 332 patients (group 1) studied in 1972 through 1973.19 All had sustained a definite MI and were admitted to the coronary care unit within 24 hr of symptom onset. A definite diagnosis of MI was made when at least two out of the following criteria were met: typical severe chest pain, typical evolving electrocardiographic changes (Q waves and/or ST segment/T wave changes), and elevated cardiac enzymes levels (aspartate aminotransferase, lactate dehydrogenase, or creatine kinase). The use of these criteria resulted in the inclusion of some patients with subendocardial infarction.

The main study population consisted of 1140 consecutive patients (group 2) admitted to the same coronary care unit during a 3 year period (1977 to 1980). These patients were treated according to the same criteria used for the first group of patients. All patients were monitored for at least 18 days. According to the current hospital discharge policy, usually no patient was discharged before day 18.

A new group of 197 consecutive patients (group 3) admitted to the same institution in 1981 and 1982 was used to test the validity of the risk prediction for individual times of discharge. The aim was to determine the discharge times for these patients according to their estimated risk.

Prognostic variables. The prognostic variables used were as follows:

1. Age.
2. Sex.
3. Previous MI (determined by patients’ history followed up by hospital records).
4. Location of MI (anterior [Q waves or ST segment/T wave changes in any precordial leads] or other location).
5. Cardiac enzyme maximum levels (aspartate aminotransferase and lactate dehydrogenase in group 1 and creatine kinase in groups 2 and 3).
6. Heart failure (definite clinical signs of congestive heart failure with persistent pulmonary rales or enlarged neck veins or peripheral edema and/or pulmonary vascular congestion from an x-ray in the upright position).
7. Acute pulmonary edema (severe shortness of breath with pink frothy sputum and numerous rales).
8. Cardiogenic shock (systolic blood pressure below 80 mm Hg and/or clinical signs of shock without extracardiac causes).
9. Cardiac arrest (ventricular fibrillation or asystole of more than 10 sec duration).
10. Supraventricular tachycardia (more than 10 successive supraventricular premature beats with a frequency of more than 100 per minute).
11. Ventricular tachycardia (more than 10 successive ven-

tricular premature beats with a frequency of more than 100 per minute. Ten beats were used in accordance with Danish practice).
12. Premature ventricular beats (more than 10% of all beats).
13. Atrioventricular block of second or third degree.
14. Nodal rhythm (no sinus impulses, regular rhythm with beat frequency below 100 per minute, and QRS duration below 0.12 sec).
15. Ventricular rhythm (no sinus impulses, no P waves, beat frequency below 100 per minute, and QRS duration of above 0.12 sec).
16. Sinus bradycardia (sinus rhythm with frequency below 50 beats/min).
17. Atrial fibrillation or flutter (irregular, totally disorganized, or rapid regular electric activity of the atria).
19. Extension of MI (at least two of the following three criteria: new recurring typical chest pain, new definite electrocardiographic changes, or new coronary enzyme elevations).

The day of the first and last occurrence was recorded for each complication during each patient’s hospitalization. The prognostic time frame for the analyses was up to 44 days after admission. Routine therapeutic procedures were carried out throughout the hospital stay in each patient. Digitalis and/or diuretics were administered for heart failure and antiarrhythmics were given for dysrhythmias, but they were not given prophylactically. Patients did not take β-blockers or other infarct-limiting drugs.

Statistical methods. Two risk-prediction schemes were used in this study. We had already developed a risk-prediction model based on the multivariate Cox model with data from group 1.19 Patients were observed during the first 5 days after admission and based on the data collected the probability of death between days 6 and 30 was estimated. This scheme did not take into account the time dependence of the prognostic variables. The model was also tested on group 2 data.

The need for a more differentiated prognostic scheme that updated the prognosis during the hospital stay and included nonfatal end points such as cardiac arrest led us to develop a new variant of the Cox model for use in analysis of data from group 2. In this daily assessment model the risk can be estimated, based on the occurrence of complications, on any day during the hospital stay.

The original model proposed by Cox23 was modified and the result was a competing-risks model with the following three end points within 14 days after admission24: death (i = 1), cardiac arrest (i = 2), and cardiogenic shock (i = 3). If more than one end point was reached the same day we defined the order for inclusion in the analysis as cardiac arrest, cardiogenic shock, and death. The model for the hazard of end point i is

$$\lambda_i(t) = \lambda_{i0}(t) \exp \left[ \beta_1 Z_1(t) + \ldots + \beta_p Z_p(t) \right]$$

where \(\lambda_{i0}(t)\) is an unspecified function common to all patients and \(Z_1(t), \ldots, Z_p(t)\) are the covariates or prognostic factors (i.e., age and complications). The values of \(Z_1(t), \ldots, Z_p(t)\) (occurrence of complications) have to be known at time t.

The regression coefficient (\(\beta_p\)) was estimated by a maximum partial likelihood method25 and the integrated hazard functions (\(\lambda_{i(t)}\)) by Breslow’s method.26 Only the significant variables were retained in the final model. Because of the very high mortality after cardiogenic shock, patients with this complication should not be considered for early discharge and cardiogenic shock was not a covariate in the model. Patients were censored at the time of cardiogenic shock. Cardiac arrest was a
covariate only for the end points of death and cardiogenic shock, not for a second cardiac arrest. The analysis of this model was reported previously in detail.27

To assess prognosis, the risk (P_e) of at least one of the events (death, cardiac arrest, or cardiogenic shock) occurring within 14 days after any day (t) was estimated by

\[
P_e = 1 - \exp \left[ - \sum_{i=1}^{3} (e ^ {\beta_i Z_i(t)} + \ldots + e ^ {\beta_t Z_t(t)}) \right]
\]

This probability predicts the occurrence of cardiac arrest, cardiogenic shock, and death, but assumes no other complications during the 14 day period. In patients not considered dischargeable before day 5 this is only a minor problem.

Individual discharge time. To evaluate the feasibility of the use of the previous and daily assessment model for determining the discharge time, the consequences for the patients in group 2 were evaluated retrospectively. The range of discharge times (t) examined was from day 5 through day 30. A patient was considered dischargeable on the day of risk of death from the discharge day through day 30 was reduced below 5% (previous model) or on the day the risk of an event (death, cardiac arrest, or cardiogenic shock) during the 14 days from the discharge day was reduced below 5% or 2% (daily assessment model).

The individualized discharge scheme was evaluated in terms of (1) number of patients discharged at a given time, (2) savings in hospitalization days compared with the present discharge policy, and (3) the in- and out-of-hospital occurrence of death and severe complications.

In addition to evaluating what would have happened to group 2 patients had this new discharge policy been in effect, the 197 group 3 patients were discharged according to a modified daily assessment model (below 2% risk) and evaluated in the same way. Because of the need for attending physicians to exercise caution, it was not possible to adhere strictly to the calculated discharge times; many low-risk patients were kept in the hospital a few days longer than dictated by their calculated risk. It was also not always possible to keep some of the high-risk patients as long as suggested.

Results

Prognostic variables. In order to compare groups 1, 2, and 3, table 1 lists the incidence of important prognostic variables. The mortality for days 1 through 5 and for days 6 through 45 was slightly higher in group 2 compared with group 3. Fewer patients in group 3 had heart failure and premature ventricular beats, whereas more experienced cardiogenic shock. No other important differences were noted.

The regression coefficients for the previous model and the daily assessment model are listed in table 2. In each model and for each end point only the variables that were selected by the analysis are included. These variables were sufficient to describe the risk of the occurrence of each end point and the method was not improved by the inclusion of other variables. The magnitude of coefficients depends partly on the scale or incidence of the variables. Thus, no comparison can be made among the coefficients within an analysis. A coefficient of 2.3 for heart failure for the end point death implies that the risk of death for a patient with heart failure is approximately 10 times greater (e^{2.3})
than the risk for a patient without heart failure but with the same value for all other variables.

Age was included in the analysis for all end points, and had a relatively low coefficient as an indicator for cardiac arrest. Heart failure ranked high in importance, especially as an indicator for cardiogenic shock. Cardiac arrest (ventricular fibrillation or asystole) was very important as an indicator for death, but less important for cardiogenic shock. The previous MI variable was included as a risk factor for cardiogenic shock, but had a relatively small coefficient.

**Prediction of risk.** The integrated hazard functions for each end point were estimated by the computer program. Figure 1 shows the difference in hazard function between any day after admission (t) and a day 14 days later. The hazard values on the ordinate ($\Lambda_0^i(t + 13) - \Lambda_0^{i-1}(t - 1)$) can be used directly for each end point, i (death, cardiac arrest, cardiogenic shock) in the formula for calculating the risk of the occurrence of an event. The higher the hazard value the greater risk.

The hazard values from figure 1 and the coefficients in table 2 can be used to estimate the risk of the occurrence of an event for an individual patient. For a 60-year-old patient without complications the score value ($\beta_1^{i}z_1 + \ldots + \beta_p^{i}z_p + \text{constant}$) for each end point i is equal to zero (i.e., for death $0.082 \times 60 - 4.9 = 0$; table 2). The hazard difference on day 10 is 0.0044 for cardiac arrest, 0.0008 for death, and 0.0006 for cardiogenic shock (figure 1). The risk of an event from day 10 to day 24 is then

$$1 - \exp \left( - \left[ (e^{0.0008} \times 0.0044) + (e^{0.0006}) \right] \right) = 0.006 = 0.6\%$$

For a 50-year-old patient with heart failure and supraventricular tachycardia the scores are $0.082 \times 50 + 2.3 - 4.9 = 1.5$ for death, $0.010 \times 50 + 2.2 + 1.0 - 0.6 = 3.1$ for cardiac arrest, and $0.028 \times 50 + 3.3 - 1.7 = 3.0$ for cardiogenic shock (table 2). The hazard difference on day 15 is 0.0032 for cardiac arrest, 0.001 for death, and 0.0004 for cardiogenic shock (figure 1). The risk of an event occurring in the period from day 15 to day 29 is then

$$1 - \exp \left( - \left[ (e^{1.5 \times 0.001}) + (e^{3.1 \times 0.0032}) + (e^{3.0 \times 0.0004}) \right] \right) = 0.08 = 8\%$$

If the patient had more complications or was older the scores were greater, meaning the risk was higher. If the patient was younger the risk would be lower.

The computation can be accomplished by an appropriately programmed calculator or with the use of a special slide rule.*

**Individual discharge time.** The consequences of discharge times determined by the present discharge policy, the previous model, and the daily assessment model for the length of hospital stay, complications outside

*Further information can be obtained from the author.
the hospital, and hospitalization days are compared in table 3.

The majority of the patients in group 2 were discharged according to the present system (on day 16 to day 30, most at approximately day 18). Only a few stayed in the hospital beyond day 30. Thirteen of the patients died between discharge and day 30, four died after readmission (three from cardiac arrest and one from cardiogenic shock), and nine died outside the hospital (seven sudden deaths).

Table 3 shows the actual number of patients who could have been discharged early according to the previous or the daily assessment model. According to the previous model 52% of group 2 patients could have been discharged from day 6 through day 15, and 20% would have had to stay until day 31 because their risk of death was not lower than 5% before day 30. This scheme would result in three out-of-hospital deaths, five cardiac arrests (the three deaths among these), and two cases of cardiogenic shock (two of the deaths among them). The savings in hospitalization days would have been 22%.

When the daily assessment model is applied, 47% of the patients could be discharged after 5 days with a risk below 2%. The high-risk patients (35%) would have to stay at least 30 days to attain the same level of risk of an event during the 14 day period after discharge from the hospital. This discharge policy would result in only one out-of-hospital death up to day 30 and very few other severe complications.

If patients at 5% risk of an event were discharged, more could be discharged early, but there would be more deaths and complications outside the hospital. Both the previous and the daily assessment model, when applied to patients at 2% risk, resulted in fewer out-of-hospital deaths than the present system and the 2% risk daily assessment model was the safest, with the lowest number of deaths and complications after discharge. In practice, therefore, an upper limit for risk of event of 2% should be set when early discharge is being considered.

The savings in hospitalization days would be 15% for the 2% system and 35% for the 5% system. These savings could be used to benefit the high-risk patients by prolonging their hospitalization time. If all 338 high-risk patients in the 2% threshold scheme were kept in the hospital beyond 30 days, each staying the same number of the saved days, then the length of stay would be increased 8 days per patient and, instead of occurring outside the hospital, 16 deaths could possibly be avoided because of the treatment available in the hospital.

Table 3 (right column) shows the results when the daily assessment model was applied in group 3 pa-
patients. The discharge times of these patients were determined mainly by risk estimation. According to this estimate, among the 169 patients surviving 5 days, 113 (67%) could be discharged from day 6 through day 15 and 42 (25%) from day 16 through day 30. We observed only two unexpected deaths. A 42-year-old man with a calculated risk of 0.4% died of cardiac arrest 2 days after discharge (at day 10) and a 62-year-old man at 0.7% risk died from a new MI 15 days after discharge (at day 9). Since the patients had been discharged we have no precise information on the occurrence of complications after discharge. Apart from the two deaths no patient was readmitted to hospital because of complications. Only a few patients (3%) stayed in the hospital for longer than 30 days. The observed reduction in hospitalization days corresponded well with the expected number (20%).

Discussion

The feasibility of the use of an individualized discharge policy (especially one in which early discharge is considered) for patients with MIs must be evaluated in detail before it can be safely introduced. The use of a new system must not result in a greater risk of death or other severe complications. In this study we evaluated our proposal for individualized discharge with exact calculations of the benefits and disadvantages with respect to the number of patients discharged on certain days after admission, complications after the discharge, and the savings in hospitalization days. We have tested the model (although somewhat cautiously) in a new group of patients who were actually discharged according to results of the use of the estimated-risk method.

The model included the variables of age, heart failure, and cardiac arrest as indicators for the end point death; age, heart failure, supraventricular tachycardia, premature ventricular beats, and extension of MI for the end point cardiac arrest; and age, previous MI, heart failure, cardiac arrest, and nodal rhythm for the end point cardiogenic shock.

With a risk of occurrence of any end point below 2% within a 14 day period from the discharge day, 47% of the patients in group 2 (retrospectively studied) could have been discharged early (after 5 days), with very few complications after discharge. Many high-risk patients did not reach the 2% risk level before day 30 and prolonged hospitalization could be proposed for these patients. In group 3, 67% of the patients were actually discharged from day 6 through day 15, with a 20% savings in the number of hospitalization days.

This new scheme for determination of time of discharge, based on calculation of risk, can therefore select a large number of patients for early discharge without adverse effects. This would result in better use of hospital beds for the high-risk patients and in a substantial reduction in the number of days spent in the hospital.

The incidence of death or other severe complications after proposed discharge was tabulated retrospectively in group 2 patients and compared with incidence of these events after discharge according to current policy. This evaluation would tend to overestimate the benefits of early discharge because the patients were actually kept in the hospital where treatment of life-threatening complications was possible. Use of the model would result in four cardiac arrests and six ventricular tachycardias after the proposed discharge day. Only one of these patients actually died, possibly because all of the patients were still hospitalized.

Unfortunately, we were not able to follow our proposed scheme strictly in the group 3 patients. Caution on the part of the attending physician dictated that some low-risk patients stay a few days longer than calculated (many patients stayed 6 to 10 days instead of 5 to 7 days) and this could underestimate the occurrence of out-of-hospital complications after early discharge. However, we had the opportunity to observe the low-risk patients a few days longer and we did not observe any cardiac arrests, incidents of cardiogenic shock, deaths, or other severe complications.

The prognostic variables we used for the end point death were in accordance with those used in previous studies (heart failure,28-30 cardiac arrest,31,32 and age.33 For the end point cardiac arrest, variables that have been shown to be important, such as heart failure,34-38 supraventricular tachycardia,36,38 premature ventricular beats,34-38 and extension of MI,16 corresponded with those we used. Ventricular tachycardia, recognized previously as an important risk factor for cardiac arrest,34-38 was not selected for use in our analysis. Ventricular tachycardia is not an indicator of a cardiac arrest that may occur more than 24 hr after the tachycardia. A recent multivariate study identified age, sex, and smoking as the most important variables for late cardiac arrest.39

Because the important prognostic variables are identical to clinically important variables, the time of discharge could be determined by the presence or absence of these variables alone. However, our proposed model can quantitate the risk for an individual patient based on a combination of important variables for three end points. This method should be a safer one for risk assessment before discharge.
The proportion of patients eligible for early discharge based on risk determination has been reported to range from 15% to 76% in studies with well-defined risk factor criteria and from 18% to 76% in studies with poorly defined criteria. A mean value for all studies would be around 50%, which is in agreement with our findings. The earliest proposed discharge day was day 3, but in most studies the patients selected for early discharge could often leave the hospital at day 7. In our study, 76% in 3 days could be discharged.

In most of the uncontrolled studies mortality up to 6 months after discharge was not higher for early discharge compared with after discharge. Our results with mortality of only 0.9% at 3 months and 6% after 1 year in the early discharge group compared well. In the controlled studies no differences were reported in mortality, the time of which ranged from 6 weeks to 2 years after admission.

Our high-risk patients with heart failure and cardiac arrest could benefit from a longer stay in the coronary care unit. In the test sample five patients were in the hospital longer than 31 days because they continued to be at high risk. These patients (all later discharged) benefited from a prolonged hospitalization. One patient was probably saved due to in-hospital treatment of late ventricular fibrillation, one patient had a late MI extension, and the other three patients had severe heart failure (one also experienced cardiogenic shock). Although we were not able to keep all high-risk patients in the hospital as long as the risk estimation suggested, none of these patients died during the period in which they were to have stayed in hospital.

The high risk of late death in some patients after their discharge from the coronary care unit is well recognized. About 5% of the patients will have anoreceptive infarctions complicated by bundle branch block, which implies a high risk for late ventricular fibrillation. It has been suggested that these patients be monitored for up to 6 weeks because those who survive longer have a good 1 year prognosis. The concept of prolonged observation in a second-stage unit or intermediate coronary care unit has also been introduced.

The introduction of this new discharge policy would also benefit high-risk patients, who could be kept in the hospital longer. Cardiac events in the high-risk group would probably result in fewer fatalities if they were still in the hospital. The time after day 30 to discharge these patients cannot be calculated exactly by the present scheme. Since their risk probably stays relatively high it might be feasible to discharge these patients when their risk levels seem to have stopped decreasing. The clinical condition of these patients should also be considered in determination of discharge time.

Factors other than risk are also relevant in the assessment of the benefits of early discharge. The effects of the hospital versus the home environment might have some bearing. For instance, in the hospital medication compliance could be higher and patients may smoke less. For some patients there may be psychological benefits of staying in hospital. However, for the majority of patients, particularly the low-risk patients, the benefits of staying in hospital decrease with time after the admission. These patients undoubtedly find a better environment at home. The economical benefits from factors such as early return to work are difficult to evaluate.

We suggest that our proposed model be used for individual risk assessment before the time of patient discharge is determined. Risk estimation gives a safe basis for early discharge, although other factors can also be important in the individual patient. The model requires assessment of simple clinical variables (heart failure and arrhythmias) followed by a few calculations on a programmable calculator or by measurement on a special ruler. Approximately half of the patients with MIs who survive day 5 can be discharged early without increased risk. The result will be better use of hospital beds for high-risk patients and a 15% to 20% reduction in the number of days spent in the hospital.

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