Can preventable adverse events be predicted among hospitalized older patients? The development and validation of a predictive model

L. VAN DE STEEG1, M. LANGELAAN1 AND C. WAGNER1,2

1NIVEL, Netherlands Institute for Health Services Research, PO Box 1568, Utrecht 3500 BN, The Netherlands, and 2EMGO Institute for Health and Care Research, VU University Medical Centre, Amsterdam, The Netherlands

Address reprint requests to: L. van de Steeg, NIVEL, Netherlands Institute for Health Services Research, PO Box 1568, Utrecht 3500 BN, The Netherlands. Tel: +31-30-2729839; Fax: +31-30-2729729; E-mail: lvandesteeg@nivel.nl

Accepted for publication 5 June 2014

Abstract

Objective. To develop and validate a predictive model for preventable adverse events (AEs) in hospitalized older patients, using clinically important risk factors that are readily available on admission.

Design. Data from two retrospective patient record review studies on AEs were used. Risk factors included patient characteristics as well as admission and organizational characteristics. Multilevel logistical regression analysis was used to develop the model. Backward elimination was applied to identify the most parsimonious model.

Setting. Twenty-one Dutch hospitals were included in the 2004 sample and 20 Dutch hospitals in the 2008 sample.

Participants. A total of 3977 patients aged 70 years or over who were admitted to a Dutch hospital in 2004 and 2119 patients aged 70 years or over admitted in 2008.

Main Outcome Measures. Identified predictors of preventable AEs in older patients.

Results. In 2004 predictors of preventable AEs in patients aged 70 years or over were increased age (OR 1.04, confidence interval (CI) 1.01–1.06); elective admission (OR 1.65, CI 1.14–2.40) and admission to a surgical department (OR 1.53, CI 1.08–2.16). The area under the receiver operating characteristic curve for the 2004 sample was 0.60 and for 2008, 0.59.

Conclusions. This study showed that several expected risk factors for preventable AEs in older patients, including comorbidity, could not predict these events. It was not possible, using in-patient data available on admission and collected during the course of two patient record review studies, to develop a satisfactory predictive model for preventable AEs in older patients.

Keywords: elderly, hospital care, adverse events, predictors, risk factors

Introduction

Older patients run an increased risk of experiencing adverse events (AEs) and preventable AEs during hospitalization, compared with younger patients [1–5]. A recent Dutch study found that 2.9% of hospitalized older patients experience a preventable AE, compared with 1.8% of hospitalized younger patients [3]. An AE is an unintended injury which results in temporary or permanent disability, death or prolongation of hospital stay. Furthermore, it must be caused by the management of health care rather than the patient’s disease [6, 7]. AEs are judged as preventable if they occurred due to a failure to follow accepted practice.

A clinical prediction model estimating the risk to older patients of experiencing preventable AEs would make it possible to identify a specific group of older patients who run a higher risk of experiencing preventable AEs than their peers. Instead of viewing all older patients as high risk this would enable clinicians to focus preventive interventions on these specific patients during their stay in hospital.

In the literature several potential predictors of preventable AEs in older patients have been identified. However, the consideration of importance of these risk factors is mostly only theoretical. Little research has been done to determine, empirically, the importance of these potential risk factors. Some authors have theorized that the reason AEs and preventable
AEs occur more often during the hospitalization of older patients than primarily due to their age, but due to the diminished physiological reserves of this patient group [2, 8, 9]. They suggest that diminished reserves make it more likely that medical mistakes will lead to actual injury. Another possible explanation that is mentioned in the literature is the increased length of stay of older patients due to the complex diseases older patients suffer from [2, 10]. A longer length of stay, according to the authors, means increased exposure to the opportunities for errors to occur. One study attempted to clarify whether age or other factors were the best predictors of preventable AEs. It found that age was not an independent predictor [11].

The objective of this study was to develop a predictive model for preventable AEs in older patients. Such a model would use clinically important risk factors that are readily available on admission. Our intention was to design a model that could be used by health-care providers in hospitals so that they could take the initiative in identifying older high-risk patients for preventive measures or closer clinical attention.

**Methods**

We used data collected during the course of two studies on AEs among hospitalized patients in the Netherlands. Both studies consisted of retrospective patient record reviews, one using patient records from 2004 and the other from 2008 [3, 12, 13]. The data from the former study were used to develop the model and the data from the latter to validate it. The overall method of data collection and analysis is presented below.

**Design and setting**

A retrospective patient record review study was conducted in 21 hospitals, sampled randomly, during 2005/06—the 2004 records—and 20 hospitals in 2009/10—the 2008 records. These were sampled out of a total of 93 Dutch hospitals. Both samples were stratified for hospital type (university, tertiary teaching and general hospitals) and contained a good representation of both urban and rural settings. Eight hospitals were included in the samples from both years. Hospitals with fewer than 200 beds or without an intensive care unit or emergency department were excluded from the samples ($n = 4$).

In both the 2004 and 2008 study, oversampling of deceased patients and patients admitted to a university hospital took place. This was in order to gain sufficient data on these relatively small—but high risk—patient groups. Patient records of patients discharged after a stay of >24 h, and of patients who died in hospital were randomly selected per hospital, each making up 50% of the sample. In reality only 3% of the patients die in hospital in the Netherlands. Our intention was to design a predictive model identifying high-risk older patients, as opposed to a model predicting preventable AE rates. This made it unnecessary to correct or weigh the results for this oversampling.

A total of 400 (2004) or 200 (2008) records was selected in each hospital. Records from patients admitted to the psychiatry or obstetrics departments were excluded, as well as records from children aged <1 year.

**Record review and outcome measures**

Trained and experienced nurses and physicians conducted the record review in both studies. They used nursing, medical and, if available, outpatient records of the patient admissions sampled. Over half of all included patient records were records for older patients (70 years or over): 3977 records from 2004 and 2119 records from 2008.

The outcome measures of these studies were AEs and preventable AEs, determined using a method comparable to those of other studies [1, 5, 14]. The nurses first reviewed all the records included using screening criteria designed to discover triggers indicating the possible presence of an AE [1, 14]. If one or more triggers were detected, the record would subsequently be reviewed by a physician. The physician would then determine whether an AE had indeed occurred, guided by a standardized procedure. An AE was defined by three criteria: (i) an unintended injury; (ii) the injury resulted in prolongation of hospital stay, temporary or permanent disability or death; (iii) the injury was caused by the management of health care rather than the patient's disease.

The AEs identified were studied further by the physician in order to determine, among other aspects, how preventable the event was [6, 13]. An AE was found to be preventable when the care given fell below the current level of expected performance for practitioners or systems [13]. The preventability was scored on a six-point Likert scale and an AE was counted as preventable if the score was 4–6. This indicated that the reviewer regarded the event as having a >50% chance of being preventable.

For each patient included, data from the patient record was supplemented with diagnosis data from the national hospital administration database (Prismant). This information was coded according to the International Statistical Classification of Diseases, 9th revision (ICD-9).

**Risk factor variables**

The potential risk factors for AEs were identified, based on the previous literature on AEs and, in particular, AEs in older patients [3, 4, 8]. Data on all the potential risk factors had to be present for all older patients at the time of admission, meaning data had to be collected routinely by hospital staff for all patients aged 70 or over. Only those risk factors were considered that were gathered as part of the two AEs studies, or that could be derived from data gathered during those studies. This meant that potential risk factor variables such as, impairment in activities of daily living [15] and frailty scores [16], were not included in the development of the predictive model.

The risk factors which were considered included patient characteristics as well as admission and organizational characteristics. These were patients’ sex; age; the Charlson co-morbidity score; their home circumstances, that is whether...
they lived independently or in a care facility; the type of hospital (general, tertiary teaching or university); whether the hospital admission was a readmission related to the original admission within 12 months after discharge; whether it was an elective or acute admission; an admission to a surgical or nonsurgical department and whether the admission was during a weekend (Saturday or Sunday). The Charlson comorbidity score was calculated based on the ICD-9 codes, using a Charlson module for STATA [17].

Model development and validation

A multivariable logistical regression analysis was used to develop the model to predict preventable AEs in older patients. This used only data from patients aged 70 and over from 2004. The analyses were carried out using multilevel analyses (MLwin 2.25) in order to account for possible clustering of patients within hospitals and hospital departments. Backward elimination was applied to identify the most parsimonious model. The variables that showed insignificant effects ($P > 0.05$) were removed in order to determine the final model. We assessed the performance of the predictive model by using the area under the receiver operating characteristic curve (ROC AUC), both in the 2004 development sample and in the 2008 validation sample. The AUC can range from 0.5 to 1.0, with 0.5 indicating no accuracy of the model in predicting the studied event and 1.0 indicating a perfect accuracy. Generally, an AUC of 0.5–0.7 is interpreted as a model with low discriminatory power, 0.7–0.9 moderate and >0.9 as a model with a high discriminatory power [18, 19]. The AUC can be interpreted as the probability that a randomly chosen patient with a preventable AE is rated as more likely to experience a preventable AE by the predictive model than a randomly chosen patient without a preventable AE [20].

To determine how stable the predictors in the final model were over time, bootstrapping of the predictors in the final model was used (STATA 12.1). Two thousand random bootstrap samples were drawn with replacement from both datasets. The odds ratios of the predictors in the final model were calculated in each bootstrap sample. This enabled us to calculate confidence intervals (CIs) for the predictors, both for 2004 and 2008. We gained insight into the stability of the predictors by comparing the intervals between 2004 and 2008. The more overlapping intervals indicate a more stable predictor.

Results

Table 1 shows the patient and admission characteristics for the development and the validation samples. The 2004 sample contained 178 older patients who had experienced a preventable AE ($n = 3977$). The 2008 sample contained 124 older patients who had experienced a preventable AE ($n = 2119$). The patient and admission characteristics did not differ greatly between the development and validation samples.

Predictive model

The nine variables considered for the predictive model are presented in Table 2. The final model for preventable AEs included three of these variables: preventable AEs were associated with older age; elective admissions and surgical admissions. The regression parameters for the predictive model appear in Table 3.

Performance of the predictive model

The predictive model for preventable AEs yielded an ROC AUC of 0.60 (95% CI 0.56–0.65), using the 2004 development sample. Using the validation sample an AUC of 0.59 (95% CI 0.53–0.64) was found. This indicates that the model fitted the data poorly and had low discriminatory power.

We found that for 2004, 18.2% of the variation could be explained by the predictors in the final model. This confirms

Table 1 Comparison of patient and admission characteristics of the study samples 2004 and 2008

<table>
<thead>
<tr>
<th>Patient and admission characteristics</th>
<th>Development sample, 2004* ($n = 3977$)</th>
<th>Validation sample, 2008* ($n = 2119$)</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years, mean (SD)</td>
<td>80.0 (6.4)</td>
<td>80.3 (6.5)</td>
<td>0.03</td>
</tr>
<tr>
<td>Male sex, %</td>
<td>49.9</td>
<td>50.4</td>
<td>0.72</td>
</tr>
<tr>
<td>Charlson comorbidity score, mean (SD)</td>
<td>1.5 (2.1)</td>
<td>1.3 (1.9)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Living at home, %</td>
<td>94.2</td>
<td>85.7</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Acute admission, %</td>
<td>78.8</td>
<td>77.9</td>
<td>0.45</td>
</tr>
<tr>
<td>Readmission, %</td>
<td>5.3</td>
<td>3.8</td>
<td>0.01</td>
</tr>
<tr>
<td>Weekend admission, %</td>
<td>19.1</td>
<td>18.8</td>
<td>0.83</td>
</tr>
<tr>
<td>Surgical admission, %</td>
<td>26.6</td>
<td>26.1</td>
<td>0.69</td>
</tr>
<tr>
<td>Admission to university hospital, %</td>
<td>13.0</td>
<td>13.8</td>
<td>0.39</td>
</tr>
<tr>
<td>Admission to tertiary teaching hospital, %</td>
<td>30.4</td>
<td>30.2</td>
<td>0.83</td>
</tr>
<tr>
<td>Admission to general hospital, %</td>
<td>56.6</td>
<td>56.1</td>
<td>0.70</td>
</tr>
<tr>
<td>Length of hospital stay, days, mean (SD/median)</td>
<td>11.6 (12.4/8)</td>
<td>10.8 (11.2/7)</td>
<td>0.02</td>
</tr>
</tbody>
</table>

*Patient admission in psychiatry and admission of <24 h for non-deceased patients were excluded.
that the model we developed has limited ability to predict preventable AEs in older patients. The bootstrap CIs for all three variables included in the final model are presented in Table 3, both for 2004 and 2008. They show that the only significant predictor of preventable AEs in both samples was the type of admission. The odds of developing a preventable AE for surgical admissions were even larger in the 2008 sample.

**Discussion**

With this study we attempted to develop a predictive model for preventable AEs in older patients, using data available on admission that were collected during record review studies. We found that we were only able to develop a predictive model with a poor performance in which preventable AEs were associated with older age; elective admissions and surgical admissions. However, only one factor was identified that contributed independently to the risk of preventable AEs in older patients in both the development and validation samples; when the admission was to a surgical department, an increased risk of preventable AEs was present both in 2004 and 2008. This information could guide hospitals when choosing how to go about improving patient safety.

In our study, we did not find that comorbidity was an independent predictor of preventable AEs in older patients, in contrast to our expectations based on the literature [2, 8, 9]. We did find age to be a predictor of preventable AEs in 2004, as opposed to an earlier study on AEs in older patients [11]. It remains unclear whether this indicates that older patients received less adequate care. It might mean that we have not included a variable that represents the physical state of the patients sufficiently, making age the best available indicator. We included not only the Charlson comorbidity score in the initial model, but home circumstances as a proxy for physical state as well. Both were not found to be predictors of preventable AEs.

By using routine in-patient data we were only able to develop a model with poor ROC AUC scores. This does not indicate that the risk of preventable AEs cannot be reliably predicted at all, but that the ability to identify at risk older patients is limited when using only routinely collected data which are available on admission. Other information, that is more difficult or costly to measure, might contain stronger predictors of preventable AEs. For instance, more detailed information on the frailty of older patients [21] or specific laboratory results regarding physical fitness could provide better predictors, if they were available on, or directly after, admission. An alternative approach would be to investigate more detailed information could guide hospitals when choosing how to go about improving patient safety.

### Table 2 Variables considered as predictors in a multilevel multivariable predictive model for preventable AEs in 2004, adjusted for clustering at the hospital level and hospital department level, \( n = 3975 \)

<table>
<thead>
<tr>
<th>Potential risk factors</th>
<th>Univariable analysis</th>
<th>Multivariable analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR (95% CI), 2004</td>
<td>P</td>
</tr>
<tr>
<td>Age (years)</td>
<td>1.03 (1.00–1.06)</td>
<td>0.039</td>
</tr>
<tr>
<td>Sex (ref. male)</td>
<td>1.14 (0.83–1.56)</td>
<td>0.428</td>
</tr>
<tr>
<td>Charlson comorbidity score</td>
<td>0.99 (0.92–1.07)</td>
<td>0.883</td>
</tr>
<tr>
<td>Elective admission (ref. acute)</td>
<td>0.59 (0.42–0.83)</td>
<td>0.003</td>
</tr>
<tr>
<td>Home circumstances (ref. institutionalized)</td>
<td>0.66 (0.37–1.18)</td>
<td>0.162</td>
</tr>
<tr>
<td>Readmission (ref. no)</td>
<td>0.91 (0.43–1.89)</td>
<td>0.791</td>
</tr>
<tr>
<td>Weekend or week day admission (ref. weekday)</td>
<td>0.75 (0.48–1.16)</td>
<td>0.190</td>
</tr>
<tr>
<td>Surgical admission unit (ref. non-surgical)</td>
<td>0.57 (0.42–0.79)</td>
<td>0.001</td>
</tr>
<tr>
<td>Hospital type (ref. general)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>University</td>
<td>1.11 (0.57–2.16)</td>
<td>0.761</td>
</tr>
<tr>
<td>Tertiary teaching</td>
<td>1.00 (0.58–1.71)</td>
<td>0.996</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk factors</th>
<th>OR (95% CI), 2004</th>
<th>P</th>
<th>Bootstrap 95% CI, 2004</th>
<th>Bootstrap 95% CI, 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>1.0 (1.0–1.1)</td>
<td>0.004</td>
<td>1.0–1.1</td>
<td>1.0–1.0</td>
</tr>
<tr>
<td>Elective admission (ref. acute)</td>
<td>1.7 (1.1–2.4)</td>
<td>0.009</td>
<td>1.1–2.5</td>
<td>0.6–1.7</td>
</tr>
<tr>
<td>Surgical admission unit (ref. non-surgical)</td>
<td>1.5 (1.1–2.2)</td>
<td>0.017</td>
<td>1.0–2.3</td>
<td>1.7–4.3</td>
</tr>
</tbody>
</table>

Including bootstrap CIs of the odds ratios for the predictors for preventable AEs in 2004 and 2008.
preventable AEs in older patients, other studies have shown good results with, for instance, a predictive model for the development of pressure ulcers during admission to hospital [22]. However, developing separate predictive models for the numerous different types of preventable AEs would not only require substantial research, but would hardly simplify life for clinicians.

Both the 2004 and 2008 samples showed that the need remains to improve the quality of care for older patients provided by surgical departments. This could be met by providing further education on geriatric medicine for surgeons and surgical nurses. Additional research should focus on preventable AEs during surgical admissions and more specifically on the causes of these events in order to guide future efforts in prevention.

One of the strengths of this study was the use of two large samples of hospitalized older patients from different years. These samples made it possible to develop and validate the predictive model in two separate groups (2004 and 2008 data). This adds to the degree to which the findings apply generally. However, by choosing record reviews as a data source, this study was also subject to several potential limitations. First, we were unable to examine some risk factors identified in previous studies, such as frailty scores. These risk factors may have improved the performance of our predictive model. However, our goal was to utilize the data readily available for all older patients on admission. This was not the case for several potential risk factors, including frailty scores. However, future studies may use the presented model to examine the incremental value of using frailty scores. Secondly, the registration and quality of patient records may vary, possibly influencing the patient characteristics and AEs found [23]. Finally, although the goal was to develop a predictive model that could be used in future patient populations; our results suggest that the predictors of preventable AEs may vary over time, making it hard to develop a stable model. This might also be due to changes in the quality of care and changes in patient case mix [13]. Residual confounding by patient complexity cannot be completely ruled out. Indications for treatment and surgery are extended to increasingly older and more complex patients with more comorbidity.

Conclusions

This study showed that several expected risk factors for preventable AEs in older patients, including comorbidity, could not predict whether these events would occur.

Using routine in-patient data available on admission and collected during the course of two patient record reviews, we were only able to develop a predictive model with a poor performance, in which preventable AEs were associated with older age, elective admissions and surgical admissions. The risk factors found were not all stable over time, suggesting that developing a predictive model for preventable AEs in older patients might not be possible due to the constant changes taking place in hospitals. The increased risk of preventable AEs in older patients admitted to a surgical department was present in both the development and the validation sample, indicating that improvement projects as well as future research efforts should continue to focus on surgical care.

Funding

This work was supported by the Dutch Ministry of Health, Welfare and Sport [grant number 314439].

References


