provided is not detrimentally affected, and further efforts must be made to improve the quality of care in regions with lower health care costs in Japan. This study helps us understand the relationship between spending and quality of health care in Japan.

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Title: Derivation and Validation of In-Hospital Mortality Prediction Models in Ischaemic Stroke Patients Using Administrative Data

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Abstract

Background: Stroke and other cerebrovascular diseases are a major cause of death and disability. Predicting in-hospital mortality in ischaemic stroke patients can help to identify high-risk patients and guide treatment approaches. Chart reviews provide important clinical information for mortality prediction, but are laborious and limiting in sample sizes. Administrative data allow for large-scale multi-institutional analyses but lack the necessary clinical information for outcomes research. However, administrative claims data in Japan has seen the recent inclusion of patient consciousness and disability information, which may allow more accurate mortality prediction using administrative data alone. The aim of this study was to derive and validate models to predict in-hospital mortality in patients admitted for ischaemic stroke using administrative data.

Methods: The sample consisted of 21 445 patients from 176 Japanese hospitals, who were randomly divided into derivation and validation subgroups. Multivariable logistic regression models were developed using 7-day, 30-day and overall in-hospital mortality as dependent variables. Independent variables included patient age, sex, comorbidities upon admission, Japan Coma Scale score, Barthel index score, modified Rankin Scale score, and admissions after hours and weekend/public holidays. Models were developed in the derivation subgroup, and coefficients from these models were applied to the validation subgroup. Predictive ability was analysed using C-statistics; calibration was evaluated with Hosmer-Lemeshow chi-squared tests.

Results: All three models showed predictive abilities similar or surpassing that of chart review-based models. The C-statistics were highest in the 7-day in-hospital mortality prediction model, at 0.906 and 0.901 in the derivation and validation subgroups, respectively. For the 30-day in-hospital mortality prediction models, the C-statistics for the derivation and validation subgroups were 0.893 and 0.872, respectively; in overall in-hospital mortality prediction, these values were 0.883 and 0.876.

Conclusions: In this study, we have derived and validated in-hospital mortality prediction models for three different time spans using a large population of ischaemic stroke patients in a multi-institutional analysis. The recent inclusion of Japan Coma Scale, Barthel index, modified Rankin Scale scores in Japanese administrative data has allowed the prediction of in-hospital mortality with accuracy comparable to that of chart review analyses. The models developed using administrative data had consistently high predictive abilities for all models in both the derivation and validation subgroups. These results have implications in the role of administrative data in future mortality prediction analyses.

INTRODUCTION

Stroke and other cerebrovascular diseases are a major cause of death and disability [1,2], and represent the third leading cause of death in Japan [3]. Despite a decrease in stroke incidence in the past few decades, factors such as the ageing population of Japan and the saturation of antihypertensive therapy may have contributed to the disease burden of stroke [4].

Within a backdrop of rising health care costs, hospitals are under pressure by governments and third-party payers to provide high standards of care with limited resources. These standards are frequently evaluated with quality indicators, which can be categorized according to the Donabedian structure, process and outcome facets of health care [5]. In addition to determining quality of care, these evaluations provide benchmarking opportunities that can be used in incentive systems or payment system reform [6].

A common outcome measure in hospital evaluations is in-hospital mortality; although not all deaths can be prevented, appropriate process of care should reduce unnecessary and preventable deaths, particularly in the early stages of admission [7]. Various timespans of in-hospital mortality are used as indicators, ranging from the short-term to the entire admission period [8–12]. But mortality rates are not easily interpretable, as failure to properly account for variations in case mix and patient severity would bias evaluations against hospitals that treat a more severe class of patients.

Predicting in-hospital mortality upon admission may help to provide accurate prognoses to patients and relatives, guide therapeutic goals, and identify high-risk patients [13–15]. Mortality prediction models that use data from chart reviews tend to be more accurate than those using administrative data, as chart reviews provide critical predictors of mortality such as patient level of consciousness and disability levels [16-20]. On the other hand, hospital performance evaluations become more meaningful when interpreted in the context of multi-institutional data, and analysing regional variations can also contribute to understanding the mortality rates of a single hospital. Large-scale data from numerous hospitals are required for such studies, but the laborious nature of chart review analyses can limit sample sizes. Also, the importance of standardized data for proper data collection and determining predictive factors had been shown in previous stroke registries [21,22].

The advent of computerized hospital claims data has brought about more opportunities for researchers and policymakers to analyse health care quality, trends, and outcomes on a scale larger than previously possible. Administrative data has become extensively used in health services research, particularly in process measures of care [23–25]. However, these data generally lack clinical information reflecting patient severity upon admission and are therefore limited in their practical applications for predicting mortality. Previous mortality prediction models that have used administrative data alone have done so with a level of discrimination lower than that of clinical data [26,27].

Recent additions to Japanese administrative claims data include information on patient consciousness and disability levels, which may improve the predictive ability of mortality prediction models based on these data. Additionally, information on the date of stroke occurrence has also become available. This allows researchers to distinguish acute stroke from chronic or subacute stroke, previously a major limitation of administrative data-based stroke analyses.

Aims

The main aim of this study was to utilize the recent additions of patient consciousness and disability levels to administrative claims data in order to derive and validate models to predict 7-day, 30-day and overall in-hospital mortality in patients admitted for acute ischaemic stroke.

METHODS

Data Source and Subjects

Administrative claims data were obtained from hospitals voluntarily enrolled in the Quality Indicator/Improvement Project (QIP), which utilizes large-scale data analysis and feedback for the monitoring, evaluation, and improvement of health care quality. Hospitals in the QIP provide data in a standardized format under the Diagnosis Procedure Combination (DPC) case-mix payment system. These hospitals represent a variety of hospital ownership, teaching statuses, size and patient casemix.

We identified the discharge records of patients who had been admitted into the sample hospitals with acute ischaemic stroke occurring on the date of admission as the main diagnosis or the condition for which the most resources had been used in that admission. We selected only patients who had stroke onset on the day of admission because patients with stroke occurring one or more days earlier would introduce an added layer of uncertainty in the factors affecting mortality, and patients with stroke occurring after admission would imply admission for other reasons. Patients admitted between July 1st, 2010 and June 30th, 2011 were included in analysis. Ischaemic stroke was identified using the International Classification of Diseases, 10th Revision (ICD-10) code for cerebral infarction (I63x). Patients were excluded from analysis if they were below 18 years of age upon admission. Furthermore, patients with extremely short length of stay durations (transferred or discharged alive within 2 days of admission) presented difficulties in post-analysis interpretation of the results. Similarly, patients with extremely long length of stay durations may not reflect mortality in acute ischaemic stroke. As such, both these groups of patients were also excluded from analysis. Finally, patients who had been admitted to hospitals with fewer than 20 cases per year were also excluded.

Mortality Prediction

Study outcomes were defined as in-hospital death for the patients within 7 days from admission, 30 days from admission, and any time within the entire hospitalization period. In this study, the terms “7-day mortality” and “30-day mortality” are used to refer to in-hospital mortality that occurs within the stated timespans, and “in-hospital mortality” is used to refer to mortality that occurs at any point during the entire admission period. Multivariable logistic regression analyses were conducted using the various outcome measures as dependent variables. Independent variables included patient age (as a continuous variable), sex, comorbidities upon admission, patient consciousness and disability levels, and arrival period. Comorbidities included acute myocardial infarction, atrial fibrillation, dyslipidemia, hypertension, peripheral vascular disease, chronic pulmonary disease, connective tissue disease, liver disease, renal disease, and cancer. These comorbidities were identified according to the criteria as stipulated in the Dartmouth-Manitoba version of Charlson comorbidity index [28]. Other comorbidities such as diabetes and paraplegia were also considered, but ultimately excluded from the final model due to low incidence. This may be related to a possible undercoding issue that limits the number of simultaneous diagnoses in the restrictive formats of administrative data.

Patient consciousness and disability/dependence levels included Japan Coma Scale

(JCS) scores, Barthel activities of daily living (ADL) index scores, and modified Rankin Scale (mRS) scores on admission; these variables have been included in DPC data from July 2010 onward. These scores are measured according to the respective standardized criteria of each of the 3 variables by clinicians and transcribed to the claims data by administrative staff. The JCS is the most widely used clinical tool for evaluating consciousness level in Japanese emergency care, and consists of a scale of ten levels categorised into four groups: (i) JCS level 0, indicating a completely alert state; (ii) JCS levels 1–3 (disoriented: awake without stimulation); (iii) JCS levels 10– 30 (somnolent: arousable only in the presence of stimulation); and (iv) JCS levels 100–300 (comatose: unarousable despite stimulation) [29]. For this analysis, we utilized JCS level 0 as the referent, with the remaining class groups as binary variables. Next, during the model construction process, we decided to use a cut-off point for Barthel ADL index score of 20 (out of a possible 100); an index score that was less than 20 was included as the independent variable, and scores that were 20 or more were used as the referent. The cut-off of 20 was selected due to as patients with scores below this value represent low functional ability, and accounted for approximately half of our sample. In the case of mRS, scores of 0 to 3 were used as the referent, as patients with these scores generally require little assistance in their daily activities; mRS scores of 4 and 5 were included as dummy variables to indicate patients with severe disabilities.

Factors concerning the arrival period included whether a patient was admitted after hours (defined as the period between 6pm and 8am), and on weekends and public holidays.

The predictive abilities of the models were assessed using the C-statistic.

The patients were randomly assigned into derivation and validation subgroups, with each group comprising approximately 50% of the overall sample. Prediction models for the three mortality outcomes were constructed using the derivation dataset and evaluated using the validation dataset. We conducted this validation by applying the regression coefficients from each independent variable obtained from the test subgroup to the validation subgroup, and calculated the C-statistic from the resulting analysis. Calibration of each model was evaluated using the Hosmer-Lemeshow chi-squared test (with P>0.05 considered favourable). All statistical analyses were conducted using SPSS software, version 17.0.0 (SPSS Inc.,Chicago,IL,USA). A two-tailed P-value below 0.05 indicated statistical significance.

RESULTS

After exclusions, overall sample size for the analysis was 21 445 patients from 176 hospitals. The derivation subgroup consisted of 10 774 patients, and the validation subgroup consisted of 10 671 patients. Table 1 shows the demographics of the overall sample, and the derivation and validation subgroups. The derivation and validation subgroups were statistically similar to each other insofar as the independent variables were concerned: a two-sided *t*-test for age (given as a continuous variable in years) as well as chi-squared tests for the other variables (given as binary variables) showed non-significant *P*-values between the two subgroups for all the variables used, as well as in all three outcomes.

Patients were approximately 75 years of age upon admission, and there were more men than women represented in the sample. There were higher incidences of atrial fibrillation, dyslipidemia and hypertension when compared to the other comorbidities. Approximately 50% of the patients were alert according to the JCS levels, with decreasing incidence in the higher JCS levels (indicating less alert states). On the other hand, there was increasing incidence in the higher mRS scores, and more than half of the patients had low functional activity (Barthel index <20).

The results of the prediction models developed in the derivation subgroup are shown in Table 2. All three models showed good calibration, with *P*-values from the Hosmer-Lemeshow tests for the 7-day mortality model, 30-day mortality model, and in-hospital mortality model being 0.716, 0.280, and 0.119, respectively. Although age did not have significant association with short-term mortality indicator of 7-day mortality, this factor gained significance when the time-line for mortality was extended to 30 days and to overall in-hospital mortality. Atrial fibrillation was significantly associated with increased mortality for all three timespans. Peripheral vascular disease was significantly associated with increased in-hospital mortality, and marginally non-significant in 30-day mortality (*P*-value: 0.051). Although renal disease and cancer had no significant association with 7-day mortality, they were associated with increased 30-day mortality and in-hospital mortality. On the other hand, dyslipidemia and hypertension were both significantly associated with reduced mortality for all three timespans.

Reduced patient consciousness was significantly associated with increased mortality: the JCS levels showed that even mild disorientation (levels 1 to 3) was associated with increased mortality. However, the adjusted ORs for JCS levels 10 to 30 and 100 to 300 were highest in 7-day mortality, but decreased with longer timespans. Disability and dependence levels were also significantly associated with increased mortality, with Barthel index scores of less than 20 and an mRS score of 5 significantly associated with all three mortality indicators. The mRS score of 4 was significantly associated in 30-day mortality and in-hospital mortality, but not in 7-day mortality.

The Figure shows the predictive ability of the models for the three mortality outcomes in the derivation subgroup and the validation subgroup. The C-statistics were highest in 7-day mortality, and were all higher than 0.872 for the various measures.

DISCUSSION

The accuracy of predicting in-hospital mortality in ischaemic stroke patients using administrative claims has been limited by the lack of information reflecting disease severity of patients upon admission. However, administrative data in Japan have recently included information on patient consciousness and disability levels. In this study, we have derived and validated in-hospital mortality prediction models for three timespans based on administrative data, and shed light on predictors of in-hospital mortality in patients admitted for ischaemic stroke.

Predictive ability was highest in the short-term 7-day mortality indicator, with the C-statistic reaching 0.906 in the derivation subgroup. This predictive ability is similar to or higher than existing mortality prediction models, whether in chart review analyses or administrative data complemented with clinical information [8–11,19]. Although predictive ability was observed to be reduced as the timespans increased, the C-statistics for both 30-day mortality and in-hospital mortality were still noticeably higher than previous attempts to predict mortality using administrative data [26,27]. Validation of all three prediction models showed a high degree of consistency between the discriminatory ability of the models in both the derivation and validation subgroups.

By analysing different mortality rates at various timespans in the same population, we were able to observe the shift in predictors that influence mortality. Age was not observed to have a significant association with 7-day mortality, but was associated with mortality in the longer timespans. Furthermore, short-term mortality was found to be most influenced by low levels of patient consciousness, which is similar to the results found using clinical information [17]. Atrial fibrillation was consistently associated with increased mortality across all three timespans, a result corroborated by previous studies [30–32]. Higher mRS and Barthel index scores, in addition to JCS levels, were significantly associated with mortality in general; however, only the highest mRS score of 5 was significantly associated with 7-day mortality. Although we did not have access to a stroke severity scale, such as the National Institutes of Health Stroke Scale (NIHSS), the combination of patient consciousness levels (which is a component of the NIHSS) and patient disability and dependency scales accorded a high level of discrimination to in-hospital mortality prediction.

Renal disease and cancer were associated in 30-day mortality and in-hospital mortality, indicating that these diseases had less impact on short-term mortality when compared to patient consciousness and disability levels, which was congruent with results found in a previous study [9,33]. Hypertension and dyslipidemia were consistently associated with lowered mortality for all three timespans. Although hypertension is associated with an increased risk of stroke [34–36], the link between hypertension and stroke mortality may be similar to the results seen in heart failure, in which higher blood pressure has been shown to be associated with reduced risk of dying [37–38]. Furthermore, another study has shown that hypertension was not an important predictor of death in stroke patients [39]. In the case of dyslipidemia, these results may be an indication of reverse epidemiology, which has been previously observed in stroke patients [40–41].

Whether patients had been admitted during office hours or after hours had no bearing on survivability, but admissions on weekends and public holidays were associated with increased 7-day mortality. This may indicate that a decreased availability of resources—possibly that of manpower—during weekends and public holidays may have resulted in poorer processes of care leading to increased short-term mortality. However, if a patient should survive past the first seven days, weekend and public holiday admissions ceased to be a significant predictor of in-hospital mortality.

Although accurately predicting mortality and its predictors in ischaemic stroke patients is unlikely to substantially improve the survivability of patients, it can strengthen the attributional validity of hospital level evaluations. Fairer evaluations of outcome measures such as mortality would then have more meaningful applications in incentive systems or contributing to payment system reform.

In addition to random categorisation at the patient level, we also conducted an additional analysis with randomisation conducted at the hospital level (data not shown). Here, hospitals were randomly divided into 2 groups and tested with the same mortality prediction models. Each of the random groups comprised of 88 hospitals, with 11,314 patients in 1 group and 10,131 patients in the other. The model produced similar results to patient-level randomized groups: in 7-day in-hospital mortality, the C-statistics were 0.894 and 0.911; in 30-day in-hospital mortality, the C-statistics were 0.885 and 0.879; and in overall in-hospital mortality, the C-statistics were 0.874 and 0.871. This showed that the models had comparable predictive abilities in different groups of hospitals.

The limitations of this study are as follows: 7-day mortality and 30-day mortality were both indicators of in-hospital mortality on stipulated timespans in this study. We were unable to track mortality that occurred post-discharge, but the acute nature of stroke would generally preclude the transfer or discharge of patients who had not been stabilized; we do not expect this limitation to have a substantial impact on our analysis. Next, the hospitals included in this analysis were all volunteer participants in the QIP, and therefore represent a group of hospitals that have an active aim to improve the quality of the health care that they provide. However, the wide variations in size, ownership and geographic location of the hospitals, as well as the large sample size may make a substantial bias unlikely.

Administrative databases are a product of hospital reimbursement systems, and not designed for the purposes of health outcomes research. As such, disease severity information has been relatively less important from a hospital's perspective when compared to information on health services and goods consumed. The novelty of this study shows that the recent addition of the JCS, Barthel ADL Index, and mRS scores to ischaemic stroke patients to the DPC database in Japan has allowed the use of this administrative database to be applied effectively to predict in-hospital mortality Our results have implications in the use of administrative data in future mortality prediction analyses, as well as to provide fairer risk-adjusted mortality rate evaluations. As the quality of administrative claims data improves, health care researchers must endeavour to make the most of this resource.

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