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National administrative data produces an accurate and stable risk prediction model for short-term and 1-year mortality following cardiac surgery

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ABSTRACT

Objectives: Various risk models exist to predict short-term risk-adjusted outcomes after cardiac surgery. Statistical models constructed using clinical registry data usually perform better than those based on administrative datasets. We constructed a procedure-specific risk prediction model based on administrative hospital data for England and we compared its performance with the EuroSCORE (ES) and its variants.

Methods: The Hospital Episode Statistics (HES) risk prediction model was developed using administrative data linked to national mortality statistics register of patients undergoing CABG (35,115), valve surgery (18,353) and combined CABG and valve surgery (8392) from 2008 to 2011 in England and tested using an independent dataset sampled for the financial years 2011–2013. Specific models were constructed to predict mortality within 1-year post discharge. Comparisons with EuroSCORE models were performed on a local cohort of patients (2580) from 2008 to 2013.

Results: The discrimination of the HES model demonstrates a good performance for early and up to 1-year following surgery (c-stats: CABG 81.6%, 78.4%; isolated valve 78.6%, 77.8%; CABG & valve 76.4%, 72.0%), respectively. Extended testing in subsequent financial years shows that the models maintained performance outside the development period. Calibration of the HES model demonstrates a small difference (CABG 0.15%; isolated valve 0.39%; CABG & valve 0.63%) between observed and expected mortality rates and delivers a good estimate of risk. Discrimination for the HES model for in-hospital deaths is similar for CABG (logistic ES 79.0%) and combined CABG and valve surgery (logistic ES 71.6%) patients and superior for valve patients (logistic ES 70.9%) compared to the EuroSCORE models. The C-statistics of the EuroSCORE models for longer periods are numerically lower than that of the HES model.

Conclusion: The national administrative dataset has produced an accurate, stable and clinically useful early and 1-year mortality prediction after cardiac surgery.

1. Introduction

Risk stratification is an important part of modern cardiac surgery and there are multiple validated risk predicting statistical models used for various purposes [1–6]. Risk prediction models are not however without limitations. There are issues regarding their construction due to the variance in size of the datasets collected in clinical speciality specific registries.

Although it is recognised that this approach may provide more detailed information for individual patients, there are a number of issues with this method. National clinical registries that underpin clinical audits are expensive. Once a registry is established, by its very nature it is unable to adapt and to include emerging prognostically important variables. Particularly when used for governance purposes (on both an institutional and individual level), given their information are usually entered by clinicians, it may lead to inaccuracies and bias [7], or require expensive external-independent validation approaches.

Most risk predicting scores are modelled to predict an early endpoint of mortality. There is debate as to exactly what constitutes such an endpoint: in-hospital death, death within 30 days, a combination of the two, and a lack of standardisation makes benchmarking comparisons difficult amongst different healthcare systems.

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Finally, although most cardiac surgical procedures are performed for their perceived late prognostic benefit, there are no reliable tools to predict such outcomes to date.

Administrative datasets are known to have several pitfalls and have not been recommended as a principal data source to construct risk-scoring systems [8]. The Hospital Episode Statistics (HES) dataset of the English National Health Service (NHS) linked to the Office of National Statistics (ONS) provides an opportunity to use routinely collected patient level national data to identify in-hospital to long-term outcomes. The accuracy of such datasets when used for the development of mortality based risk algorithms for a national health care system has been previously demonstrated by our group [9]. The aim of this study was therefore to develop a methodology for cardiac surgery by constructing procedure specific prognostic models both for early (in-hospital and 30 days) to 1-year mortality following cardiac surgery and to assess their performance.

2. Methods

2.1. Data source

Data was extracted from the National Hospital Episode Statistics (HES) dataset (http://www.hscic.gov.uk/hes). Mortality data was obtained from the Office of National Statistics and linked to the HES data by the Health and Social Care Information Centre, England, United Kingdom. For the purpose of this study patients were selected on the basis of having undergone isolated coronary artery bypass grafting (CABG), isolated valve surgery or a combined valve and CABG procedures (CABG + Valve). Patients having undergone aortic surgery, procedures for adult congenital heart disease, thoracic organ transplantation and implantation of a primary ventricular assist device or postinfarction VSD repair were excluded. The sample and independent variables i.e. the additive and logistic EuroSCOREs were extracted from the local cardiac surgical database.

2.2. Statistical analysis and model development

This study was conducted in two stages. In stage 1, HES data was used to construct models predicting short-term (in-hospital and 30 days from operation) and mid-term mortality (90 days, 180 days and 1 year from operation). The sample and independent variables for the HES models were derived from clinical, demographic and administrative data contained within NHS Health Episode Statistics (http://www.hscic.gov.uk/hesdatadictionary). In stage 2, the HES based predictions were compared with the additive EuroSCORE, recalibrated EuroSCORE as described by Hickey et al. [10] and logistic EuroSCORE.

2.3. Development of HES model

National patient data for the financial years 1 April 2008 to 31 March 2011 were extracted from HES and split 70:30 as development and test samples. The same procedure was repeated for the 3 clinical groups (CABG, Valve and CABG + Valve surgery) and for the different mortality endpoints (in-hospital, 30, 90, 180 and 365 days). A second independent dataset was extracted from HES for the financial years 2011/2012 and 2012/13 to assess the time stability of the models.

All procedures were identified using Office of Population, Censuses and Surveys taxonomy (OPCS codes) selected by a team of cardiac surgeons. In admissions with multiple episodes the earliest episode having cardiac surgery was chosen.

Explanatory variables were constructed using diagnoses and admission data in the year preceding the admission considering existing knowledge on items likely to be associated with mortality in admissions to the NHS and based upon previous experience. Diagnoses were recorded using the International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10) [11]. The following explanatory variables were included: age, gender, ethnicity, deprivation score (Index of Multiple Deprivation, IMD), hospital trust, individual components of the Charlson comorbidity score, type and method of admission (determined on the basis of admissions ending within the specified time period), total number of previous emergency admissions, worst Charlson score on previous admissions, hospital length of stay and trust – year (identifying the patients admitted to each trust over each of the three included years) [12,13]. The index of multiple deprivations comprises seven indicators on a scale of 0 (least deprivation) to 100 (highest deprivation). Models were constructed to predict mortality using stepwise logistic regression on a 70% development sample from April 2008 until March 2011. After validation on the 30% test sample models were recalibrated on the full dataset. Individual logistic mortality models were constructed for CABG, valve and combined valve and CABG procedure at hospital discharge and at 30, 90, 180 and 365 days post operation.

2.4. Performance of HES model

The risk models were evaluated in terms of discrimination and calibration. Discrimination was assessed by determining the C-statistics. Calibration was assessed constructing calibration plots comparing observed versus predicted mortality across different risk strata. We assessed the performance of the HES model within the development dataset (years 2008–2011) and on a yearly basis (2008–2013) for all mortality endpoints.

The second part of this study assessed the performance of the HES models against the EuroSCORE and its variants. Access to EuroSCOREs was limited to patients admitted locally. Additive and logistic EuroSCOREs were extracted for patients with the same medical profile as in stage 1 i.e. patients who received CABG, valve surgery and CABG + Valve surgery. A re-calibrated EuroSCORE (Rec-ES), compensating for drift in the calibration over time, was calculated using the methodology provided by the National Institute for Cardiovascular Outcomes Research [14]. HES risk scores were calculated using the HES models, but may also be calculated from local episode tables providing prior emergency and non-emergency admissions are known. The final data set contained:

- Additive EuroScore; Logistic EuroScore; Re-calibrated EuroSCORE
- HES scores predicting In-hospital, 30, 90, 180 and 365 day mortality post operation
- ONS mortality recorded In-hospital, 30, 90, 180 and 365 day mortality post operation from 2008/09 to 2013/14.

C-statistics were compared using bootstrapping [15]. Sampling the original data with replacement and calculating the C-statistic on each sample for each score generated 1000 C-statistics.

The resultant dataset contains paired data and facilitates direct comparison of C-statistics. Analyses were performed using SAS 9.2. This study has been approved by the University Hospitals Birmingham Clinical Governance Board (code: CARMS-00050).

3. Results

The HES model was developed using data of patients undergoing CABG (35,115), valve surgery (18,353) and CABG + Valve (8392) between 1/4/2008 and 31/3/2011 in England. In-hospital mortality for CABG was 1.82% (650/35,115), for valve surgery 3.6% (666/18,353) and for combined CABG + valve procedures 6.0% (505/8392). Patients' summary statistics including type of cardiac surgery and In-hospital outcomes are described in Table 1. The model variables to predict In-hospital mortality are illustrated in Table 2. The remaining models predicting mortality at 30, 90, 180 days and 1 year following surgery are available in supplemental file 1. The predictive model for In-hospital mortality was tested additionally on patients undergoing surgery from 1/4/2011 to 31/03/2013.

Performance statistics for the HES models for In-hospital- at 30-, 90-, 180 days and 1-year mortality post-surgery are described in Table 3 (discrimination) and Fig. 1 (calibration). Calibration of the HES model demonstrates a small difference between observed and expected mortality and delivers a good estimate of risk of mortality for patients undergoing CABG, isolated valve or combined CABG and valve surgery. Across the 10 risk strata and all time periods the median absolute difference between observed and expected mortality rates is 0.15% for CABG, 0.41% for valve and 0.61% for combined CABG and valve procedures; the upper quartile for differences are 0.21%, 0.59% and 1.1% respectively. Analysis of In-hospital deaths during the developmental (2008/09, 2009/10, 2010/11) and extended validation periods (2011/12, 2012/13) shows under prediction in 2008/09 and good prediction within the bounds of error for the remaining years on isolated CABG and valve procedures and concomitant CABG and valve. Quarterly calibration of the In-hospital mortality model over time (2008–2014) is illustrated in Fig. 2.

Comparison of the HES models against the EuroSCOREs was performed on an eligible set of 2580 patients. HES surgical procedure classifications as CABG, valve and combined procedures decoded from OPCS codes agree with surgical (99.8%, 99.2%, 98.0%) respectively. Comparison data of the HES model with EuroSCORE discrimination are described in Table 4. Calibration was not attempted given the small number of events in a small dataset.

Additional bootstrap results for the In-hospital deaths indicate the discrimination of the EuroSCORE variants is the same within each type of operation: CABG 81%, combined CABG and valve 74%, and valve 69%. The HES based models have the same discrimination as the EuroSCORE for CABG and combined CABG and valve procedures. HES discrimination of the valve only procedure is 9.4% higher than EuroSCORE alternates. There was no significant difference between the HES and the Rec-ES in the local dataset. Nonetheless an increase in