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ORIGINAL ARTICLE

An Absolute Risk Prediction Model to Determine Unplanned Cardiovascular Readmissions for Adults with Chronic Heart Failure

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Background Frequent readmissions are a hallmark of chronic heart failure (CHF). We sought to develop an absolute risk prediction model for unplanned cardiovascular readmissions following hospitalisation for CHF.

Methods An inception cohort was obtained from the WHICH? trial, a prospective, multi-centre randomised controlled trial which was a head-to-head comparison of the efficacy of a home-based intervention versus clinic-based intervention for adults with CHF. A Cox's proportional hazards model (taking into account the competing risk of death) was used to develop a prediction model. Bootstrap methods were used to identify factors for the final model. Based on these data a nomogram was developed.

Results Of the 280 participants in the WHICH? trial 37 (13%) were readmitted for a cardiovascular event (including CHF) within 28 days, and a further 149 (53%) were readmitted within 18 months for a cardiovascular event. In the proposed competing risk model, factors associated with an increased risk of hospitalisation for CHF were: age (HR 1.07, 95% CI 0.90-1.26) for each 10-year increase in age; living alone (HR 1.09, 95% CI 0.74-1.59); those with a sedentary lifestyle (HR 1.44, 95% CI, 0.92-2.25) and the presence of multiple co-morbid conditions (HR 1.69, 95% CI 0.38-7.58) for five or more co-morbid conditions (compared to individuals with one documented co-morbidity). The C-statistic of the final model was 0.80.

Conclusion We have developed a practical model for individualising the risk of short-term readmission for CHF. This model may provide additional information for targeting and tailoring interventions and requires future prospective evaluation.

Keywords Heart failure • Hospitalisation • Risk assessment • Risk factors • Risk model

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Background

Chronic heart failure (CHF) is a major cause of morbidity and mortality and is a frequent cause of hospitalisation [1]. High rates of hospitalisation place a burden not only on the individual and their family but also society [2]. Increasingly readmission to the hospital is identified as an important marker of the quality of care, and highlights many of the vulnerabilities for patients in their transition from the hospital to the community. Reducing readmissions holds the potential of not only improving patient outcomes but also decreasing costs [3]. As many hospitalisations have been noted to be preventable, identifying those patients at most risk and developing interventions to prevent readmission have been a focus of clinicians and policy makers [3].

Risk prediction models identify individuals and characteristics which are considered at greater risk for a particular event [4]. Identifying individuals with CHF at higher risk of readmission has the potential to decrease adverse events and costs [5]. A number of models have been developed [6–16] predicting the risk of adverse events including hospital readmission and death, yet these models have demonstrated only modest discriminative ability [3,15]. The challenge of identifying individuals at the highest risk, particularly from administrative databases, has been noted and the need to identify factors, such as length of stay, which increase the sensitivity of these models, considered [7]. In order to more accurately target individuals at risk of readmission to hospital after an admission with CHF, we sought to develop an absolute risk prediction model using data from a contemporary CHF trial.

The Which Heart failure Intervention is most Cost-effective & consumer friendly in reducing Hospital care (WHICH?) trial tested the hypothesis that, compared to an equivalent clinic-based program [CBI] of management, a home-based, nurse-led, post-discharge, multidisciplinary management program [HBI] for CHF patients would be more effective in optimising health outcomes due to a better overall understanding of the patient and their environment [17]. As part of the WHICH? Program, we wanted to identify those patients who were most at risk for readmission in the early (28 days) and medium (12 months) term.

Methods

Subjects and Setting

The design and primary results for the WHICH? trial have been published previously. [18,19]. Briefly, all patients admitted to participating centres were screened for study eligibility according to the following criteria: i) aged $\geq$ 18 years; ii) discharged to home with a diagnosis of CHF as confirmed by a cardiologist; iii) persistent moderate to severe symptoms (NYHA II-III); and iv) a recent history of $\geq$ 1 admission for acute heart failure. Individuals living outside a 30 km radius of the hospital, those who had a terminal condition, were non-English speaking and/or were unable to provide informed consent were ineligible to participate. All events in the WHICH? trial were reviewed by a blinded endpoint committee and adjudicated on the type (elective versus unplanned) and cause of all readmissions. The WHICH? trial was undertaken according to the principles outlined in the Declaration of Helsinki and CONSORT guidelines for pragmatic trials [20,21] (Trial no. 418967). All WHICH? trial participants provided written informed consent and ethics approval for the study was obtained from Curtin University Human Research Ethics Committee. All participants in the WHICH? trial (n = 280) were included in this analysis.

Steps in Model Development

Following a comprehensive review of current risk models [22] variables predicting readmission were identified. To ensure relevance and appropriateness these variables were subsequently verified in an online survey of heart failure experts [23]. For the purposes of this analysis only unplanned cardiovascular readmissions were included in the model development.

Statistical Methods

A modified Cox's proportional hazards model that included death as a competing risk was used to develop the multivariate prediction model, using the methods suggested by Therneau [24]. Data items, such as age and comorbidities, identified from previous literature and surveys of experts in CHF were forced into all models [11,13]. Potential effect modification was assessed using interaction terms (none were significant at a 0.10 level). Bootstrap methods were used to identify factors for our final model and presented in a nomogram. In this process, variables were selected using a backward-deletion-method, with a generous p-value for retention (0.2). This procedure was repeated 200-times, and predictors appearing in at least 60% of Bootstrap models were included in the final model [25]. Verification of the proportional hazards assumption was based on a visual inspection of smoothed Schoenfeld residual plots [26].

Model Validation

The ability of the final model to discriminate between individuals who had been readmitted and those without a readmission, was assessed by the C-statistic [27]. Internal validation of the final predictive model included Bootstrap methods. This was done to assess how accurately the model would predict readmission in a similar population of individuals with CHF. In this method, a sub-sample of 50 patients was used to create a training model which was then applied to the whole data set to estimate biases between the observed and predicted rates of readmission. This was repeated 200 times to create a distribution of bias between predicted and observed rates, and to estimate the maximum calibration error [28]. The design package developed by Harrell was used to create the nomogram [28]. Using the final model a nomogram for predicting the probability of readmission for a cardiovascular event within 28-days or

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