The use of linked ambulance data to estimate the effect of comorbidity on determinants and outcomes of out-of-hospital cardiac arrest in Perth, Western Australia

Judith Finn

Senior Lecturer in Clinical Epidemiology, Department of Public Health, The University of Western Australia

35 Stirling Highway, Crawley, WA 6009, ph: +61 8 9380 7375, fax: +61 8 9380 1188, email: jfinn@cyllene.uwa.edu.au

Professor D'Arcy Holman

Professor of Public Health, Department of Public Health, The University of Western Australia

Dr Ian Jacobs

Associate Professor, Department of Emergency Medicine, The University of Western Australia

Abstract

In order to describe the epidemiology and survival from out-of-hospital cardiac arrests in Perth, Western Australia, three years of St John Ambulance Australia (WA Ambulance Service Incorporated) data were linked to the WA hospital morbidity and mortality data using probabilistic matching. Whilst there have been numerous publications reporting short-term outcomes of out-of-hospital cardiac arrests, the challenges posed by longitudinal follow-up of cases has limited the capacity for reports of longer-term outcomes. Similarly, there have been no large studies where the effect of comorbid status on survival has been estimated. As a result of data linkage it was possible to report 28-day and 12–month survival for all arrest victims and to model the effects of comorbidity on survival outcomes.

Of the 2,303 adults who experienced out-of-hospital cardiac arrests (excluding those from non-cardiac causes) in 1996–98, 85% (1,936) of the ambulance records linked to one or more WA hospital morbidity records for hospitalisations after 1980. Three approaches to the generation of an estimate of comorbidity were examined within this study, namely: 1) the generation of a Charlson comorbidity index (with and without the inclusion of heart disease); 2) a hierarchical classification of previous hospitalisation related to cardiovascular disease; and 3) total previous hospitalisation episodes and sum of hospital lengths of stay.

No statistically significant association was found between any of these comorbidity 'scores' and 28-day survival. Of note however, was the seemingly counterintuitive finding that the likelihood of survival was higher for those victims with some comorbid history as compared to those with no previous comorbidity (as estimated by the Charlson score). More specifically, a history of hospitalisation with mention of Ischaemic Heart Disease within 12 months of the arrest and was found to be associated with a two-fold increase in the likelihood of survival. No differences in patient and/or arrest characteristics were sufficient to explain this finding. One suggestion was that perhaps therapeutic interventions performed or medications prescribed during or subsequent to the hospital admission might have affected survival from cardiac arrest. Alternatively, different pathophysiologic processes may underpin cardiac arrest in patients with existing IHD.

Data linkage also enabled an estimation of the relationship between the victim's comorbid status and the hitherto unexplained association between the location of arrest and survival. Whilst a decreased likelihood of survival in those cardiac arrests occurring at the victim's residential address has been clearly identified within the literature, and comorbid status mooted as the likely explanation, in most previous studies there has been insufficient information about the past medical history of the victim for conclusions to be drawn. Within this study, it was shown that when the Charlson comorbidity index was added to the adjusted logistic regression model of survival, location of arrest was no longer associated significantly with survival.

This study is the first in Australia to describe the epidemiology of out-of-hospital cardiac arrest in a population-based cohort. It brought together complete data from different sources through the process of record linkage that has allowed the novel application of indices of comorbidity to be incorporated in the identification and explanation of determinants of outcome.

This paper aims to describe the development and utility of measures of comorbidity, using St. John Ambulance clinical data linked to WA Linked Database, for risk adjustment in survival following out-of-hospital ('ooh') cardiac arrest in Perth, WA. The ultimate purpose of this research was to answer the question 'does comorbidity affect survival outcomes in out-of-hospital cardiac arrest victims?

The WA Linked Database brought together, initially, 15 years of population–based mental health service data, hospital morbidity data, mortality records, cancer registrations and

midwives' notifications (over six million records) for the period 1980–1994 in WA.1 This was then extended to 1997 and is now updated on a regular basis. Figure presents the status of linkage as at October 2000. Linkages are identified using probabilistic matching,2 based on six Automatch (software package) passes with unit medical record number (unique only to teaching hospitals), surname, first given name, initial, data of birth, sex and address as the principal matching fields. Clerical checking of additional information is undertaken for possible matches that fall within a 'grey area' between definite matches and definite non-matches. The quality of the hospital morbidity data linkage has been assessed by a sampling technique to the percentage of invalid links (false positives) and missed links (false negatives) estimated to both be 0.11%.[1]

Cardiac arrest is defined as the cessation of cardiac mechanical activity, confirmed by the absence of a detectable pulse, unresponsiveness, and apnoea (or agonal, gasping respirations),[3] and whilst it can be caused by trauma, drowning and drug overdose, is often related to ischaemic heart disease. Comorbidity can be described as 'a clinical condition that exists before a patient's admission to the hospital, is not related to the principal reason for the hospitalisation, and is likely to be a significant factor influencing mortality and resource use in the hospital'.[4] There have been numerous papers published that describe cardiac arrest occurrence and outcome, however only one paper was found that has examined the effect of comorbidity on survival after out-of-hospital cardiac arrest.[5]

In 1999, the St John Ambulance Perth cardiac arrest database, consisting of 2,303 records of cardiac arrest calls attended (where the cause was presumed to be cardiac in nature) between January 1989 and December 1998 was linked to the morbidity and mortality files of the WA Health Services Research Linked Database,[1] using a probabilistic matching technique.[2] Since there is no unique person identifier that is used by both the Ambulance Service and the Linked Database, matching was based on personal and demographic identifiers including name and date of birth. Of the 2,303 people who experienced out-of-hospital cardiac arrests of presumed cardiac cause during 1996–98, 85% (1,936) of the ambulance records were linked to one or more hospital morbidity records for hospitalisations after 1980. The number of 'links' (ie separate hospitalisation episodes) in patient chains ranged from 1 to 449 records – the mean being 9.7 _ 16.8. An additional 220 ambulance records were linked to a death record but not a morbidity chain, resulting in a 94% linkage to a hospital and/or death record.

The most widely used summative measure of comorbidity reported in the literature is the Charlson index,[6] which is a weighted measure that takes into account the number and severity of comorbid diseases. It was generated empirically from relative risks of mortality in a cohort of medical patients (training population) where the adjusted relative risks were employed as weights for the different comorbid conditions, and validated on a cohort of breast cancer patients (testing population). The authors argued that it was " a prospectively applicable method for classifying comorbid conditions which might alter the risk of mortality for use in longitudinal studies".[6]

Charlson et al identified 30 individual comorbid diseases of which 17 had adjusted relative risks of one-year mortality above 1.2 and it was these conditions that were included in the index.[6, 7] The weight assigned for each condition is listed in Table and these weights were summed to form a single ordinal score (index) for each patient.[6] As shown, metastatic cancer and AIDS were assigned the highest weight, reflecting the high adjusted relative risks of one year mortality (6.3 and 7.4 respectively) associated with these conditions within the training population.[6] A higher Charlson index score is associated with greater comorbid burden and has been shown to be associated with a stepwise increase in observed mortality, even when the severity of index conditions was controlled.[6, 8]

An adaptation of the SPSS syntax[9] based on the Dartmouth-Manitoba algorithm,[7] developed by the Centre for Health Services Research at The University of Western Australia for risk adjustment in the analysis of vertically linked longitudinal data (using ICD codes), was used to generate a comorbidity index for each of the 2,303 patients with arrests of cardiac origin, in the SJA-WA database. Unlike the usual analysis situation where the index admission of interest is to be found within the data itself, not all ambulance attendances for cardiac arrest resulted in a hospital admission. Due to the high mortality rate associated with cardiac arrest, there was not necessarily a hospital morbidity record relating to the out-of-hospital cardiac arrest event. Therefore the usual syntax needed to be modified to accommodate the fact that a considerable time lag could exist between the last hospital morbidity record for the patient and the date of their cardiac arrest.

A further consideration in the development of the comorbidity index, based on recent work conducted by the UWA Centre for Health Services Research,[10] was the potential that including comorbid conditions relating to hospitalisations that occurred more than 12 months prior to the event of interest could result in an over-estimation of the comorbid effect, particularly for those conditions that may have subsequently resolved with treatment (eg peptic ulcer disease). It has thus become established practice within the Centre for Health Services Research to only include comorbid conditions identified within HMD records where the admission date is within a 12-month period immediately prior to the event of interest. However, given that the true relationship between duration of comorbid conditions and cardiac arrest outcome has yet to be established, the effect of extending the inclusion criteria for comorbid episodes of hospitalisation to various lengths of time beyond the immediate 12 months prior to the index cardiac arrest was examined and compared.

The comorbidity index generated based on hospitalisation records within one year of the cardiac arrest was compared with the value generated when based on two years, five years and ten years of previous hospital records. As shown in Figure , the number of cases with a comorbidity score of zero decreased progressively as the number of years of previous hospitalisation data included increased from one to ten years. Similarly, the proportion of cases with any comorbidity increased as the number of years of prior hospital records that were included

increased. However this relationship of increasing comorbid score with increasing numbers of years of hospital morbidity data included in the calculation tended to be more pronounced at the lower end of comorbidity scores.

The method adopted in the development of the comorbidity index was as follows. Any mention of the 17 diagnostic categories of the Charlson Index on any hospital morbidity record prior to the cardiac arrest date, with a separation date within 365 days of the date of the cardiac arrest, was counted as the presence of a comorbid condition. Where the time between the last hospital admission and the cardiac arrest date was greater than 365 days the Charlson index was set to zero. In addition, the cardiac arrest cases where no link to the hospital morbidity system was made were assumed to have had no previous hospitalisations and their Charlson Index set to zero.

The Friedman statistic, a non-parametric equivalent of a one-way repeated measures design, was used to test the null hypothesis that each of the four comorbidity indices generated have the same distribution.[11] The mean ranks for the one, two, five and ten-year comorbidity indices were found to differ significantly (_2 = 1769, 3df, p < 0.001), necessitating a decision to be made as to which one was the most 'appropriate' to use. The difference between an individual's comorbidity score based on 10 years of data versus one year of data ranged from 0 to 11, with a mean difference of 0.89, standard deviation of 1.40 and a median value of 0. Fifty-seven percent of the cases matched to the HMD had no difference between their comorbidity score based on ten years of data and that based on one year of data, 20% had a difference of a score of '1' and 12% had a difference of a score of 2.

A series of adjusted logistic regression models of cardiac arrest survival were performed, varying the number of years of morbidity data included in the comorbidity index. Fractional polynomials were used to account for the non-linearity of the comorbidity score. Model performance was assessed by the log likelihood and area under the ROC curve and showed little difference in model performance irrespective of the number of years included in the index. Given the previous work of the Centre for Health Service Research, which favours limiting previous hospital records to those within one year of the event of interest, coupled with the fact that no empirical reason could be shown to do otherwise, the Charlson comorbidity index used in this research was based on one year of previous hospitalisation data.

The 1996–1998 cohort of cardiac arrests of presumed cardiac origin (n=2,303) formed the basis for the analysis of the effect of comorbidity on survival, adjusting for ambulance response time, initial arrest rhythm, bystander CPR, age and gender. Overall, the Charlson scores ranged from 0 to 11, with over two-thirds of cases scoring zero (see Table). Logistic regression techniques were used to estimate the relationship between comorbidity and outcome, with fractional polynomials used to model the nonlinearity in comorbidity scores. Models were assessed using formal tests of model discrimination and calibration such as the c-statistic and the likelihood ratio chi-squared statistic and the results for several distinct sub-sets of the data were compared.

For cardiac arrests of presumed cardiac origin where resuscitation was attempted (n=851), the multivariable adjusted best-fit fractional polynomial model (Figure) showed that survival was actually better for those cases with some comorbidity rather than no comorbidity (ie score = 0), although this 'advantage' became less pronounced as the comorbidity increased above scores of 2 to 3.

The association between a comorbidity score of one (ie 'some' comorbidity) and improved survival compared with those without any comorbidity (ie a score of zero) led to consideration that perhaps the inclusion of heart disease (specifically MI and heart failure) in the generation of the Charlson index might account for the somewhat spurious results. This was further supported by the finding that in 43% of the 276 people with a Charlson score of one, the diagnostic category involved was 'Myocardial Infarction'. In order to quantify the effect of the inclusion of heart disease on the performance of the comorbidity index in the model of cardiac arrest survival, the Charlson index was re-calculated, excluding the diagnostic categories 'Myocardial Infarction' and 'Congestive Heart Failure' (see Table). When compared with the original Charlson scores, the 'new' method of generating the Charlson index resulted in a greater number of scores of zero (73% versus 67% previously). A similar number of cases had a Charlson score of one (12%), however the predominant diagnostic category shifted from 'myocardial infarction' to 'diabetes (mild to moderate)'. As was previously found, the plot of the multivariable adjusted fractional polynomial curve of the Charlson index (without MI or HF) against survival showed a small rise in survival as the score increased from zero to one, before decreasing with increasing comorbid scores.

It was found that cases with a score of one still had a slightly better chance of survival than those with a score of zero. However when survival rates between cases with a score of one were compared with those with a score of zero, there was no statistically significant difference observed (_2(1) = 0.4, p=0.52). This contrasts with the statistically significant differences in survival observed between cases with a Charlson score of zero (5%) and one (12%), calculated with the inclusion of myocardial infarction and heart failure (_2(1) = 7.3, p=0.007). Moreover, a logistic regression model adjusted for age, gender, response time, bystander-witness status, bystander-CPR and initial cardiac rhythm showed a statistically significant relationship between hospital admission related to Ischaemic Heart Disease (ICD–9 410–414) within 12 months of the arrest and improved survival (OR =2.08, 95% CI = 1.01–4.30, p=0.05).

Thus the exclusion of the diagnostic categories relating to heart disease in the generation of the Charlson index failed to eliminate all of the rise in survival percentage associated with a comorbidity score of one. However, what did change was that there was no longer a statistically significant difference in survival in those with a comorbidity score of one compared with those with a score of zero. Nonetheless, the 'new' comorbidity index still did not significantly improve the predictive ability of the multivariate adjusted model of cardiac arrest

outcome. There was minimal difference in the log likelihood of the model with the 'new' comorbidity index included (–2LL = 365.5) compared to the model without it (–2LL = 365.8). Similarly, the area under the ROC curve remained essentially the same (approximately 72%) for both models.

It was concluded that the inclusion of heart disease related conditions in the generation of the original Charlson index contributed to (but did not totally explain) the potentially spurious association between a Charlson score of one and improved survival following cardiac arrest. Notwithstanding the significance of this finding, it was still considered appropriate to include MI and HF in the generation of the Charlson comorbidity index for two reasons. Firstly, within the pre-hospital context an arrest is classified as being due to cardiac causes based on exclusion of other obvious causes, rather than on any definitive diagnostic method. Thus it is quite feasible that some arrests classified as cardiac in cause are in fact not. In any case, ischaemic heart disease is not the only cardiovascular related condition that can give rise to a cardiac arrest. The second reason why MI and HF were included in the generation of the Charlson index was that to do otherwise would be to deviate from the method used by other researchers and thus reduce the potential for evaluation of the performance of the Charlson index across different clinical contexts.

In a separate line of enquiry comorbidity was shown to contribute to the 'explanation' of the well-documented but poorly understood phenomena of location of arrest (at home/not at home) affecting survival. Previous research has demonstrated a relationship between location of cardiac arrest and outcomes, with arrests occurring at the victim's home address having a worse prognosis than those who arrest elsewhere.[12, 13] Several reasons have been postulated for this association, including the possibility that general health status is poorer in those arresting at home. The argument posited is that patients with significant medical disease are less likely to venture far from home and hence their chance of sustaining a cardiac arrest at home is greater.[13] However, there has been a paucity of studies that have been able to explore this possible relationship further.

Within the Perth data for arrests of cardiac origin that occurred before the arrival of the ambulance and where resuscitation was attempted (n=1,078), a statistically significant difference was found between arrests occurring away from the patient's home (9.6% survival) compared with those persons whose arrest occurred at home (3.7%). Of note was that the mean Charlson score was statistically significantly higher (p=0.02) in those arresting at home (0.83 ± 1.03) compared with away from home (0.49 ± 1.61). Moreover, when the Charlson score was added to the adjusted model of survival, location of arrest ceased to be a significant predictor of survival.

In conclusion, no statistically significant association was found between the Charlson comorbidity score and survival, irrespective of whether or not heart disease was included in the generation of the index. There was some variation in the Charlson comorbidity scores between survivors and non-survivors of out-of-hospital cardiac arrests, however there was no dramatic improvement in the ability to predict outcome by the inclusion of the Charlson comorbidity index in logistic regression models of survival. Of note however, was the seemingly counterintuitive finding that the likelihood of survival was higher for those victims with some comorbid history as compared to those with no previous comorbidity (as estimated by the Charlson score), which was subsequently found to be predominantly (but not totally) due to the inclusion of heart disease in the generation of the comorbidity index.

More specifically, a history of hospitalisation with mention of IHD within 12 months of the arrest was found to be associated with a two-fold increase in the likelihood of survival. A plausible explanation for this association could not be found in differences in patient and/or arrest characteristics. Notwithstanding the possibility of it being artifactual, one possible explanation might be that persons with known pre-existing heart disease could have been prescribed medications and/or subjected to other therapeutic interventions (such as re-vascularisation procedures) that mitigated in favour of survival from a cardiac arrest. Alternatively, it might be that a different pathophysiology underpins cardiac arrests in patients with existing IHD, which likewise results in a greater likelihood of survival.

This presentation has demonstrated the utility of data linkage of ambulance clinical data to hospital morbidity data and death records in the estimation of comorbid status of out-of-hospital cardiac arrest patients. Data linkage has permitted the inclusion of an index of comorbidity in multivariate models of survival and thus facilitated risk adjustment for comorbidity. The use of linked data has also served to highlight a possible hitherto unidentified relationship between 'recent' past history of hospitalisation for IHD and improved survival following out-of-hospital cardiac arrest.

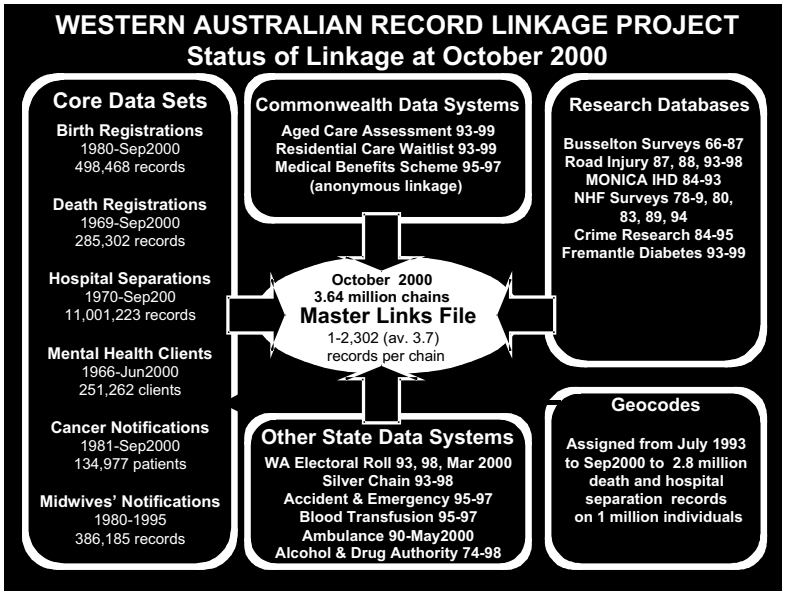
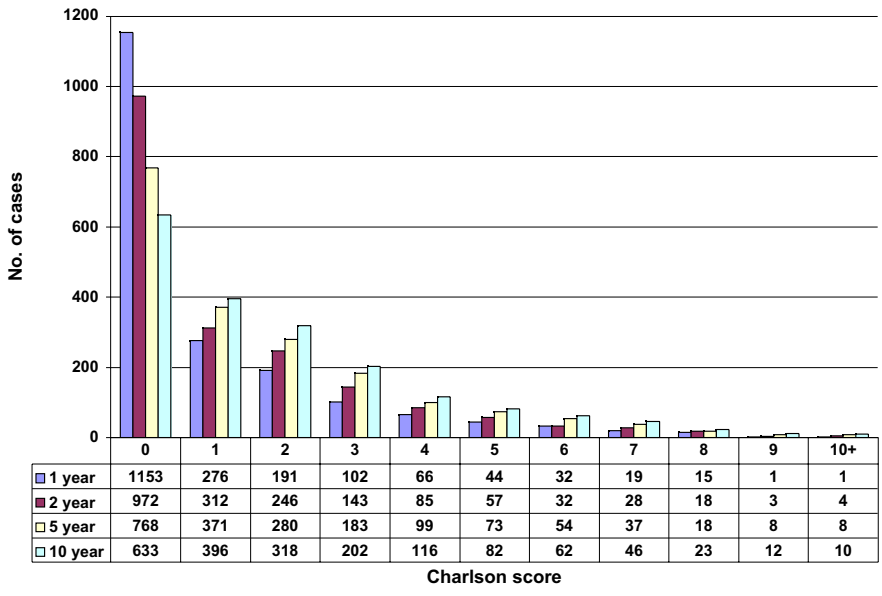


Figure 1 Status of Linkage of the Western Australian Health Services Research Linked Database at October 2000.

Diagnostic category	Weight [6]	Dartmouth-Manitoba ICD-9-CM codes [7]
Myocardial Infarction	1	410.xx, 412
Congestive heart failure	1	402.01, 402.11, 402.91, 425.x, 428.x, 429.3, 404.01, 404.03, 404.11, 404.13, 404.91, 404.93
Peripheral vascular disease	1	440.x,441.x, 442.x, 443.1-443.9, 447.1, 785.4, 38.13-38.14(P), 38.16(P), 38.18(P), 38.33-38.34(P), 38.36(P), 38.38(P), 38.43-38.44(P), 38.46(P), 38.48(P), 39.22-39.26(P), 39.39(P)
Cerebrovascular disease	1	362.34, 430-436, 437-437.1, 437.9, 438, 781.4, 784.3, 997.0, 38.12(P), 38.42(P)
Dementia	1	290.x, 331-331.2
Chronic pulmonary disease	1	415.0, 416.8-416.9, 491.x-494, 496
Rheumatologic disease	1	710.x, 714.x
Peptic ulcer disease	1	531.xx-534.xx
Mild liver disease	1	571.2, 571.5-571.6, 571.8-571.9
Diabetes (mild to moderate)	1	250.0x-250.3x
Diabetes with chronic complications	2	250.4x-250.9x
Hemiplegia or paraplegia	2	342.x, 344.x
Renal Disease	2	585-586, V42.0, V45.1, V56.x, 39.27(P), 39.42(P), 39.93-39.95(P), 54.98(P)
Any malignancy, including lymphoma and leukaemia	2	140.x-171.x, 174.x-195.x, 200.xx-208.x, 273.0, 273.3, V10.46, 60.5(P), 62.4-62.41(P)
Moderate or severe liver disease	3	572.2-572.4, 456.0-456.2x, 39.1(P), 42.91(P)
Metastatic solid tumour	6	196.x-199.x
AIDS	6	042.x-044.x

Table 1 ICD–9-CM codes for Charlson comorbidity index as per the Dartmouth-Manitoba adaptation and the index weights for each condition as originally described by Charlson



	0	1	2	3	4	5	6	7	8	9	10+
1 year	1153	276	191	102	66	44	32	19	15	1	1
2 year	972	312	246	143	85	57	32	28	18	3	4
5 year	768	371	280	183	99	73	54	37	18	8	8
10 year	633	396	318	202	116	82	62	46	23	12	10

Figure 2 Comparison of the value of the Charlson comorbidity index generated based on one, two, five and ten years of previous hospitalisation records

Note: Only those SJA-WA cardiac arrest cases for 1996–1998 that were linked to a hospital morbidity record (n= 1936) were included in this analysis.

Charlson Score	Frequency	Percent
0	1,556	68%
1	276	12%
2	191	8%
3	102	4%
4	66	3%
5	44	2%
6	32	1%
7	19	1%
8	15	1%
9	1	.%
10+	1	.%
	2,303	**100%**

Table 2 Distribution of Charlson scores based on one year of hospital records prior to the cardiac arrest

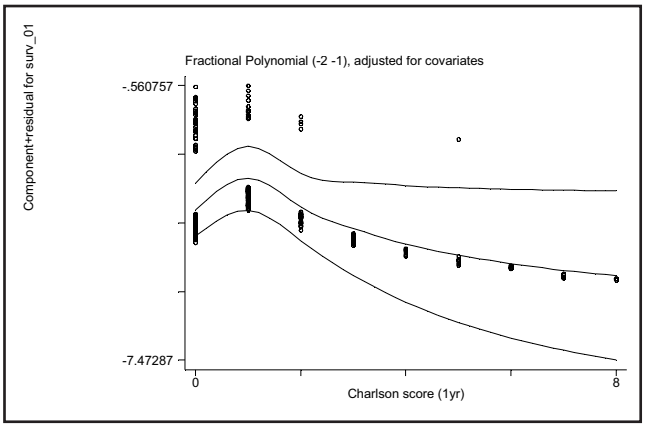


Figure 3 Plot of the multivariable adjusted fractional polynomial curve of the Charlson index against survival for cardiac arrests of cardiac aetiology where resuscitation was attempted, excluding EMS witnessed arrests (n = 851)

References

1 Holman C.D., Bass A.J., Rouse I.L., Hobbs M.S. Population-based linkage of health records in Western Australia: development of a health services research linked database. Aust N Z J Public Health 1999;23(5):453–9.

2 Jaro M.A. Probabilistic linkage of large public health data files. Stat Med 1995;14(5–7):491–8.

3 Cummins R.O., Chamberlain D.A., Abramson N.S., Allen M., Baskett P.J., Becker L., et al. Recommended guidelines for uniform reporting of data from out-of- hospital cardiac arrest: the Utstein Style. A statement for health professionals from a task force of the American Heart Association, the European Resuscitation Council, the Heart and Stroke Foundation of Canada, and the Australian Resuscitation Council. Circulation 1991;84(2):960–75.

4 Elixhauser A., Steiner C., Harris D.R., Coffey R.M. Comorbidity measures for use with administrative data . Medical Care 1998;36(1):8–27.

5 Hallstrom A., Boutin P., Cobb L., Johnson E. Socioeconomic status and prediction of ventricular fibrillation survival. Am J Public Health 1993;83(2):245–8.

6 Charlson M.E., Pompei P., Ales K.L., MacKenzie C.R. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chronic Dis 1987;40(5):373–83.

7 Romano P.S., Roos L.L., Jollis J.G. Adapting a clinical comorbidity index for use with ICD–9-CM administrative data: differing perspectives. J Clin Epidemiol 1993;46(10):1075–9; discussion 81–90.

8 D'Hoore W., Bouckaert A., Tilquin C. Practical considerations on the use of the Charlson comorbidity index with administrative data bases. J Clin Epidemiol 1996;49(12):1429–33.

9 Holman C. SPSS syntax to derive Charlson comorbidity index using the Dartmouth-Manitoba algorithm. Perth: Centre for Health Services Research, The University of Western Australia; 1998.

10 Holman C. The effect of recency of comorbid hospitalisation in relation to the event of interest on the validity of the Charlson index as a risk-adjustment tool.; 2001.

11 Riffenburgh R.H. Statistics in Medicine. San Diego: Academic Press; 1999.

12 Litwin P.E., Eisenberg M.S., Hallstrom A.P., Cummins R.O. The location of collapse and its effect on survival from cardiac arrest. Ann Emerg Med 1987;16(7):787–91.

13 Jackson R.E., Swor R.A. Who gets bystander cardiopulmonary resuscitation in a witnessed arrest? Academic Emergency Medicine 1997;4(6):540–4.