Assessing equitable and efficient solutions to reduce hospital demand

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- Despite the development of evidence-based clinical guidelines for a wide range of clinical conditions, there is significant variation in clinical practice across alternative hospitals.
- The aim of this study was to develop a generic method that uses routinely collected data to compare the costs and benefits of alternative forms of clinical practice.
- The developed method is labelled risk adjusted cost-effectiveness (RAC-E), referring to the need to adjust for differences in casemix (i.e. risk of high costs and/or bad outcomes).

Methods

- A dataset was assembled that comprised linked, routinely collected hospital separations data, area level socioeconomic data, and mortality data. The dataset grouped hospital separations and date of death (where applicable) for individual patients, which inform event pathways.
- Priority areas for investigation were specified based on evidence suggestive of variation in practice.
- RAC-E involves the estimation of long-term costs and survival for individual patients, which is compared to expected costs and survival to generate net costs and survival. Mean net costs and survival are compared across groups (e.g. hospitals) to identify cost-effective clinical practice.
- RAC-E was analysed in the clinical areas of stroke, chest pain, and hip fracture for the year to July 2006, as well as for two community-based programs and a preoperative clinic for high risk patients.

Results

- Significant differences in RAC-E were identified across the four main public hospitals in SA:
  - For stroke, two hospitals had higher net costs and lower net survival than at least one other (i.e. these hospitals were dominated). Of the other hospitals, if all patients were to be treated at the more effective hospital, additional life years could be gained at a cost of $16,068 per life year.
  - For patients presenting with chest pain, two hospitals were dominated, and the more effective hospital gained additional life years at an incremental cost of $2,909.
  - For hip fracture, two hospitals were dominated, and the more effective hospital had a mean incremental cost per life year gained of $31,243.
- Preliminary analyses to identify specific areas of variation in clinical practice were undertaken using the technique of process mining, and some potentially important differences in clinical practice for patients presenting with chest pain were identified.

Conclusions

- RAC-E provides an empirical basis for defining cost-effective clinical practice, which can be applied across wide areas of clinical practice at relatively low cost.
- Further refinement of the RAC-E methodology is required (and ongoing), but the existing methodology generates robust estimates of the consequences of variation in clinical practice, which in combination with pathway methods, provides a powerful research tool to inform and encourage the adoption of cost-effective clinical practice.
- To facilitate the routine use of RAC-E to improve policy and practice, easier access to more detailed and more contemporary data would be of great value.

EXECUTIVE SUMMARY

Despite the development of evidence-based clinical guidelines for a wide range of clinical conditions, there is significant variation in clinical practice across alternative hospitals (Board & Watson 2010). A robust methodology using linked, routinely collected data (including registry data, where available) to analyse the relative costs and benefits of clinical practice at different hospitals would enable the identification of best clinical practice across a wide range of diagnostic areas. Such cost-effectiveness data, in combination with additional analyses of process (using mainly routinely collected data), is hypothesised to provide strong incentives to underperformers to improve. This will lead to the more efficient use of scarce hospital resources, meaning more health benefits will be derived from current health care budgets. In some cases, separation costs per patient will be reduced, thus reducing hospital demand and enabling hospitals to treat more patients more quickly with existing budgets.

The aim of this study was to develop and apply a robust methodology using routinely collected data to analyse the relative costs and benefits of clinical practice at alternative hospitals, across a wide range of diagnostic areas.

Data

Routinely collected data was obtained and linked from the following sources:

- **Hospital separation data:**

  4,072,341 records from the Integrated South Australian Activity Collection (ISAAC), describing patient and admission characteristics, for all public and private hospital separations in South Australia (SA) from 2001 to 2008.

  Socioeconomic data:

  Area (postcode) level variables describing socioeconomic areas, socioeconomic disadvantage, economic resources, and education and occupation.

  Costing data:

  1,530,634 separation-specific cost estimates at the four largest hospitals in SA from 2003 to 2008.

- **All-cause mortality data:**

  92,288 deaths from the Register for Births, Deaths, and Marriages between 2001 and 2008.

The resulting dataset grouped hospital separations and date of death (where applicable) for individual patients, which inform event pathways.

Identifying priority areas for investigation

Using the data described above, a process was developed to prioritise conditions for investigation. The criterion for further investigation was specified as evidence suggestive of variation in practice. Analysis of changes in activity and costs over time, as well as comparisons of mean separation costs across the four key public hospitals were undertaken, and individual meetings with a range of clinical experts assisted with the interpretation of analyses.

Stroke and chest pain were selected for the first applications of the RAC-E framework, as both patient cohorts had large increases in admission rates over the observation period, especially for chest pain (+75%). The total costs expended on the two patient groups were significant, and the mean costs of the most costly hospitals were approximately double the costs of the least costly hospitals for both conditions.

The following eight key conditions were also selected for further analysis: hip replacement, transient ischaemic attack, headache, lens procedures sameday, chronic obstructive airways disease, implantable cardioverter defribillator, cardiac pacemaker, and percutaneous coronary intervention.

Risk adjusted cost-effectiveness (RAC-E)

The framework for the comparative analysis of the costs and benefits of clinical practice was labelled risk adjusted cost-effectiveness (RAC-E), highlighting the need to adjust for differences in the casemix of patients treated at different hospitals (i.e. risk of high costs and/or bad outcomes).

Using the chest pain case study to illustrate, the analytic framework is summarised as the following six stage process:

1. A cohort of eligible patients is defined as all patients with a principal diagnosis of chest pain who were admitted to any of the four main public hospitals in SA within a defined time period.
2. A set of intermediate outcomes is defined (e.g. cardiac-related readmission, death, or no related event). Using the linked data for the eligible patient cohort, each patient is assigned to one of the intermediate outcomes over a defined (retrospective) observation period (e.g. 2 years from the admission date for the chest pain separation).
3. Using the full set of linked data for all chest pain patients, separate regression models are developed to predict future costs and mortality on the basis of relevant patient characteristics (e.g. age, co-morbidities, socioeconomic status) and the intermediate endpoints.
4. Combining the observed and predicted data, each patient is assigned a *predicted* lifetime cost and a survival (life years gained) estimate.
5. Using the lifetime cost and survival estimates for the eligible patient cohort, separate regression models are developed to derive *expected* lifetime costs and survival on the basis of relevant patient characteristics at the time of the initial chest pain admission (e.g. age, co-morbidities, socioeconomic status).
6. Each eligible patient is assigned a net cost and a net benefit value, estimated as *predicted* minus *expected* lifetime costs and survival, respectively. The net costs and benefits are summed across all eligible patients at each of the four hospitals to calculate the mean net costs and benefits at each hospital. The mean net costs and benefits are compared across the hospitals to identify the hospital with the most cost-effective practice.

RAC-E applications

Results of applied RAC-E analyses in the clinical areas of stroke, chest pain, and hip fracture are reported below. The main report describes further RAC-E analyses of two community-based programs, a preoperative clinic for high risk patients, and clinical practice for amputation.

Table I presents the mean results for the comparative analysis of clinical practice for patients presenting with stroke across the four main public hospitals in SA in the year to July 2006. For both hospitals B and C, at least one other hospital had lower net costs and higher net survival (i.e. these hospitals were dominated). Of the remaining hospitals, if patients currently treated at hospital D were to be treated at hospital A, we could gain additional life years at a cost of $16,068 per life year. Uncertainty analyses showed that if we are willing to invest $50,000 to gain additional life years, hospital A has a 65% probability of being the most cost-effective hospital.

Table I. Risk adjusted cost-effectiveness (RAC-E) results for patients presenting with Stroke

Hospital	Unadjusted separation costs	Net lifetime costs per patient	Net life years gained per patient	Notes
B	$ 12,762	$ 179	-0.24	Dominated by hospital D
C	$ 11,479	$ 1,412	-0.18	Dominated by hospitals A & D
D	$ 6,329	-$ 4,698	0.05	
A	$ 10,771	$ 335	0.36	
		Cost difference	**LYs difference**	**Incremental cost per LY gained**
A vs D		$ 5,033	0.31	$ 16,068

For patients presenting with chest pain, hospitals 3 and 4 were dominated, and hospital 1 gained additional life years at an incremental cost of $2,909 compared to hospital 2. At a value of $25,000 per life year gained, hospital 1 has a 99% probability of being the most cost-effective hospital.

For hip fracture, hospitals B and D were dominated. Hospital A had a mean incremental cost per life year gained of $31,243 relative to hospital C. At a life year value of $50,000, hospital A had the largest expected net benefits and a 35% probability of being the most cost-effective hospital.

Investigating determinants of variation in RAC-E

Preliminary analyses to identify specific areas of variation in clinical practice were undertaken. In chest pain, for example, the hypothesis was generated that cost-effective clinical practice involved more nursing time and medical intervention, with less test ordering.

More detailed analyses of process are required, and so ongoing research is investigating alternative approaches to the comparative analysis of clinical practice. As with the application of RAC-E, the underlying objective is to facilitate widespread application across multiple hospitals, without the need for the collection of large amounts of additional data. Preliminary analyses using the technique of process mining have identified some potentially important differences in clinical practice as applied to patients presenting with chest pain.

Conclusions

The significance of the developed RAC-E methodology is that it provides an empirical basis for defining cost-effective clinical practice (practice-based evidence). The use of routinely collected data means that RAC-E can be applied across wide areas of clinical practice at relatively low cost.

Further refinement of the RAC-E methodology is required (and ongoing). In particular, further exploration and application of process mining is required to define optimal, and preferably standardised, approaches to the validation of evidence of variation in RAC-E.

However, the existing methodology generates robust estimates of the consequences of variation in clinical practice (i.e. differences in costs and outcomes), which in combination with pathway methods, such as process mining (to identify specific areas of variation) provides a powerful research tool to inform and encourage the adoption of cost-effective clinical practice.

To facilitate the routine use of RAC-E to improve policy and practice, easier access to more detailed and more contemporary data for both RAC-E analyses and process mining would be of great value.

FULL REPORT

1 BACKGROUND

Clinical practice involves the delivery of individual technologies used in the diagnosis, acute treatment, rehabilitation, and/or long-term care of patients. Despite published guidelines in many clinical areas, there is evidence of significant variation in clinical practice at alternative institutions (e.g. hospitals), as reflected in a recent supplement of the Medical Journal of Australia (Board & Watson 2010).

To date, analyses of clinical practice have focused on frontier efficiency measurement of hospital performance at an aggregate hospital level, and with relatively crude approaches to incorporating health outcomes (Agency for Healthcare Research Quality 2008; Hollingsworth 2008).

Recognition of the potential value of linked routinely collected data as an asset to research has been growing over the last decade (House of Lords 2001), but recent developments appear to herald a new era in the availability and access to such data. In Australia, the Population Health Research Network has received over Aus$60 million from Federal and State governments to establish linked access to de-identified data from a wide range of health datasets. In the UK, as part of the Research Capacity Programme, a pilot Health Research Support Service was due to begin providing widespread access to linked patient data in Autumn 2010.

The increasing availability of linked routinely collected data provides a valuable data source that will no doubt lead to improvements in frontier efficiency methods, which could certainly be applied at a condition level to support the identification of best practice. However, it is not certain whether they are needed in this context. By defining best practice as cost-effective practice, it seems apparent that such judgments should be made on the same basis as judgements of the cost-effectiveness of new health technologies, and that there is already a highly developed set of analytic tools available for that purpose.

A robust methodology using linked, routinely collected data (including registry data, where available) to analyse the relative costs and benefits of clinical practice at different hospitals would enable the identification of best clinical practice across a wide range of diagnostic areas. Such cost-effectiveness data, in combination with additional analyses of process (using mainly routinely collected data), is hypothesised to provide strong incentives for underperformers to improve. This will lead to the more efficient use of scarce hospital resources, meaning more health benefits will be derived from current health care budgets. In some cases, separation costs per patient will be reduced, thus reducing hospital demand and enabling hospitals to treat more patients more quickly with existing budgets.

In other cases, some additional upfront resources may be required at particular hospitals to support the improved use of existing technologies. In these cases, cost-effectiveness analyses of clinical practice will inform the value of allocating resources to facilitate improvement in clinical practice relative to the value of investments in new technologies.

This report describes the development and application of a general methodology using linked, routinely collected data to analyse the risk adjusted cost-effectiveness (RAC-E) of clinical practice for specific diagnostic areas at different hospitals. RAC-E provides a means of extrapolating costs and outcomes to ensure all important differences are captured, whilst controlling for variation in relevant risk factors to ensure that one hospital does not appear superior to another simply on the basis of their treating subjects with differing casemix. As part of the RAC-E framework, we recognise the need to combine analyses of cost-effectiveness with comparative analyses of process, and preliminary work is also reported around the

development of methods using routinely collected data to compare processes. Following a description of the RAC-E methods, three case studies comparing different areas of clinical practice at the four main public hospitals in South Australia are presented to illustrate the methodology.

2 METHODS

The following sections describe the components of the RAC-E analysis, including the data, the analytic structure, the component regression models, and the final analyses undertaken to estimate the relative cost-effectiveness of clinical practice at alternative hospitals and to represent the uncertainty around the mean results. All analyses were undertaken using Stata, release 11.0 (StataCorp 2009).

2.1 DATA LINKAGE

Data sources

Routinely collected data was obtained and linked from the following sources:

- **Hospital separation data:**

  4,072,341 records from the Integrated South Australian Activity Collection (ISAAC), describing patient, admission, and inpatient stay characteristics, including diagnosis related group (DRG), principal and additional diagnoses, and procedure codes, for all hospital separations in SA from July 2001 to June 2008. For risk adjustment, co-morbidities were coded using the same performance indicators as defined by Queensland Health in their application of the Variable Life Adjusted Display (VLAD) methodology (Duckett *et al.* 2008), based on recorded principal and additional diagnoses in the year preceding the index event.

- **Socioeconomic data:**

  Area (postcode) level variables describing socioeconomic areas, socioeconomic disadvantage, economic resources, and education and occupation. Variables were created that represented the Indices as continuous variables (scores), and as categorical variables (placing scores into deciles).

- **Costing data:**

  1,530,634 separation-specific cost estimates at the four largest hospitals in SA from July 2003 to June 2008, presented in 16 categories covering direct and indirect ward, surgery, allied health, diagnostics, pharmacy, and prostheses related costs.

- **All-cause mortality data:**

  92,288 deaths from the Register for Births, Deaths, and Marriages between July 2001 and December 2008.

Linkage process

The two main data linkage tasks involved defining the linkages within the ISAAC hospital separations dataset, and linking the mortality data to the ISAAC data. The cost data contained identifiers that matched directly to specific inpatient separations, and so no linkage was required. Patient-level costs (State Cost Weight Database) or year-specific DRG costs (where patient-level costs were unavailable) were used.

Within the ISAAC hospital separations data, the aim was to identify sets of separations experienced by individual patients. Available patient identifiers included date of birth, gender, postcode and encrypted

Medicare number (a unique ten digit number assigned to Australians to manage the health care rebate system). Patient names were not available due to ethics constraints.

During the linkage of the de-identified hospital data, the following actions were taken as part of the data cleaning and linkage process:

1. **Date of birth**

   Potential errors in recorded date of birth were corrected, focusing on one-digit data entry errors. The correction process specified that if the encrypted Medicare number, year of birth and gender were the same, and there was only a one-digit error in the month of birth, the recorded separations were assumed to be for the same patient.

2. **Medicare numbers**

   Medicare numbers were assumed to be for the same patient if:

   - encrypted Medicare number, date of birth and gender were the same
   - separations where encrypted Medicare numbers differed only by the last digit but the date of birth, gender and postcode were the same, as the last digit change could be due to Medicare card renewal or reissue.

   Deterministic approaches were developed to correct potential Medicare number data entry errors and to assign numbers to separations with missing Medicare numbers, but in the first instance no further adjustments were made to the data, and separations with missing Medicare numbers were deleted from the dataset. 369,574 (9%) separations without a recorded Medicare number were excluded from the Master dataset.

3. **Simultaneous admissions**

   There were cases where multiple separations had the same encrypted Medicare number, date of birth, gender, postcode, admission date and admission time. Most were duplicates with some triplicates. All simultaneous admissions were manually checked to determine which separation to keep (only one separation was kept). Examples of reasons for deletion were:

   - Patient was transferred to another hospital
   - Earlier separation date or time
   - Non-specific principal diagnosis
   - Less severe principal diagnosis
   - Missing Medicare number

4. **Other issues**

   - There were cases where a date of death was followed by another hospital separation, which could be due to same-sex twins where one twin had died. In such cases, all separations for that PIV were deleted from the dataset.
   - Non-South Australian postcodes were excluded
   - Dates of death were adjusted for separations where patients died in hospital but no date of death was recorded

In total 455,222 separations were excluded from the final dataset. The remaining 3,617,119 separations were assigned to individual patients using the (corrected) date of birth, gender, and Medicare number variables to form a single patient identification variable (PIV), and separations with the same PIV were assigned to the same patient.

Linkage of the ISAAC data to the mortality data was undertaken by staff within the State Department of Health, who had access to patient names. Manual checks of the results of a probabilistic linkage revealed significant uncertainty around many linkages, which led to a process of manual linkage for around 66,000 of the 92,288 mortality records, with reference to the Electoral register for confirmation of many identified linkages.

Postcode variables were used to merge socioeconomic indicators into the Master dataset.

A link_id number was assigned to each separation (record) in the master dataset so the master dataset could be split into smaller datasets for analysis whilst still maintaining linkages.

Ethical approval for this project was granted by the SA Health Human Research Ethics Committee (HREC protocol no: 264-11-2011).

2.2 AREAS FOR INVESTIGATION

Analysis of non-linked ISAAC data

A process was developed to identify, select and prioritise conditions for investigation. The criterion for further investigation was specified as evidence suggestive of variation in practice, either over time (temporal variation) or between hospitals (geographic variation). The prioritisation process involved initial analysis of the unlinked hospital separations data (ISAAC) and aggregate DRG cost estimates, followed by discussion of the analysis with clinical experts across a range of specialties to identify potential causes of the observed variation.

The dataset was analysed by Australian Refined Diagnosis Related Groups (AR-DRGs) to identify those DRGs with the greatest variation in numbers of separations and bed days over time (indicating changes in practice). Changes in costs and bed days for the corresponding 3-digit DRG stems, as well as related DRG groups (e.g. F70 and F71 – major and non-major arrhythmia, respectively), were also investigated to check that costs and/or bed days had not been transferred across DRG codes.

Table 1 presents a selection of the top ranked diagnostic related groups (DRGs) with respect to absolute increases in costs and occupied bed days in South Australia over the period 2001-02 to 2006-07.

Two high profile cardiac DRG codes – percutaneous coronary intervention (F10Z) and chest pain (F74Z) accounted for additional annual costs of over $9 million, and over 6000 additional bed days per year. Very large increases were also observed for implantation or replacement of automatic implantable cardiac defibrillator (AICD) (F01), which had increased costs of over $5.6 million across the stem DRG.

Chronic Obstructive Airways Disease (E65A) has a similarly large increase in activity (+ $4.2 million and 4,734 bed days per year). However, there appears to be some movement between respiratory related DRGs – activity declined in the respiratory infections (E62), other respiratory system (E02) and bronchitis and asthma (E69) DRGs. Across six related respiratory DRG stems (E02, E62, E65, E67, E69, and E74), there were actually reductions in the aggregate annual costs and bed days of $2.266 million and 4,034, respectively.

Caesarean delivery annual costs increased significantly – by almost $5.7 million across the O01 DRG stem. Vaginal delivery costs also increased, though associated occupied bed days decreased by over 1,500 per year.

Table 1. Top DRGs ranked by change in costs and occupied bed days between 2001-02 and 2006-07

DRG	DRG Description	DRG		Change in annual bed days	DRG 3-digit stem		Change in annual bed days
		Change in annual costs	% change in costs		Change in annual costs	% change in costs	
F10Z	Percutaneous Coronary Intervention W AMI	$ 4,710,664	123%	1,852			
F74Z	Chest Pain	$ 4,671,624	72%	4,329			
E65A	Chronic Obstructive Airways Disease W Catastrophic or Severe CC	$ 4,237,080	40%	4,734	$ 4,627,470	27%	3,871
U63A	Major Affective Disorders Age >69 or W (Catastrophic or Severe CC)	$ 3,982,590	54%	431	$ 3,061,005	11%	2,669
F01A	Implantation or Replacement of AICD, Total System W Cat or Sev CC	$ 3,927,597	266%	632	$ 5,627,053	256%	770
O01C	Caesarean Delivery W/O Catastrophic or Severe CC	$ 3,737,280	24%	1,700	$ 5,693,916	23%	2,827
G02A	Major Small and Large Bowel Procedures W Catastrophic CC	$ 2,805,488	33%	2,541	$ 3,201,686	24%	2,495
G67B	Oesophagitis, Gastroent & Misc Digestive Systm Disorders Age>9 W/O Cat/Sev CC	$ 2,465,658	40%	3,073	$ 4,332,040	42%	5,573
O60B	Vaginal Delivery W/O Catastrophic or Severe CC	$ 2,306,895	9%	-512	$ 2,011,775	5%	-1,554
J64B	Cellulitis (Age >59 W/O Catastrophic or Severe CC) or Age <60	$ 2,235,352	36%	3,118	$ 2,350,680	28%	3,763
Q61C	Red Blood Cell Disorders W/O Catastrophic or Severe CC	$ 2,138,514	79%	2,257	$ 2,348,645	42%	3,076
K01Z	Diabetic Foot Procedures	$ 2,040,766	60%	1,879			
G67A	Oesophagitis, Gastroent & Misc Digestive System Disorders Age>9 W Cat/Sev CC	$ 1,866,382	44%	2,500	$ 4,332,040	42%	5,573
E71A	Respiratory Neoplasms W Catastrophic CC	$ 1,806,462	58%	2,480	$ 1,736,096	24%	1,721
B70A	Stroke W Catastrophic CC	$ 1,797,494	26%	1,697	$ 985,694	6%	-665
F04A	Cardiac Valve Proc W CPB Pump W/O Invasive Cardiac Inves W Cat CC	$ 1,655,676	55%	523	$ 2,214,916	49%	614
I08A	Other Hip and Femur Procedures W Catastrophic or Severe CC	$ 1,450,176	17%	1,090	$ 1,713,720	14%	786
F73B	Syncope and Collapse W/O Catastrophic or Severe CC	$ 1,424,664	71%	1,781	$ 2,565,024	66%	3,662
I03B	Hip Replacement W Cat or Sev CC or Hip Revision W/O Cat or Sev CC	$ 1,419,450	15%	895	$ 1,591,159	8%	768
F71B	Non-Major Arrhythmia and Conduction Disorders W/O Catastrophic or Severe CC	$ 1,184,895	34%	1,764	$ 1,890,459	32%	2,959
F73A	Syncope and Collapse W Catastrophic or Severe CC	$ 1,140,360	61%	1,881	$ 2,565,024	66%	3,662
G60A	Digestive Malignancy W Catastrophic or Severe CC	$ 422,994	15%	1,770	$ 82,379	2%	1,099
U63B	Major Affective Disorders Age <70 W/O Catastrophic or Severe CC	-$ 921,585	-4%	2,238	$ 3,061,005	11%	2,669

AMI - acute myocardial infarction; W - with; W/O - without; CC - complications and/or co-morbidities.

Consultation with experts

The full set of analyses was presented, individually, to the following experts. The four represented specialties were selected on the basis of the top ranking DRGs:

- Prof Jeffrey Robinson and A/Prof Peter Baghurst (Obstetrics and Gynaecology)
- A/Prof Peter Devitt (General surgery)
- A/Prof Robert Adams (Respiratory)
- Prof Paddy Phillips (Cardiovascular)

Nine conditions were selected for further investigation. Table A1 (Appendix 2) lists the nine conditions with their respective reasons for consideration and recommendations for further research. Stroke and chest pain were selected for the first applications of the RAC-E framework, as both patient cohorts had large increases in admission rates, especially for chest pain (+75%). The total costs expended on the two patient groups were significant, and the mean costs of the most costly hospitals were approximately double the costs of the least costly hospital for both conditions. Local clinicians advised that variation in clinical practice was a likely explanation of the observed cost differences.

Analysis of linked ISAAC data

Upon completion of the data linkage, this process was revised using the linked master dataset, which included patient-level separation cost estimates to better inform the identification of areas of hospital activity in which there were potentially important variations in clinical practice.

Mean separation costs for each DRG in 2006-07 across the four key hospitals were calculated. Comparisons of the aggregate annual costs and the differences in the mean costs across hospitals identified the DRGs with the greatest potential for variation in practice.

Potential case study DRGs within each major disease category were selected for the shortlist (Table 2), based on the following criteria:

- Significant increase in absolute mean cost
- Significant increase in relative mean cost
- Significant sample size
- Significant total cost

There were a large number of same-day lens procedures (C16B) with a total annual cost of over $4 million and a 143% difference in mean separation costs across the hospitals. A large number of patients were also admitted for chest pain accounting for almost $5 million in annual costs and a 82% difference in mean costs between the hospitals. The mean costs across the four hospitals varied greatly, particularly for other kidney and urinary tract diagnoses (hospital C had a minimum mean cost of $735 compared with a maximum mean cost of $3,577 for hospital A, a difference of 387%) and the implantation or replacement of an automated implantable cardioverter defribillator (126% difference). Interestingly, the mean costs for a diagnosis of headache suggested variations in practice across hospitals with a minimum mean cost of $909 at hospital D and a maximum mean costs of $1,877 at hospital A, a difference on 107%.

Table 2. Shortlisted DRGs ranked by highest change in DRG costs in 2006-07*

DRG	Description	Hospital A mean cost	Hospital B mean cost	Hospital C mean cost	Hospital D mean cost	Total separations	Total Cost	Difference in mean costs†	% difference in mean costs
L67C	Other Kidney & Urinary Tract Diagnoses W/O Cat or Sev CC	$ 3,577	$ 1,349	$ 735	$ 1,684	1,337	$ 2,455,153	$ 2,842	387%
C16B	Lens Procedures, Sameday	$ 2,162	$ 2,178	$ 1,381	$ 3,354	2,015	$ 4,571,887	$ 1,974	143%
F01A	Implantation or Replacement of AICD Total System W Cat or Sev CC	$ 20,986	$ 47,468	$ 30,373	$ 34,230	123	$ 4,091,547	$ 26,482	126%
F01B	Implantation or Replacement of AICD Total System W/O Cat or Sev CC	$ 15,333	$ 34,083	$ 26,322	$ 29,540	90	$ 2,368,773	$ 18,750	122%
B70A	Stroke W Catastrophic CC	$ 18,412	$ 21,674	$ 18,479	$ 9,889	354	$ 6,058,220	$ 11,785	119%
I04Z	Knee Replacement & Reattachment	$ 29,362	$ 14,542	$ 13,591	$ 16,926	357	$ 6,642,126	$ 15,771	116%
B63Z	Dementia & Other Chronic Disturbances of Cerebral Function	$ 12,448	$ 8,920	$ 11,284	$ 5,834	453	$ 4,358,558	$ 6,614	113%
K60A	Diabetes W Cat or Sev CC	$ 11,032	$ 7,590	$ 9,184	$ 5,274	298	$ 2,464,511	$ 5,758	109%
B77Z	Headache	$ 1,877	$ 1,087	$ 996	$ 909	599	$ 729,101	$ 968	107%
B69A	TIA & Precerebral Occlusion W Cat or Sev CC	$ 4,750	$ 6,026	$ 4,965	$ 3,186	140	$ 662,416	$ 2,841	89%
F74Z	Chest Pain	$ 1,424	$ 1,375	$1,271	$ 780	4,120	$ 4,996,158	$ 644	82%
B70B	Stroke W Severe CC	$ 8,217	$ 10,549	$ 10,230	$ 5,847	318	$ 2,769,978	$ 4,702	80%
F62A	Heart Failure & Shock W Catastrophic CC	$ 8,790	$ 9,370	$ 7,012	$ 5,315	477	$ 3,635,645	$ 4,054	76%
B69B	TIA & Precerebral Occlusion W/O Cat or Sev CC	$ 2,859	$ 2,381	$ 1,832	$ 1,709	296	$ 649,759	$ 1,150	67%
U63B	Major Affective Disorders Age <70 W/O Cat or Sev CC	$ 8,174	$ 10,513	$ 6,343	$ 8,673	920	$ 7,751,392	$ 4,170	66%
F62B	Heart Failure & Shock W/O Catastrophic CC	$ 3,785	$ 4,127	$ 3,378	$ 2,810	871	$ 3,070,427	$ 1,317	47%
G02A	Major Small & Large Bowel Procedures W Catastrophic CC	$ 23,362	$ 28,063	$ 23,041	$ 20,255	284	$ 6,725,129	$ 7,808	39%
F12Z	Cardiac Pacemaker Implantation	$ 10,717	$ 12,284	$ 11,387	$ 8,939	466	$ 5,047,554	$ 3,345	37%
I03B	Hip Replacement W Cat or Sev CC or Hip Revision W/O Cat or Sev CC	$ 21,463	$ 17,567	$ 15,793	$ 18,304	397	$ 7,257,831	$ 5,669	36%
F15Z	Percutaneous Coronary Intervention W/O AMI W Stent Implantation	$ 7,778	$ 7,230	$ 6,809	$ 5,952	640	$ 4,443,088	$ 1,826	31%
F10Z	Percutaneous Coronary Intervention W AMI	$ 10,332	$ 8,429	$ 9,622	$ 8,277	633	$ 5,801,580	$ 2,055	25%
E65A	Chronic Obstructive Airways Disease W Cat or Sev CC	$ 5,648	$ 5,725	$ 6,024	$ 4,871	1,306	$ 7,270,436	$ 1,152	24%
I08A	Other Hip & Femur Procedures W Cat or Sev CC	$ 15,461	$ 18,440	$ 16,396	$ 15,733	424	$ 6,999,266	$ 2,979	19%

* based on data from the 4 key public hospitals in SA ; † between the highest cost and lowest cost of the 4 key public hospitals in SA. AMI - acute myocardial infarction; W - with; W/O - without; CC - complications and/or co-morbidities; AICD - automated implantable cardioverter defribillator; TIA - transient ischaemic attack.

The following eight key conditions were analysed further: hip replacement (I08A, I03B), transient ischaemic attack (B69), headache (B77Z), lens procedures sameday (C16B), chronic obstructive airways disease (E65), automated implantable cardioverter defribillator (F01), cardiac pacemaker (F12Z), and percutaneous coronary intervention (F10Z, F15Z, F16Z). A disaggregated analysis of the costs incurred in each of the 16 cost categories used in the hospital costing process identified specific areas in which costs varied most between hospitals. Table A2 (Appendix 2) lists the eight potential conditions that were identified with recommendations for further research. This revised ranking confirmed stroke and chest pain as case studies and identified hip fracture as the next case study.

2.3 RISK ADJUSTED COST-EFFECTIVENESS (RAC-E) ANALYSES

Having described the creation of a master dataset, and the identification of priority areas for investigation, the following sections describe the sequential components of the RAC-E process. The methodology used to undertake the analyses presented in this report is described, though as this is a new analytic framework it should be recognised that an iterative process was used to refine the methodology. It is also the case that further development and validation approaches are planned, which are discussed in the concluding section of this report.

The stroke and chest pain case studies were undertaken in parallel, led by different researchers (CP – stroke; OC – chest pain). In addition to the clinical members of the research team (DBT and MC), the following clinical experts contributed to the development of the analytic framework to ensure that the specification for each case study captured all relevant clinical factors and outcomes:

Dr Andrew Lee, Consultant Neurologist at the Flinders Medical Centre, was the primary clinical advisor for the stroke study.

Professor Derek Chew, Director of Cardiology at the Flinders Medical Centre, and Professor Paddy Phillips, Chief Medical Officer of South Australia, were the primary clinical advisors for the chest pain study.

Associate Professor Craig Whitehead, Geriatrician at the Repatriation General Hospital, was the primary clinical advisor for the hip fracture study.

The aim

The aim of the analytic framework was to estimate differences in the long-term costs and benefits associated with clinical practice for specific conditions at alternative hospitals, controlling for relevant differences in the clinical and sociodemographic characteristics of patients treated at different hospitals.

The analytic framework

Using the chest pain case study to illustrate, the analytic framework is summarised as the following six stage process:

1. A cohort of eligible patients is defined as all patients with a principal diagnosis of chest pain who were admitted to any of the four main public hospitals in SA within a defined time period.
2. A set of intermediate outcomes is defined (e.g. cardiac-related readmission, death, or no related event). Using the linked data for the eligible patient cohort, each patient is assigned to one of the intermediate outcomes over a defined (retrospective) observation period (e.g. 2 years from the admission date for the chest pain separation).
3. Using the full set of linked data for all chest pain patients, separate regression models are developed to predict future costs and mortality on the basis of relevant patient characteristics (e.g. age, co-morbidities, socioeconomic status) and the intermediate endpoints.

4. Combining the observed and predicted data, each patient is assigned a predicted lifetime cost and a survival (life years gained) estimate.
5. Using the lifetime cost and survival estimates for the eligible patient cohort, separate regression models are developed to derive expected lifetime costs and survival on the basis of relevant patient characteristics at the time of the initial chest pain admission (e.g. age, co-morbidities, socioeconomic status).
6. Each eligible patient is assigned a net cost and a net benefit value, estimated as predicted minus expected lifetime costs and survival, respectively. The net costs and benefits are summed across all eligible patients at each of the four hospitals to calculate the mean net costs and benefits at each hospital. The mean net costs and benefits are compared across the hospitals to identify the hospital with the most cost-effective practice.

The following sub-sections expand on the methods within each of these six steps.

1. Defining the eligible patient cohort

The first task is to define the method for identifying eligible patients, through the specification of the range of principal diagnoses to be included. Here, clinical advice is required to select a patient cohort for whom clinical practice is relatively homogeneous, i.e. there are no major differences in the expected management pathways across patients within the defined cohort.

Secondly, consideration is given to obtaining numbers of patients to inform a sufficiently precise estimate of the differences in costs and benefits of clinical practice between hospitals. Sample size may be increased by specifying a longer time period for the analysis, but here we also need to consider the relevance of the time period analysed to current clinical practice, the length of the observation period (over which we identify relevant intermediate endpoints - steps 2 and 3).

2. Choice of intermediate endpoints

The specified intermediate endpoints form the structure of the analytic framework; it is from these endpoints that the final costs and outcomes will be estimated. Intermediate endpoints are events that are potentially related to the index event, i.e. we would expect differences in the rates of these events with variations in the quality of clinical practice. In this study, intermediate endpoints were defined on the basis of hospital separations experienced during the follow-up period.

In defining the endpoints, there is a trade-off between choosing enough intermediate endpoints to be able to capture important differences in long-term costs and outcomes, and the analytic burden and loss of precision (due to reduced sample sizes) of undertaking large numbers of regression-based extrapolation analyses (step 3).

Clinical advice is essential to identify endpoints (hospital admissions) that are potentially related to the index event, and to inform the grouping of sets of hospital admissions (e.g. according to principal diagnosis). In addition, evidence from the literature can inform relevant categorisations, for example, reviewing previous economic models in the disease area. Finally, analyses of the assembled linked dataset may also be useful, for example, short-term mortality rates can be estimated to provide estimates of the relative severity of alternative principal diagnoses.

Each eligible patients is then assigned to one of the defined intermediate endpoints representing the first event experienced by the patient (if any) over the defined follow-up period.

3. Extrapolating costs and survival

To generate predicted estimates of lifetime costs and survival, datasets are created that contain all hospital separations for all patients who experienced the index event (e.g. chest pain) over the period July 1, 2002 to June 30, 2008. In addition to variables describing clinical and sociodemographic characteristics of patients at the time of their index event, additional variables are created that describe the intermediate endpoint experienced by each patient (e.g. cardiac readmission, death, or no event), mortality status and date of death (where appropriate), and annual cost estimates. The annual cost estimates are based on experienced hospital admissions in each year following the index event.

The following sub-sections describe the regression analytic methods used to extrapolate lifetime costs and survival beyond each intermediate endpoint using these datasets.

3.1 Survival models

Flexible parametric models for survival analysis, introduced by Royston and Parmar (Royston & Parmar 2002), were applied to the three datasets to predict survival beyond the follow-up endpoints. These models use restricted cubic splines to estimate log cumulative hazards, controlling for the effect of relevant patient characteristics.

To fit the models, we used backwards stepwise selection using the full range of demographic, socio-economic, and clinical explanatory variables. The criterion for inclusion in the model was $p \leq 0.05$. These initially defined models were then expanded to test for significant interactions between the included explanatory variables. Interaction terms were included in the models if they improved model fit, as judged by the Akaike's Information Criterion. The final stage of the analysis tested the effect of alternative functional forms by comparing models that fitted a restricted cubic spline with between 1 and 5 knots.

To assess the overall fit of the parametric survival models, the mean survival curve was plotted against the Kaplan-Meier survival curve.

3.2 Cost models

Annual costs in each full year of life beyond the intermediate endpoints were estimated using a two-stage process that estimated the probability of patients incurring any hospital costs (using logistic regression), followed by an estimate of the magnitude of the cost, if incurred (using generalised linear models - GLMs). In some cases, e.g. following the recurrent stroke and cardiac intermediate endpoints, separate cost models were specified to differentiate between costs incurred in the first year post-event, and costs incurred in subsequent years.

Similar model selection criteria to those used for the survival models were applied. For the logistic regression analyses, overall model fit was established using the Ramsey RESET test. For the GLMs, the modified Park test was used to determine the most appropriate distribution, and the appropriate link function was selected by testing different power functions with respect to the Pearson correlation, Pregibon link, and the Modified Hosmer-Lemeshow tests.

Annual survival probabilities for each patient were derived from the estimated survival functions, to which annual cost estimates and a 5% discount rate were applied. The discounted annual costs and survival probabilities were summed to a maximum age of 100 years, which were then added to the costs incurred and life years gained up to and including each patient's intermediate endpoint to estimate lifetime costs and survival for each patient.

4. Predicted lifetime costs and survival

Overall survival is predicted for each eligible patient by combining the time to patients' intermediate endpoint (e.g. either cardiac readmission or the end of the two year follow-up period for chest pain patients) with the extrapolated survival time from the intermediate endpoint (as described in step 3). If a patient dies during the follow-up period, lifetime survival is not extrapolated.

Predicted lifetime costs estimates for each eligible patient are generated by combining the costs incurred during the index event (e.g. the hospital admission for the initial chest pain event), and readmission costs for patients with the cardiac readmission intermediate endpoint, with the extrapolated costs predicted by the regression models. Extrapolated lifetime costs are estimated by multiplying the estimated annual costs by the predicted proportion of surviving patients in each year following the index event.

5. Expected lifetime costs and survival

The predicted lifetime costs and survival estimates for all eligible patients are combined into a single dataset, and separate regression models are fitted to generate *expected* lifetime cost and survival estimates. The models control for clinical and socio-economic and demographic factors that are observed at the time of the index event.

As in the regression analyses described in step 3, GLM and Royston-Parmar parametric model are fitted to estimate expected lifetime costs and survival, respectively.

6. Comparing net cost and benefit values

The final step involves the estimation of the net cost and benefits values for each eligible patient, which are generated by subtracting *expected* (step 5) lifetime costs and survival from *predicted* lifetime costs and survival (step 4), respectively.

The net costs and benefits are summed across all eligible patients attending each of the four hospitals to calculate the mean net costs and benefits at each hospital. From these data, we identified hospitals that were costing more (or less) and/or achieving better (or worse) patient outcomes than expected, controlling (or adjusting) for differences in the baseline risk of patients incurring high costs or achieving poor outcomes. Differences in net cost and survival estimates between hospitals can be interpreted as risk adjusted differences in costs and survival: if costs incurred by patients at hospital A are $300 more than expected, whilst costs incurred by patients at hospital B are $200 less than expected, then the risk adjusted difference in per patient costs between hospitals A and B is $500.

A comprehensive sensitivity analysis involved a multi-stage bootstrapping (sampling with replacement) approach, which precludes the need to parameterise the correlation between lifetime costs and survival. The datasets for each of the intermediate endpoints were bootstrapped, and the coefficients for each of the extrapolation models re-estimated. Each resulting dataset of lifetime costs and survival was also bootstrapped and the coefficients for the expected costs and survival regression models re-estimated. This sequential bootstrapping process was repeated for 2,000 iterations. The output data were used to plot cost-effectiveness acceptability curves which display the probability that each hospital is cost-effective at different threshold values for gaining additional life years.

2.4 INVESTIGATION OF POTENTIAL DETERMINANTS OF DIFFERENCES IN COSTS AND BENEFITS

An important area of development within the RAC-E framework is the subsequent investigation of potential determinants of the estimated differences in risk adjusted costs and survival between hospitals. Analyses involving routinely collected data will always be subject to criticism regarding the limitations of the data

and the lack of randomisation to control for unobservable biases. The sequential investigation of differences in the process of clinical practice, in areas where important differences in risk adjusted costs and benefits have been identified, is intended to provide supplementary evidence to support the RAC-E findings: if expert analysis of observed processes identifies better (more efficient) processes at the hospitals that were estimated to have the best RAC-E, the combined evidence set should be harder to ignore.

Appraisal of available methodologies for the comparative analysis of clinical practice processes is ongoing, though the technique of process mining has been identified as a promising approach that may be applied using routinely collected data.

Initial analyses of the following routinely reported hospital activity and cost data were undertaken, from which crude differences in the use of broad resource categories were identified:

Hospital activity data

- Length of hospital stay
- Provision of rehabilitative services (where applicable)
- Rehabilitation length of stay (where applicable)
- Diagnostic or clinical procedures (where applicable)
- Hospital capacity

Cost data

In deriving separation-level cost estimates, hospitals assigned costs to 16 different categories, including ward medical, ward nursing, non-clinical salaries, pathology, imaging, allied health, pharmacy, critical care, operating room, emergency department, ward supplies and other overheads, specialist procedures, oncosts, prostheses, hotel services, and depreciation.

3 APPLICATIONS OF RAC-E ANALYSES

The results for stroke, chest pain and hip fracture are presented below, including initial analyses of potential determinants of the estimated differences in risk adjusted costs and survival for each case study.

3.1 STROKE

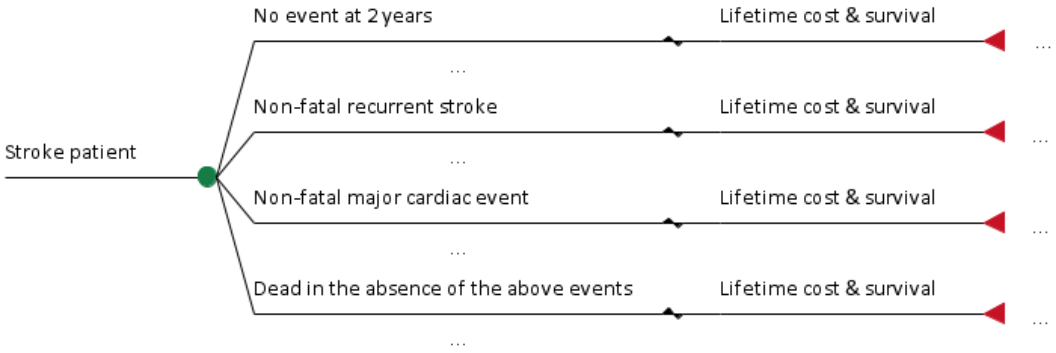
Patient cohort

Stroke events were stratified on the basis of the AR-DRG codes B70A, B70B and B70C (stroke with catastrophic comorbidities or complications (CC), with severe CC, and without catastrophic or severe CC, respectively), as the ICD-10.5-AM coding for stroke subtype was unreliable with the proportion of unspecified stroke ranging between 0.5-32% across hospitals. Patients who died within 5 days of admission or whose principal diagnosis was stroke but were categorised under the AR-DRG codes for craniotomy (B02), extracranial vascular procedure (B04) or tracheostomy or ventilation >95 hours (A06) were excluded from the analysis.

Figure 1 displays the structure of the extrapolation model, showing that beyond an initial stroke separation, hospital admissions for non-fatal recurrent stroke, and non-fatal major cardiac event were categorised as intermediate endpoints. In this analysis, a major cardiac event was defined by ranking all cardiac events (in Major Disease Category 5 - Diseases of the Circulatory System) following a stroke event by frequency of death. Those associated with the highest frequencies of death (proportion of death ≥40%) in the linked

dataset were considered major. Other endpoints within the two year observation period were 'death without, or within 28 days of an intermediate outcome', and 'no intermediate outcome or death'. From the non-dead endpoints, lifetime costs and survival values were predicted using relevant regression-based models.

Figure 1. Stroke extrapolation model structure



Results

Details of the cost and survival regression models are provided in a separate appendix. The models include measures of stroke severity and co-morbidity as explanatory variables, as well as socioeconomic variables (indicating an additional effect of socioeconomic status). Interaction variables, particularly with age, were also included. The survival curve plots for each intermediate outcome indicate that the models were of good fit and produced sensible estimates.

Table 3 presents the mean results, ordered by increasing magnitude of net survival. For both hospitals B and C, at least one other hospital had lower net costs and higher net survival (i.e. these hospitals were dominated). Thus, the mean incremental cost per life year gained was only estimated between hospitals A and D, with patients treated at Hospital A gaining life years at an additional cost of $16,068 relative to Hospital D.

Table 3. Separation costs and net costs and survival for Stroke

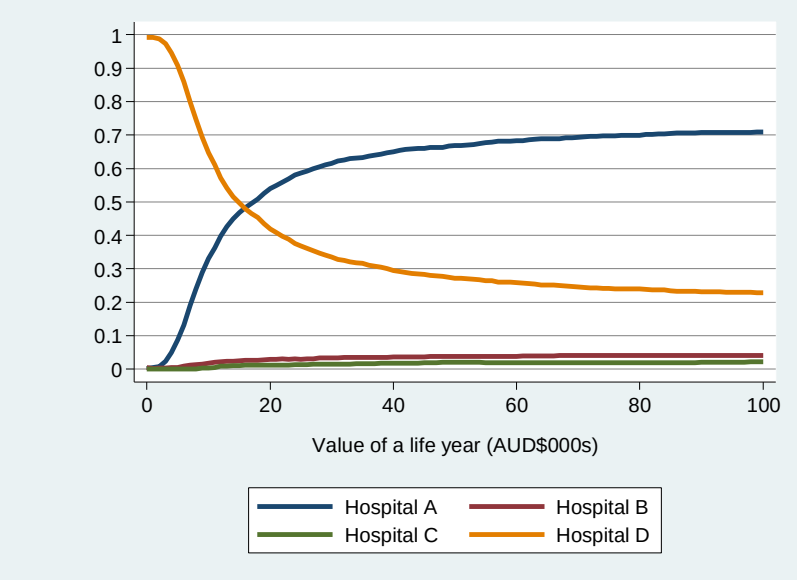
Hospital	Unadjusted separation costs	Net costs per patient	Net LYs per patient	Notes
B	$ 12,762	$ 179	-0.24	Dominated by hospital D
C	$ 11,479	$ 1,412	-0.18	Dominated by hospitals A & D
D	$ 6,329	-$ 4,698	0.05	
A	$ 10,771	$ 335	0.36	
		Cost difference	**LYs difference**	**Incremental cost per LY gained**
A vs D		$ 5,033	0.31	$ 16,068

Costs are reported in AUD. LYs indicates life years.

Figure 2 displays the cost-effectiveness acceptability curves, which shows the probability that each of the hospitals is the most cost-effective hospital at different monetary values for gaining life years. Hospital A had the largest expected net benefits and a 65% probability of being cost-effective at a life year value of

$50,000. Comparing hospitals A and D directly (the non-dominated hospitals), hospital A had a 70% probability of being the most cost-effective hospital at a threshold of $50,000.

Figure 2. Cost-effectiveness acceptability curves for Stroke for all 4 included hospitals



Investigation of variation in costs and benefits

Potential determinants of the observed variation in costs and outcomes across the hospitals can be identified from the available data, including acute length of stay, allied health costs, and admission for sub-acute stroke rehabilitation. Lower than expected costs for Hospital D could be explained by patients having a significantly shorter acute stay and significantly lower ward, allied health, imaging, pathology, and pharmacy costs, which could be related to the absence of a stroke unit at this hospital.

The main difference between the services provided at Hospitals A, B, and C (all of which had specialised stroke units) appears to be around the use of allied health (costs of which are higher in the more effective Hospital A) and imaging and pathology costs, which are higher at the less effective Hospitals B and C. Interestingly, intensive care costs are higher in Hospital A for patients with severe CC, but higher in hospital C for patients with catastrophic CC.

A previous observational cohort study, comparing costs and survival of stroke patients across Europe, found that the type of staff input varied across centres: nursing input at a stroke unit in Florence was provided entirely by fully qualified nurses, whereas at a stroke unit in London, 40% of the nurses had only received a basic level of training (Grieve *et al.* 2001). Grieve *et al.*(Grieve *et al.* 2001) also noted that spending more on stroke services did not necessarily improve outcomes, which is the case here for Hospitals B and C.

Conclusions

The results from this study indicate important differences in mean net lifetime costs and outcomes for patients receiving acute stroke services at the four largest metropolitan hospitals in SA. The mean results imply that if patients currently treated at hospital D were to be treated at hospital A, we could gain additional life years at a cost of $16,068 per life year. If this is considered to be a cost-effective use of resources, the care pathways should be investigated with a view to disseminating practice at hospital A to

the other hospitals. This analysis has identified hospitals for further investigation to assess differences in clinical pathways using improvement tools such as process mapping to describe patient journeys and gain a better understanding of the complexity and the sequence of steps involved in the provision of care at each hospital, with the intention of informing recommendations regarding the efficient use of hospital resources for acute stroke management.

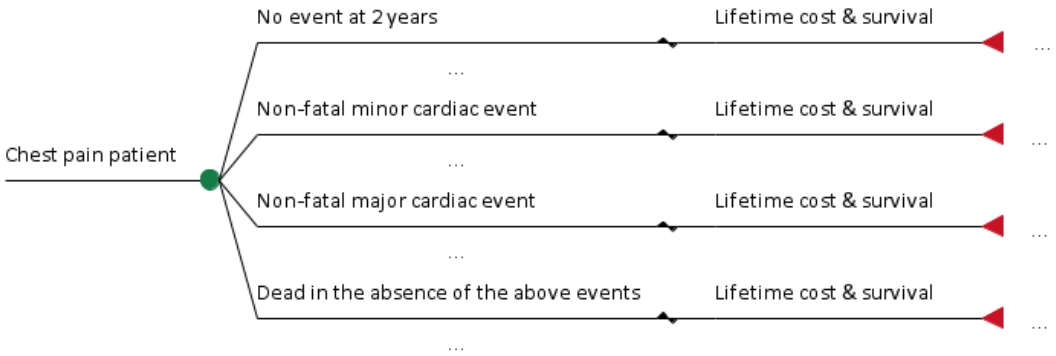
3.2 CHEST PAIN

Patient cohort

Eligible patients were admitted to hospital via an emergency department and had a principal diagnosis of chest pain, defined using the ICD-10 AM code R07, in combination with one of two DRG codes: "Chest Pain" (F74Z) or "Chest pain with invasive procedure" (F42B). Patients with a hospital admission in the year prior to the qualifying chest pain admission, which was classified in the Major Diagnostic Category: Diseases and Disorders of the Circulatory System, were excluded in order to focus on chest pain that was unlikely to be related to recently treated heart disease.

Figure 3 displays the structure of the model used to extrapolate lifetime costs and survival. Over a two-year observation period, patients were assigned to one of four intermediate endpoints (no event, non-fatal minor, or major cardiac event, or dead), from which subsequent lifetime costs and survival was predicted. Categorisation of cardiac events as major or minor was based on 1-year mortality rates, as observed across the full dataset. All first cardiac admissions following an eligible chest pain admission, categorised by ICD-10 AM code, were ranked by 1-year mortality rates. Codes with mortality rates >15% were defined as major cardiac events, and codes with mortality rates between 5 and 15% were assigned to the minor category.

Figure 3. Chest pain extrapolation model structure



Results

Details of the cost and survival regression models are provided in a separate appendix. Across the extrapolation models, age and presence of an existing vascular co-morbidity were the most common explanatory variables, with both interacting with a range of other co-morbid conditions. Sex was more commonly significant in the survival models. Socioeconomic indicators were significant in four of the ten cost models, and two of the three survival models – a positive relationship was observed in all cases, though less so for costs.

In the expected models, vascular co-morbidity was not predictive of short-term survival, but did reduce predicted longer-term survival and lifetime costs. Socioeconomic variables were not significant predictors of expected survival, though the inclusion of hospital dummy variables as well as the wide range of co-

morbidity variables may be capturing the effects of socioeconomic status on expected survival. Socioeconomic disadvantage was a significant, but not strong, predictor of expected lifetime costs.

Table 4 presents the results from the base case analysis, which is consistent with the distributions of the risk factors across the hospitals and the corresponding probabilities of the different intermediate endpoints. The data show that services provided at hospitals 3 and 4 cost more than expected, given the casemix of patients treated. Patients at hospital 3 and 4 also have lower survival than expected. Thus, hospital 1 dominates hospitals 3 and 4, i.e. demonstrating a greater reduction in costs, and a greater gain in survival, compared to expected costs and survival, respectively. Hospital 2 has the lowest costs, relative to expected costs, but also has lower than expected survival.

An incremental cost per life year gained can be estimated between the two non-dominated hospitals, which shows that hospital 1 gains additional life years at an incremental cost of $2,909 compared to services provided at hospital 2.

Table 4. Separation costs and net costs and survival for Chest Pain

Hospital	Unadjusted separation costs	Net costs per patient	Net LYs per patient	Notes
3	$ 1,474	$ 290	-0.04594	Dominated
2	$ 1,233	-$ 489	-0.04588	
4	$ 732	$ 17	-0.03038	Dominated
1	$ 1,589	-$ 65	0.10012	
		Cost difference	**LYs difference**	**Incremental cost per LY gained**
1 vs 2		$ 424	0.146	$ 2,909

Costs are reported in AUD. LYs indicates life years.

Investigation of variation in costs and benefits

A key potential determinant of the estimated differences in both costs and effects is the use of angiography (the invasive procedure in DRG F42B) as part of the diagnostic pathway. The most effective hospital used angiography most commonly, though the second most effective hospital did not have access to the required equipment (i.e. no patients received this technology). These findings might reflect efficient use of the technology in hospital 1, with angiography being used to identify patients with an underlying treatable condition (who are subsequently discharged under an active treatment diagnostic code). In hospital 4, this finding might reflect the more careful selection and interpretation of non-invasive diagnostic tests, in the absence of angiography. In patients receiving angiography, hospitals 2 and 3 report 13% and 11% fewer patients remaining event free, compared to hospital 1, respectively.

Comparing patients not receiving angiography, length of stay is significantly shorter at hospital 4 (lifetime costs at hospital 4 are increased compared to hospitals 2 and 3 because fewer patients die in the 2 year follow-up period).

Figure 4 presents the probability that each service is most cost-effective at different monetary values of a life year, which shows that beyond low monetary values, the probability of hospital 1 providing the most cost-effective services approaches 1. Pairwise comparisons between hospital 1 and the three other

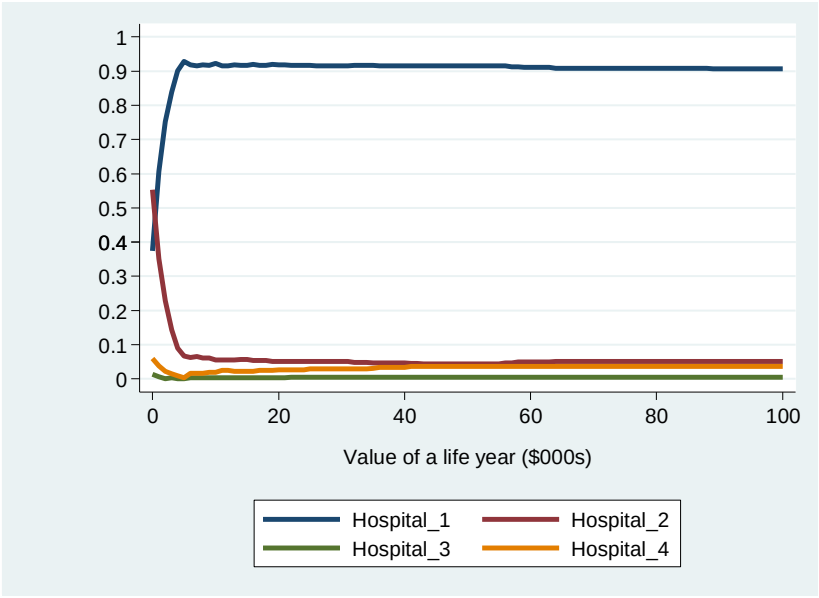
hospitals show that at a $25,000 threshold value, hospital 1 has a minimum 99% probability of being cost-effective.

Investigation of variation in costs and benefits

A key potential determinant of the estimated differences in both costs and effects is the use of angiography (the invasive procedure in DRG F42B) as part of the diagnostic pathway. The most effective hospital used angiography most commonly, though the second most effective hospital did not have access to the required equipment (i.e. no patients received this technology). These findings might reflect efficient use of the technology in hospital 1, with angiography being used to identify patients with an underlying treatable condition (who are subsequently discharged under an active treatment diagnostic code). In hospital 4, this finding might reflect the more careful selection and interpretation of non-invasive diagnostic tests, in the absence of angiography. In patients receiving angiography, hospitals 2 and 3 report 13% and 11% fewer patients remaining event free, compared to hospital 1, respectively.

Comparing patients not receiving angiography, length of stay is significantly shorter at hospital 4 (lifetime costs at hospital 4 are increased compared to hospitals 2 and 3 because fewer patients die in the 2 year follow-up period).

Figure 4. Cost-effectiveness acceptability curves for Chest Pain for all 4 included hospitals



Also in the majority non-angiography cohort, there are some interesting differences between hospital 1 and the other hospitals. Compared to hospitals 2 and 3, hospital 1 reports higher costs with respect to staff time on medical and nursing wards, and on pharmaceuticals, but lower costs associated with imaging and pathology. This finding may reflect more time being spent with patients in hospital 1, which may correspond to increased prescription of pharmaceuticals targeted at cardiovascular risk factors, whilst the other hospitals spend more time ordering tests that have limited effects on long-term outcomes.

Conclusions

The results from this study indicate that there are important differences in the long-term risk adjusted cost-effectiveness (RAC-E) of services provided for patients presenting with chest pain at the four largest metropolitan hospitals in SA. The mean results indicate that two of the four hospitals incur greater costs

and achieve poorer outcomes than at least one other hospital (i.e. are dominated). Of the non-dominated hospitals, the mean results imply that if patients currently treated at hospital 2 were to be treated at hospital 1, we would gain additional life years at a cost of $2,909 per life year. If this is considered to be a cost-effective use of resources, the care pathways should be investigated with a view to disseminating practice at hospital 1 to the other hospitals.

If all hospitals were able to achieve the same level of costs and effects as hospital 1, the health service could expect to save $78 per patient treated at hospital 2, 3, or 4, and these patients would expect to gain an additional 0.14 life years. Annually, this equates to net present value savings of $142,892 to the health service and gains of 258 life years to this cohort of 1,843 patients.

Differences in costs and effects are likely to be a function of three factors:

- differing thresholds for admitting patients presenting at an emergency department (ED) with chest pain,
- more accurate identification of patients presenting with chest pain who have, and do not have a clinically relevant underlying cause for the symptoms,
- better management of underlying factors that increase the risk of a future clinical event.

To assess these factors, comparative analyses of the clinical practice processes within the ED of the different hospitals, for patients presenting with chest pain, is ongoing. These analyses are using the technique of process mining as applied to routinely collected data.

3.3 HIP FRACTURE

Patient cohort

All hospitalisations for hip fracture were identified using ICD-10 AM codes S720 (fracture of neck of femur), S721 (pertrochanteric fracture) and S722 (subtrochanteric fracture). The index hip fracture event was defined as the first hip fracture hospital admission that occurred for a patient from July 1, 2002 onwards to exclude patients who had experienced a recent hip fracture (i.e. within the previous year). Transfers for the same hip fracture separation were excluded from the analysis so as to avoid double counting.

Figure 5 presents the structure of the model used to predict lifetime costs and survival following an initial hip fracture. Patients were categorised into one of five intermediate endpoints based on events experienced within a year of the index event: another hip fracture, a fracture other than hip (ICD-10 AM codes S02, S12, S22, S32, S42, S52, S62, S82, S92 and S72), a hip revision (ICD-10 AM code T84), no subsequent event, or dead (with no prior relevant readmission event).

Results

Details of the cost and survival regression models are provided in a separate appendix. Across the extrapolation models, age and presence of an acute lower respiratory tract infection were the most common explanatory variables. Sex, dementia including Alzheimer's disease, malignancy, and admission as an emergency patient were more commonly significant in the survivial models.

In the expected models, hip complications, dementia including Alzheimer's disease, chronic obstructive pulmonary disease, renal co-morbidity and malignancy were predictive of longer-term survival.

Figure 5. Hip fracture extrapolation model structure

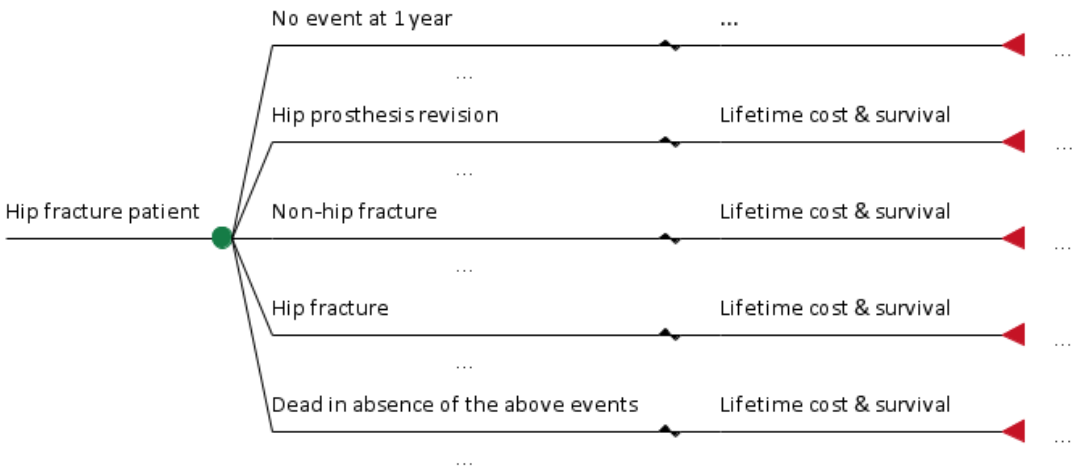


Table 5. Separation costs and net costs and survival for Hip Fracture

Hospital	Unadjusted separation costs	Net costs per patient	Net LYs per patient	Notes
D	$ 13,228	$ 156	-0.414	Dominated by hospital C
B	$ 16,128	$ 1,475	-0.27	Dominated by hospitals A & C
C	$ 13,799	-$ 808	0.015	
A	$ 16,935	$ 348	0.052	
		Cost difference	**LYs difference**	**Incremental cost per LY gained**
A vs C		$ 1,156	0.04	$ 31,243

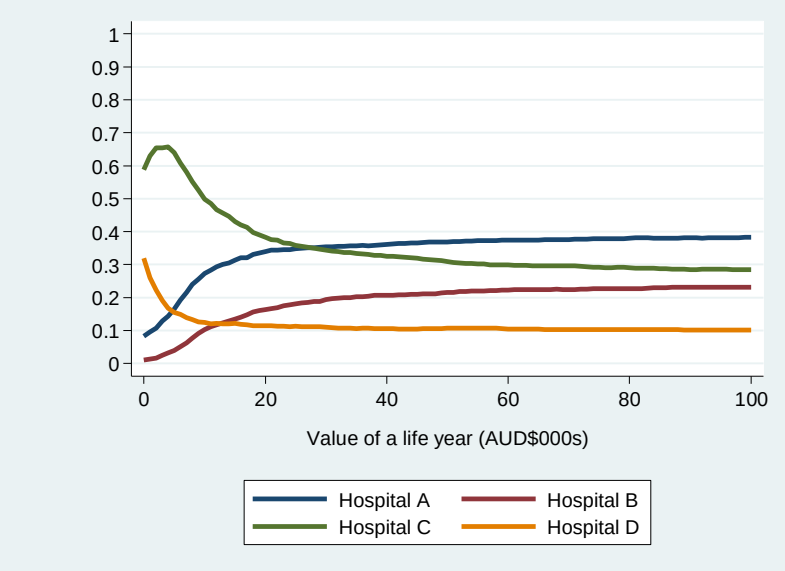
Costs are reported in AUD. LYs indicates life years.

Figure 6 displays the cost-effectiveness acceptability curves, which shows the probability that each of the hospitals is the most cost-effective hospital at different monetary values for gaining life years. At a life year value of $50,000, Hospital A had the largest expected net benefits and a 35% probability of being cost-effective, Hospital C had a 30% probability of being cost-effective and Hospital B had a 21% probability of being cost-effective.

Investigation of variation in costs and benefits

The results of the cost-effectiveness analyses suggest hospitals A and C were the most efficient. Potential determinants of these differences include that a larger proportion of patients attending hospital A received rehabilitation (p=0.036), whilst patients who did not receive rehabilitation had a longer length of stay (LOS) for their acute separation (p=0.012). Patients who did not receive rehabilitation also had higher separation costs at hospital A (p=0.005). Hospital D had the lowest proportion of patients receiving rehabilitation and the lowest acute length of stay for non-rehabilitation subjects. Hospital D was associated with the worst standardised survival and higher than expected costs. These findings suggest that greater provision of rehabilitation services for hip fractures may be associated with better than expected survival.

Figure 6. Cost-effectiveness acceptability curves for Hip Fracture for all 4 included hospitals



The apparent cost efficiency at hospital C may in part be attributable to choice of prosthesis type: hospital C was associated with the lowest average prosthesis cost for use in performing hip replacements with (p=0.0021) and without (p=0.0002) complications (diagnosis related groups I03B and I03C).

In examining admission trends, hospital C has the highest number of admissions for hip fracture across the hospitals, accounting for 44% of all admissions over the years. Thus, hospital C was considered to be the *largest* hospital. The better than expected survival at hospital C (and A, the second largest hospital), and worse than expected survival at the *smaller* hospitals (B and D) suggests hospital size is related to efficiency i.e. the more procedures undertaken the more efficient is clinical practice and hence the better are patient outcomes. The second largest hospital (A) was associated with the highest standardised survival among the hospitals. However, unlike hospital C, hospital A had higher than expected costs suggesting (in relative terms) that it did not provide cost efficient services.

Conclusions

The results of this study suggest that hip fractures are costly: the average cost of a hip fracture separation followed by rehabilitation is around $24,000 (or $14,500 without rehabilitation), although there was variation between the hospitals. Looking at differences in net lifetime costs and survival for patients treated at different hospitals, hospital C dominated hospitals B and D, i.e. had lower net costs and higher net survival. Hospital A had greater net costs and net survival than hospital C. The differences were interpreted to estimate that if hospital C provided services at the same level of efficiency as hospital A, we would gain additional life years at a cost of $31,243, which is well below accepted norms for cost-effectiveness (George, Harris & Mitchell 2001).

In looking at potential determinants of the estimated differences in costs and outcomes, it seems that hospital size is related to better survival (at hospitals A and C) and cost efficiency (hospital C). There is also a suggestion that greater provision of rehabilitation services for hip fractures may be associated with better than expected survival.

3.4 AMPUTATION

A RAC-E analysis of amputation procedures across the four main public hospitals in South Australia is currently being undertaken as a part of a PhD thesis. All hospitalisations for lower limb amputation will be

identified using ICD-10 codes. Following initial amputation, patients will be categorised into intermediate outcomes (no subsequent event, amputation of another body part, revision surgery, death). The student is supervised by Professor Maria Crotty, with further input from the RAC-E team on the RAC-E case study.

3.5 FURTHER RAC-E RELATED APPLICATIONS

The RAC-E methodology can be applied across a wide range of health care activities, including community-based programs. Following completion of the case study analyse reported above, RAC-E analyses were undertaken of two community-based programs, and evaluations of a preoperative clinic for high risk patients, and clinical practice for amputation are ongoing. The following sections describe the application of the RAC-E methodology in these areas.

Community-based interventions

The cost-effectiveness of two community-based interventions initiated by the Southern Adelaide Health Service was analysed: the out-of-hospital home nursing heart failure management program and the falls prevention program.

1. Out-of-hospital home nursing heart failure management program

The Heart Failure Service at Flinders Medical Centre (FMC) provides a comprehensive heart failure management program to residents in the Southern Adelaide region. In 2006, a home nursing heart failure programme was commenced, which provided out of hospital support following inpatient care for heart failure. The aim was to improve patient health outcomes and reduce hospital readmissions.

Methods

The RAC-E methodology was applied using a 1-year follow-up, over which period the following endpoints were identified: hospital admission for heart failure, no heart failure readmission, death without repeat heart failure. Costs and survival beyond 1-year were extrapolated, based on patient and condition characteristics, and intermediate endpoint experienced.

Of the 14,123 patients who had at least one record of heart failure between July 2001 and June 2008, 57% (n=8,089) had no record of a subsequent heart failure admission, 19% (n=2,747) had at least one other heart failure admission and 24% (n=3,377) died without another heart failure admission.

The primary analysis compared costs and outcomes across the four main public hospitals in South Australia across three non-sequential time periods: the first 6 months of 2005, 2006, and 2007. The eligible cohort of patients were those patients with a hospital admission for heart failure within these time periods.

Results

In the first 6 months of 2005, 3 hospitals had lower survival estimates than expected, observed and expected survival was approximately equal at hospital 4; FMC and hospital 2 showed lower than expected costs. In the first 6 months of 2006, all hospitals had lower survival estimates than would be expected; all hospital except FMC had lower than expected costs. FMC continued to have higher risk adjusted costs than the other hospitals in the first 6 months of 2007, but three of the four hospitals (including FMC) reported higher than expected survival.

An incremental analysis of the change in costs and survival between the 1st 6 months of 2005 and the 1st 6 months of 2007 at FMC shows that although risk adjusted costs increased by $720 per patient, risk adjusted expected survival increased by 0.21 life years (2.5 months), resulting in an incremental cost per additional life year gained of $3,385 (Table 6a).

There is likely to be a learning and uptake period for new community-based interventions such as the home nursing heart failure program. Thus, although the heart failure programme commenced in January 2006 it may not have been 'up and running' until the second half of 2006; in which case it is instructive to perform a comparative analysis of the change in costs and survival in the intermediate period (January – June 2006) to the period following the programme's introduction (January – June 2007). The results of this latter analysis show that costs increased slightly between periods ($365), but survival also increased (0.28 life years), leading to an incremental cost per additional life year gained of $1,309 (Table 6b).

It is noted that the costs of providing the home nursing program are not included in the above calculations but we can estimate the program cost per patient that would be required to take the incremental cost per QALY above alternative cost-effectiveness thresholds.

Table 6. Incremental analysis by hospital and year

Hospital	Incremental Costs	Incremental LYs	Incremental cost per LY gained
(a) Before/After Incremental Analysis (First halves of 2005 vs. 2007)			
FMC	$ 720	0.21	$ 3,385
2	-$ 85	0.48	-$ 178
3	-$ 918	0.50	-$ 1,849
4	-$ 2,345	0.26	-$ 9,106
(b) Before/After Incremental Analysis (First halves of 2006 vs. 2007)			
FMC	$ 365	0.28	$ 1,309
2	-$ 285	0.77	-$ 371
3	$ 330	0.01	$ 24,112
4	$ 2,206	1.10	$ 1,997

Costs are reported in AUD. LYs indicates life years.

Comparing costs and outcomes in a period 1-year after the initiation of the program (January to June 2007) with a prior time period (January to June 2005) and an intermediate time period (January to June 2006) showed that, between 2005 and 2007, FMC was associated with a favourable cost-effectiveness estimate of $3,385 per life year gained. Between 2006 and 2007, FMC was associated with a cost-effectiveness estimate of $1,309 per life year gained. Both estimates of cost-effectiveness indicate an improvement in survival and an overall slight increase in costs for heart failure in the primary before and after analysis and are well below accepted threshold for cost-effectiveness.

2. Evaluating the effectiveness and cost-effectiveness of the falls prevention program

A falls prevention program was initiated in the Southern region of Adelaide in September 2007 (fully operational by June 2008), which was anticipated to reduce fall-related hospital admissions, and in turn reduce health care costs and adverse health outcomes.

Methods

The primary analysis was a before and after comparison of changes in the rates of admissions, costs and survival in the periods surrounding the introduction of the falls program that commenced in June 2008.

Patients admitted to each of the four main public hospitals in SA with a principal diagnosis of a fall were evaluated for the following time periods:

- Before period = July 2006 – June 2007
- Intermediate period = July 2007 – June 2008
- After period 1 = July 2008 – June 2009
- After period 2 = July 2009 – June 2010

A cost-effectiveness evaluation of the falls program was undertaken based on the costs and survival effects associated with changes in the number of hip fracture separations (fall and non-fall related) between the baseline (before) period and each of the subsequent periods.

Results

The numbers of admissions for falls and hip fractures has generally increased over time for all of the major public hospitals in SA. However, at FMC all fall-related and hip fracture admissions started to decline in the second year of the program. Furthermore, FMC had the lowest cost growth for fall admissions without a hip fracture compared to the other major hospitals in 2009/10 versus 2006/07. Table 7 presents the cost-effectiveness analyses of all hip fracture admissions comparing the lifetime costs and the gain in survival from the avoidance of hip fractures. All hospitals (except hospital B) increased total costs and gained lost life years. Hospital B was cheaper and gained lost life years, at a cost-effectiveness ratio of $1,670 per life year gained from the avoidance of a hip fracture. The results of the longer-term cost-effectiveness analysis of hip fracture separations suggest most hospitals treated more fractures over time; this corresponded to increases in total separation costs and life years lost from having a hip fracture.

Table 7. Cost-effectiveness analyses of all hip fracture admissions

Cost-effectiveness analysis: Change in lifetime costs		
Hospital	**Analysis 1: (2008/09) - (2006/07)**	**Analysis 2: (2009/10) - (2006/07)**
FMC	$801,652	$355,540
B	$260,855	-$86,956
C	$1,478,538	$820,038
D	$1,760,661	$982,264
Cost-effectiveness analysis: Change in life years lost		
Hospital	**Analysis 1: (2008/09) - (2006/07)**	**Analysis 2: (2009/10) - (2006/07)**
FMC	-126.14	-316.60
B	-18.65	-52.07
C	-153.62	-399.42
D	-205.90	-167.82
Cost-effectiveness analysis: Cost per life year lost avoided		
Hospital	**Analysis 1: (2008/09) - (2006/07)**	**Analysis 2: (2009/10) - (2006/07)**
FMC	-$6,355	-$1,123
B	-$13,990	$1,670
C	-$9,625	-$2,053
D	-$8,551	-$5,853

Costs are reported in AUD.

In conclusion, the Southern Adelaide Health Services' falls prevention initiative may have restricted growth in fall-related and hip fracture admissions below a level that might have otherwise been observed. Admissions for a fall and/or hip fracture at FMC increased in the year following the introduction of the falls program. However, admissions at FMC started to decline in the second year of the program. Additional investigation is indicated to understand why the anticipated reduction in fall-related admissions were not observed.

Pre-operative clinic for high risk patients

A preliminary evaluation of the Perioperative High Risk Clinic at the Royal Adelaide Hospital was also undertaken utilising the RAC-E methodology. The main aim was to determine the costs and benefits of preoperative management of medical co-morbidities at specialist clinics. The case study evaluated the cost-effectiveness of the clinics for patients referred for transurethral resection of the prostate (TURP), compared with standard practice.

Methods

Between January 2008 and December 2010, 336 patients were placed on the surgical waiting list for an elective TURP. Of these, 46 (14%) were referred to the high risk clinic for preoperative optimisation of medical co-morbidities. A range of preoperative (e.g. age, co-morbidities) and postoperative (e.g. length of stay, complications, readmissions) data were extracted from the OACIS hospital data repository for the 46 TURP patients referred to the clinic, and 184 patients who were listed for TURP, had at least one recorded modifiable co-morbidity, but who were not referred to the high risk clinic. Eight modifiable co-morbidities that are specifically targeted at the high risk clinic were identified: anaemia, diabetes mellitus, heart failure, stroke, renal impairment, ischaemic heart disease, dementia including Alzheimer's disease, asthma or chronic obstructive pulmonary disease. To control for differences in baseline characteristics, the extracted preoperative data were used to match clinic and control patients who proceeded to surgery, and those who did not.

Results

The matched analysis of elective TURP patients indicates that patients who attended the high risk clinic for preoperative medical optimisation of co-morbidities and went on to surgery had shorter length of stay and lower numbers of postoperative complications and deaths. In the cohort of patients who did not go on to surgery, 15% (4/26) of control patients cancelled on the day of surgery, whilst only 4% (1/26) of patients who attended the high risk clinic cancelled on the day.

A combined analysis of patients who did, and did not go onto surgery is ongoing. The RAC-E methodology will be used to predict separation costs, length of stay, and the likelihood of a TURP without serious complications, and so inform estimates of net costs and net benefits for clinic and control patients. In this analysis, data on outpatient attendances is also being accessed in order to provide more information on outcomes, i.e. more frequent post-operative outpatient attendances may reflect worse outcomes.

Subsequent analyses of net costs and net benefits of different patient sub-groups (e.g. as defined by age, and number and type of modifiable co-morbidities) across a broader range of surgical procedures will identify those sub-groups with the greatest potential for cost-effective referral to the preoperative clinic. This will inform optimal clinic capacities and referral patterns.

3.6 METHODS TO INVESTIGATE POTENTIAL DETERMINANTS OF VARIATION IN RAC-E

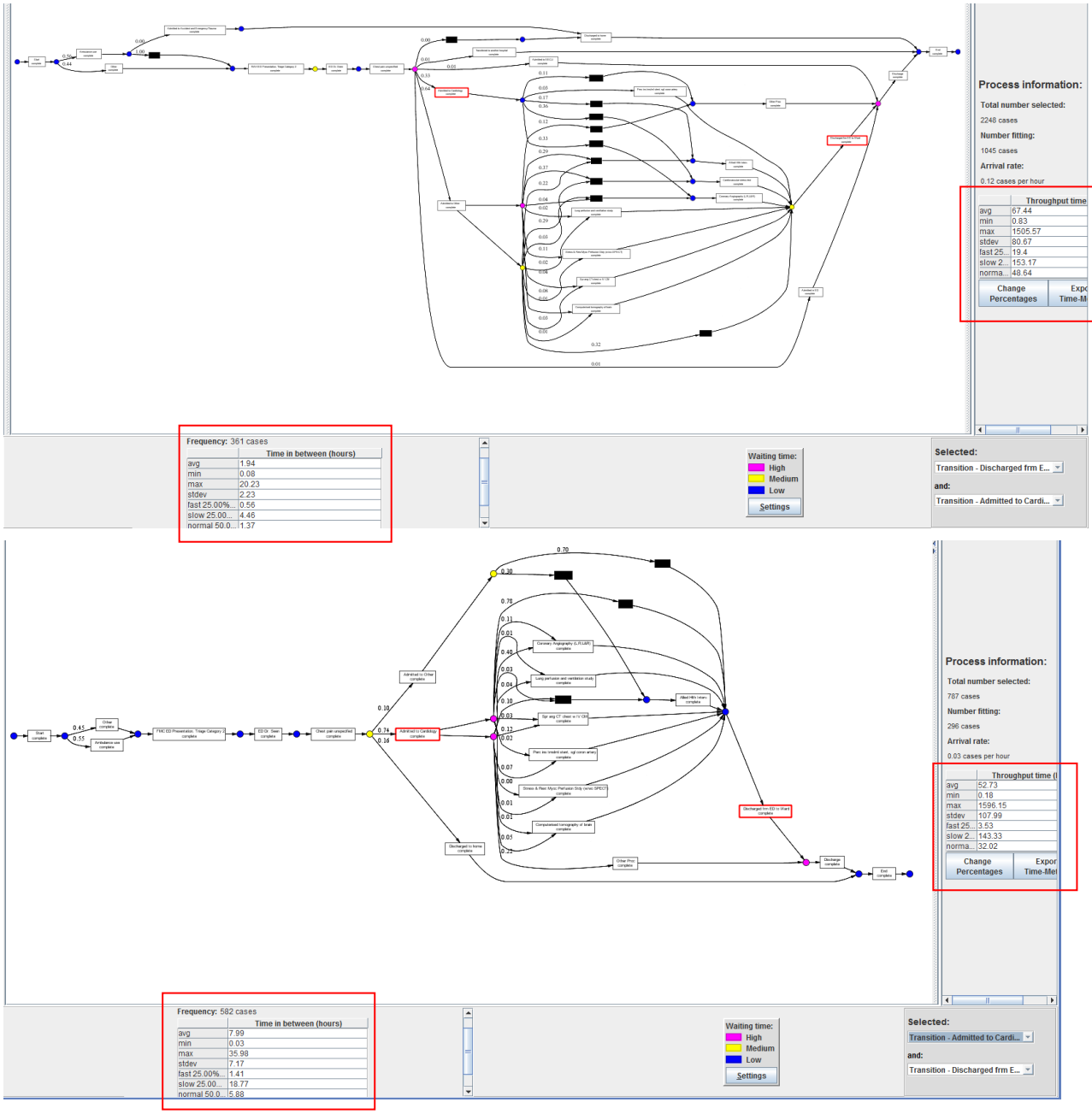
The presented analyses of potential determinants of variation in RAC-E in sections 3.1 to 3.3 are necessarily crude, and it is recognised that further evidence of differences in care pathways might be required to complement the results of the RAC-E analyses. To this end, an Honours student (Andrew Partington) has been investigating alternative approaches to pathway analysis of clinical practice. A distinction was noted between prescriptive and descriptive approaches, and within the latter category three possible approaches to representing applied clinical practice were identified: group-based assessments, statistical process control (SPC), and process mapping.

As with the application of RAC-E, our underlying objective in the analysis of pathways of care is to facilitate widespread application across multiple hospitals, without the need for the collection of large amounts of additional data. As an example of a group-based assessment, Lean Thinking is a proven method (Ben-Tovim *et al.* 2008), but it requires significant logistical organisation that would not be feasible on a widespread basis. SPC is commonly applied to outcomes (e.g. monitoring mortality rates), though it can be used to compare differences in throughput it lacks the flexibility to represent complex clinical pathways in sufficient detail.

Process mining involves the analysis of process information to represent applied pathways of clinical practice. It comprises a wide range of analytic approaches, including cluster analyses of dominant pathways and mapping to represent the sequential order of clinical decision making, which can also capture timing between events/across a process, and the proportion of event occurrence (van der Aalst 2011).

Figure 7 illustrates one form of process mining output – Petri-nets, which represent the frequency and timing of alternative processes. In this analysis of patients with an emergency department (ED) diagnosis of chest pain, who are assigned to triage category 2 (patients seen within 10 minutes), there is a difference in the total time from admission to ED to discharge from hospital (hospital A 67.44 vs. hospital B 52.73 hours). The analysis can also hone in particular aspects of the process, for example, 53% (A) vs. 74% (B) of patients are admitted to a cardiology ward, and the average delay between the decision to admit a patient to a cardiology ward and discharge from the ED to the ward is 1.94 hours (A) vs. 7.99 hours (B).

Figure 7. Petri-net for Triage Category 2 with Chest Pain at Hospital A (top) and B (bottom)



4 FURTHER RESEARCH AND CONCLUSIONS

The feasibility of Risk Adjusted Cost-Effectiveness (RAC-E) to evaluate the cost-effectiveness of alternative applied forms of clinical practice has been established during the course of the report research project. To increase the impact of RAC-E with respect to improving policy and practice, there are three broad areas in which further developments are required.

Data

Initial RAC-E applications used the minimum hospital dataset (as collected by the Integrated South Australian Activity Collection). Over the course of the project data recorded on the Open Architecture

Clinical Information System (OACIS) was found to provide significantly more information on clinical aspects, for example, instead of potential inconsistent recording of whether a patient has diabetes (ISAAC), laboratory test results recording glycated haemoglobin levels are available on OACIS, which provide a more robust basis for controlling for differences in casemix between hospitals. As such OACIS is an extremely useful data source, but there is no routine process for accessing OACIS data for research purposes. Future research will be aided by improved access to OACIS data.

In the short- to medium-term, the intention is to start applying RAC-E to hospitals across Australia, and hence identify cost-effective clinical practice from a wider set of institutions. This will require access to a national source of linked, routinely collected data. Work in this area is starting to pick up pace, and the Population Health Research Network has been established to create Australia's first national data linkage network. It is expected that applications from researchers to undertake national data linkage projects will be accepted in the first half of 2012 [http://www.phrn.org.au/for-data-users/register-your-interest].

Alternatively, access to registry data potentially provides an even better source of data to inform RAC-E. Registries often collect more detailed demographic and clinical information than routinely collected data, and data quality is generally better, for example, systems are put in place to reduce the amount of missing data and quality audits check data validity. The research team has established good contacts with the lead investigators of the Australian Stroke Registry (Professor Craig Anderson, University of Sydney), and the Acute Coronary Syndrome Prospective Audit (ACACIA) and the SNAPSHOT ACS study (Professors Derek Chew, Flinders University and David Brieger, University of Sydney). Future research will use data from these studies to analyse RAC-E in these clinical areas.

Methodological RAC-E issues

A range of methods issues need to be explored. A key issue concerns the approach used to risk adjust. Initial applications used fixed effects (or non-hierarchical) regression models to estimate expected cost and outcome values. More recent applications have looked at the use of genetic matching algorithms to identify matching cohorts of patients with similar baseline demographic and clinical characteristics.

If applied nationally, matching becomes infeasible. However, it will be important to control for differences in hospital characteristics (e.g. size, teaching status, etc.) and so hierarchical (or multilevel) modelling approaches will be required. The validity of regression-based approaches will need to be established against more conservative methods, such as matching.

As in all observation studies, unmeasured confounding is a potential source of bias. Instrumental variables (variables that are highly correlated with the probability of attending a particular hospital, but unrelated to the measured outcomes) can be used to imitate the process of randomisation (Gowrisankaran & Town 1999). Further work is required to assess the potential for using variables such as distance between hospitals and patients' location prior to hospitalization, within the RAC-E framework.

Other issues include investigation of the trade-off between using recent data (to evaluate contemporary clinical practice) and the duration of the observation period used to identify intermediate endpoints (from which long-term costs and benefits are extrapolated). This will involve assessing the stability of RAC-E across alternative observation periods, noting that the optimal observation period may vary by clinical area.

Another area of methodological development involves the use of the quality adjusted life year (QALY) as a measure of outcome in RAC-E. The QALY is the preferred measure of outcome for cost-effectiveness analysis because it represents both survival and quality of life (QoL) effects. Decision analytic frameworks facilitate the estimation of QALYs via the assignment of QoL weights to health states represented in the

model. Approaches to extending RAC-E to incorporate QoL effects will be investigated, perhaps by extending the health states and pathways represented in the decision analytic model structures.

Determinants of variation in RAC-E

As noted in section 3.6, the perceived limitations of linked routinely collected data, with respect to completeness and detail, means that on their own, RAC-E analyses are unlikely to provide sufficient evidence to change practice. Corroborating data, that identifies links areas of variation in clinical practice to estimated differences in costs and benefits, are hypothesised to provide a greater incentive to both clinicians and health service managers to change processes in order to improve performance.

The research team has identified the area of 'process mining' as a potentially useful quantitative method that can be used to represent processes (or pathways) of care using routinely collected clinical data. Preliminary applications to compare pathways of care for patients presenting with chest pain have shown that it is particularly useful for identifying variations in processes between different hospitals.

Further exploration and application of process mining is required to define optimal, and preferably standardized, approaches to the collection and formatting of routinely collected data, analysis, and reporting of the outputs, so as to validate evidence of variation in RAC-E across institutions.

Conclusions

The significance of the developed RAC-E methodology is that it provides an empirical basis for defining cost-effective clinical practice (practice-based evidence). The use of routinely collected data means that RAC-E can be applied across wide areas of clinical practice at relatively low cost.

Further refinement of the RAC-E methodology is required (and ongoing). In particular, further exploration and application of process mining is required to define optimal, and preferably standardised, approaches to the validation of evidence of variation in RAC-E.

However, the existing methodology generates robust estimates of the consequences of variation in clinical practice (i.e. differences in costs and outcomes), which in combination with pathway methods, such as process mining (to identify specific areas of variation) provides a powerful research tool to inform and encourage the adoption of cost-effective clinical practice.

To facilitate the routine use of RAC-E to improve policy and practice, easier access to more detailed and more contemporary data for both RAC-E analyses and process mining would be of great value.

5 ADDITIONAL RESOURCES

Manuscripts:

Karnon J, Ben-Tovim D, Pham C, Caffrey O, Hakendorf P, Crotty M, Phillips P. The efficient price: an opportunity for funding reform. **Australian Health Review (accepted March 2011).**

Karnon J. Fixing the postcode lottery is a matter of life and death, theconversation.edu.au/articles/fixing-the-hospital-postcode-lottery-is-a-matter-of-life-and-death-1373. **The Conversation (published 5 May 2011).**

Caffrey O, Pham C, Karnon J, Ben-Tovim D, Hakendorf P, Crotty M. Comparing hospital services for patients presenting with chest pain: risk adjusted cost-effectiveness (RAC-E). **Revised version submitted to Health Economics, October 2011.**

Pham C, Caffrey O, Karnon J, Ben-Tovim D, Hakendorf P, Crotty M. Evaluating acute stroke services: risk adjusted cost-effectiveness (RAC-E) analysis using routinely collected data. **Submitted to BMC Health Services Research, March 2011**.

Gordon J, Pham C, Karnon J, Crotty M. Assessing the longer-term effectiveness and efficiency of hospital-based hip fracture services: a retrospective analysis using linked routinely collected data. **Submitted to Journal of Health Services Research and Policy, October 2011.**

Gordon J, Pham C, Karnon J, Crotty M. Trends in hip fracture admission rates and outcomes in South Australia. **Draft manuscript.**

Presentations:

Evaluating acute stroke services: risk adjusted cost-effectiveness (RAC-E) analysis using routinely collected data. **Australian Health Economics Society Conference, Sydney**, September 2010.

Identifying efficient acute clinical pathways for chest pain: using risk adjusted cost-effectiveness (RAC-E) and linked, routinely collected data to compare hospitals. **International Society for Pharmacoeconomics and Outcomes Research, Baltimore**, March 2011.

Economic analysis of health services: developing methods to identify, investigate, and disseminate best clinical practice. Presented at the **Health Economics Study Group, Bangor, Wales**, July 2011.

Risk adjusted cost-effectiveness analysis of clinical practice: a first step, **National Stroke Data and Quality Improvement Meeting** (NSDQI), Adelaide Convention Centre, 13 September 2011.

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APPENDIX 1

Project management

- How well the research team worked together to fulfil the objectives of the project

The research team was assembled for the purposes of this project, and the team has worked extremely well. The combination of health economics (Karnon), clinical epidemiology (Ben-Tovim and Hakendorf), and clinical expertise in key areas of investigation (Crotty) has been of great value and led to ongoing research relationships that have involved specific applications of RAC-E, as well as applications for funding to continue the development and application of the RAC-E methodology.

- Whether there was adequate support from the reference, advisory and/or user groups, as appropriate

The team have had ready access to a range of relevant clinical and policy expertise. In addition to the round of interviews conducted with key clinical experts to inform priority areas for investigation, input to analytic structure and interpretation of the results of the various applied RAC-E analyses have been obtained from individual clinicians (as listed in the report), clinical networks (e.g. the Statewide Stroke Clinical Network), policy forums (e.g. the Data Analysis group at SA Health, the Do It for Life co-ordinators, as well as the policy steering group at SA Health).

- The contributions made by the above groups to the production of the research, and research outputs, and the effectiveness of collaborative arrangements across these groups

As above, the range of groups and individuals listed above provided significant input to the research at various stages. All contacted groups and individuals had a keen interest in the subject of the research and so collaborative arrangements worked well.

- Any problematic issues which hindered the progress of the research

As RAC-E uses linked, routinely collected data, a significant period of time was required to assemble the master dataset. SANT Datalink only came into being during the course of the research project and so we were not able to access their services.

Initial RAC-E applications used the minimum hospital dataset (as collected by the Integrated South Australian Activity Collection). Over the course of the project we moved towards the use of data collected by OACIS, which provides significantly more information on clinical aspects of eligible patients (e.g. instead of potentially inconsistent recording of whether a patient has diabetes (ISAAC), laboratory test results recording HbA1c levels are available, which provide a more robust basis for controlling for differences in casemix between hospitals. As such OACIS is an extremely useful data source, but there is no routine process for accessing OACIS data for research purposes. Future research will be aided by improved access to OACIS data.

APPENDIX 2

Table A1. Potential case studies identified from initial prioritisation method

Condition	Reasons for consideration	Recommendations regarding further research
Caesarean section (DRG O01C)	Ranked 8th in terms of highest change in total costs between 2001-02 and 2006-07. The birth rate in SA is increasing and so to are the rates of caesarean section, with a significant proportion of women opting for an elective caesarean section. There is potential for improvement, as there are various models of care across the SA hospitals.	Despite the significant increase in the birth-adjusted rate of elective caesarean section, it is recommended that further investigation be postponed due to the difficulties with changing patient and clinician behaviour. Prof Jeffrey Robinson advised that the significant increase in elective caesarean section was patient and clinician-led, and several interventions such as motivational pamphlets and a peer support network had not influenced a behavioural change. A/Prof Peter Baghurst from the Epidemiology Unit at the Women's & Children's Hospital also mentioned these difficulties to explain his current focus on emergency caesarean section rates and addressing clinical decision-making. However, there is some scope for identification of risks and benefits and a cost consequence analysis of elective caesarean section if further investigation is warranted.
Chest pain, unspecified (DRG F74Z)	Ranked 4th in terms of highest change in total costs and 5th for OBDs between 2001-02 and 2006-07. From discussion with clinicians, it was highlighted as a possible priority area and proposed that increased costs could be associated with: 1. The patients grouped into this DRG are thought to be low-risk patients who are given numerous diagnostic tests unnecessarily. 2. Patients admitted as inpatients as a precautionary measure – in case there is a heart condition that could have serious health consequences if patient is discharged without treatment.	Discussion within the research team identified that future research should examine the organisation of services for chest pain patients. It was deemed unlikely that we would be able to influence the actual diagnostic procedures performed. However, there was great potential for improving the pathways and patient flows through the system.
Falls (external cause codes were used to identify fall-related injuries)	Investigations into the DRG for Syncope & Collapse led to the identification of Falls as a condition of interest. Falls were identified as a potentially important area in which the threshold for admitting patients who fall may have lowered over time. Our clinical advisor also thought there may be variation between hospitals in terms of investigating the consequences of falls.	The findings indicate that the threshold for admission has lowered. The main potential area for further research is around diagnostic pathways for patients presenting following a fall, in particular for patients for whom fracture is excluded as a diagnosis.

Table continued over page

Table A1 continued

Condition	Reasons for consideration	Recommendations regarding further research
Hip replacement (DRG I08A & I03B)	Ranked 24th and 26th in terms of highest change in total costs between 2001-02 and 2006-07. It was highlighted as an area of interest by the clinical advisors on the steering committee, as there was thought to be significant variation in the process of rehabilitation post-surgery. Also, the scope for identifying differences in downstream events is increased due to the older age profile of the patient population, and high levels of co-morbidities that lead to increased risk of complications, and subsequent readmissions.	Discussion within the research team identified two main areas amenable to change. Therefore, it is recommended that further investigations focus on the length of hospital stay for both acute care and rehabilitation and the rehabilitation processes across different hospitals. There would also be minimal delay in the commencement of subsequent analyses, as linked patient data on rehabilitation already exists.
Oesophagitis (DRG G67)	Ranked 14th and 19th in terms of highest change in total costs between 2001-02 and 2006-07. It was hypothesized that the increasing costs and OBDs could be the result of a lowering of the threshold for admission and partly caused by increased incidence of alcohol-related conditions.	The findings indicate that the threshold for admission has lowered. There was potential for improving the pathways and patient flows through the system; however, the complexity due to the broad DRG category and the difficulty with differentiating within the category may limit further analysis.
Respiratory (multiple DRGs)	Several respiratory DRGs had increased costs and/or increased OBDs between 2001-02 and 2006-07. From discussion with clinicians, it was highlighted as an area of interest as management protocols differed greatly across hosptials with increasing admissions for COPD, respiratory failure, and respiratory infections.	The findings indicate that further investigation into the COPD, pneumonia, and respiratory infections groups will stop since each group cannot be analysed independently of each other due to coding issues. With respect to non-specific respiratory symptoms (NSRS), we could analyse the cost-effectiveness of alternative processes for investigating patients presenting with NSRS. This would include a review of the literature to identify previous analyses, guidelines, and test characteristics of the tests that could be used.
Septicaemia (DRG T60A)	There was a 31% cost increase in treating septicaemia between 2001-02 and 2006-07. From discussion with clinicians Septicaemia was highlighted as a possible priority area and proposed that increased costs could be associated with: 1. increasing prevalence of septicaemia 2. a definitional change around the diagnosis of septicaemia 3. additional investigations for patients identified as having a chest infection, e.g. previously an infection would be identified and treated (with antibiotics).	At this stage, the possible future direction of the analysis was discussed within the research team. The key issue was determined to be the increasing number of hospital acquired Sepsis. It is probable that further research in this area would result in controversy among clinicians and the key hospitals, which in turn, could have a detrimental impact on the project.

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Table A1 continued

Condition	Reasons for consideration	Recommendations regarding further research
Stroke (DRG B70)	Ranked 19th in terms of highest change in total costs between 2001-02 and 2006-07. It was highlighted as an area of interest by the clinical advisors on the steering committee, as it is classified as a high burden of disease illness with many stroke survivors requiring ongoing rehabilitation and support in the community. The practices for the management and treatment of stroke have also changed. In 2003-04, the Flinders Medical Centre established a multidisciplinary stroke unit and the National Stroke Foundation have recently published NHRMC-approved clinical guidelines.	Discussions within the research team identified that further research should evaluate the management and treatment of stroke, comparing models of care in different hospitals, and the effects of stroke rehabilitation. Similar to the case study for hips, there would be minimal delay in the commencement of the rehabilitation analyses, as linked patient data on rehabilitation already exists.
Transient ischaemic attack (TIA) (DRG B69)	This was lower down on the rankings of highest change in total costs but was deemed important by the clinical advisors as treatment and management of this condition would have a direct impact on the risk of stroke. Awareness of this condition has also increased markedly in recent years through the National Stroke Foundation.	Discussions within the research team identified that further research should examine the management of TIA (including the effects of increased tissue plasminogen activator use) and its impact on the likelihood of stroke.

Table A2. Potential case studies identified from revised prioritisation method

Condition	Analysis of differences in costs*		Recommendations regarding further research
Hip replacement (DRG I08A & I03B)	Cost difference:	19% for I08A 36% for I03B	The preliminary investigation indicates that the management of hip replacement patients in terms of surgery and rehabilitation would make a good case study. The main sources of cost appear to be for the types of prostheses used, which vary across the key hospitals. Costs for pathology and nursing ward also differ across hospitals. Analyses should be stratified by principal diagnoses: S72 (fracture neck of femur) and M16 (coxarthrosis).
	Overall mean cost:	$ 16,508 for I08A $ 18,282 for I03B	
	Aggregate costs for 2006-07:	$ 6,999,266 for I08A $ 7,257,831 for I03B	
Transient ischaemic attack (DRG B69)	Cost difference:	89% for B69A 67% for B69B	The management of TIA is currently a topical issue and the preliminary investigation indicate that it would make a good case study. The principal diagnoses and DRG categories are fairly simple, the average costs between hospitals for the management and treatment varies greatly, and the number of hospital admissions has increased (94% for B69A and 17% for B69B) from 2003-04. The main sources of cost appear to be for the nursing and medical wards and supplies (overhead), which vary across the key hospitals. Costs for imaging, pathology and allied health also differ across the hospitals.
	Overall mean cost:	$ 4,732 for B69A $ 2,195 for B69B	
	Aggregate costs for 2006-07:	$ 662,416 for B69A $ 649,759 for B69B	
Headache (DRG B77Z)	Cost difference:	107%	The preliminary investigation indicate that it would make a good case study; however, due to the complexities with the diagnosis and treatment of headache, this will be given a lower priority rating. The principal diagnoses and DRG categories are fairly simple, the average costs between hospitals for treatment varies greatly, and the number of hospital admissions has increased by 44% from 2003-04. The main sources of cost appear to be for nursing and medical wards, which vary across the key hospitals. Costs for imaging and pathology also differ across the hospitals.
	Overall mean cost:	$ 1,217	
	Aggregate costs for 2006-07:	$ 729,101	
Lens procedures, sameday (DRG C16B)	Cost difference:	143%	The preliminary investigation indicate differences in costs across the hospitals; however, as patient level costs are not available for NHS and private, the risk adjusted cost-effectiveness will not be complete. The main sources of cost appear to be for surgery and the prostheses. Costs for the nursing and medical wards and non-clinical salaries also differ across the hospitals.
	Overall mean cost:	$ 2,269	
	Aggregate costs for 2006-07:	$ 4,571,887	

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Table A2 continued

Condition	Analysis of differences in costs*		Recommendations regarding further research
Chronic obstructive airways disease (DRG E65)	Cost difference:	24% for E65A 107% for E65B	The preliminary investigation indicate differences in costs across hospitals for imaging, pathology and pharmacy; however, the lack of patient level cost data for the Repatriation General Hospital (RGH) may limit the analyses, particularly for pulmonary rehabilitation. Consultation with a respiratory physician indicated that some hospitals have more aggressive discharge as part of management protocol (e.g. Princess Alexandra Hospital - Brisbane, The Alfred Hospital - Melbourne). Also, facilities offering pulmonary rehabilitation were limited in Adelaide (only RGH).
	Overall mean cost:	$ 5,648 for E65A $ 3,155 for E65B	
	Aggregate costs for 2006-07:	$ 7,270,436 for E65A $ 2,119,973 for E65B	
Automated implantable cardioverter defibrillator (AICD) (DRG F01)	Cost difference:	126% for F01A 122% for F01B	Despite the large variations in cost across hospitals, particularly for the prostheses, this may not be a good case study due to the heterogeneity of the principal diagnoses.
	Overall mean cost:	$ 33,265 for F01A $ 26,320 for F01B	
	Aggregate costs for 2006-07:	$ 4,091,547 for F01A $ 2,368,773 for F01B	
Cardiac pacemaker (F12Z)	Cost difference:	37%	There appears to be a large difference in costs across hospitals for what should be a standard procedure and would make a good case study for comparing the costs and outcomes of different prostheses. Other sources of high costs include medical and nursing wards and goods and services supplies.
	Overall mean cost:	$ 10,832	
	Aggregate costs for 2006-07:	$ 5,047,554	
Percutaneous coronary intervention (DRG F10Z, F15Z & F16Z)	Cost difference:	25% for F10Z 31% for F15Z 71% for F16Z	Despite the variations in cost across the hospitals, particularly for the prostheses (e.g. stents), this may not make a good case study due to the heterogeneity of the PDs. Other sources of high costs include nursing ward and pharmacy.
	Overall mean cost:	$ 9,165 for F10Z $ 6,942 for F15Z $ 3,754 for F16Z	
	Aggregate costs for 2006-07:	$ 5,801,580 for F10Z $ 4,443,088 for F15Z $ 60,059 for F16Z	

* where the cost difference is the difference between the highest cost and the lowest cost of the 4 key hospitals, the mean cost is based on the mean costs from the 4 key public hospitals, and aggregate costs are across all hospitals in SA.