BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2017-019226
Article Type:	Research
Date Submitted by the Author:	21-Aug-2017
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Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Cardiovascular medicine, Research methods
Keywords:	Coronary heart disease < CARDIOLOGY, Cardiac Epidemiology < CARDIOLOGY, STATISTICS & RESEARCH METHODS

Title: Exploring the effects of transfers and readmissions on trends in population counts of hospital admissions for coronary heart disease: a Western Australian data linkage study

Type of manuscript: Original research article

Running title: Transfers, readmissions and heart disease counts

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Word count: 3,024 words

Abstract: 250 words

References: 25

Figures: 2

Tables: 2

Supplementary tables: 2

ABSTRACT

Objective To test and develop more reliable methods for counting hospital admissions using linked administrative hospital data to monitor trends in coronary heart disease (CHD) and its subtypes in the population.

Design Cohort study

Data source Person-linked hospital administrative data covering all admissions for CHD in Western Australia from 1988 to 2013.

Main outcome Ratios of (i) unlinked admission counts to contiguous admission (CA) counts (accounting for transfers), and (ii) 28-day episode counts (accounting for transfers and readmissions) to CA counts stratified by CHD subtype, sex and age-group.

Results In all CHD subtypes, the ratios changed in a linear or quadratic fashion over time and the coefficients of the trend term differed across CHD subtypes. Furthermore, for many CHD subtypes the ratios also differed by age-group and sex. For example, in females aged 35-54 years, the ratio of unlinked to CA counts for non-ST elevation myocardial infarction admissions in 2000 was 1.10 and this increased in a linear fashion to 1.30 in 2013, representing an annual increase of 0.0148.

Conclusion The use of unlinked counts in epidemiological estimates of CHD hospitalisations overestimates CHD counts. The CA and 28-day episode counts are more aligned with epidemiological studies of CHD. The degree of overestimation of counts using only unlinked counts varies in a complex manner with CHD subtype, time, sex and age-group and it is not possible to apply a simple correction factor to counts obtained from unlinked data.

Key words: coronary heart disease; transfers; readmissions; ratios; counts

Strengths and limitations of this study

- Use of statewide administrative data captures all hospital admissions in Western Australia.
- Record linkage allowed the identification of contiguous admissions to account for transfers and 28-day episodes.
- Whilst the complex pattern of counts and ratios presented are from a single jurisdiction in Australia, it is likely that the methods described will be generalisable to other states and territories.
- The limitation of this study includes the validity of coding for coronary heart disease in administrative data.
- The use of 28-day episodes may miss a small number of related readmissions which occur beyond 28 days.

INTRODUCTION

Coronary heart disease (CHD) remains a major cause of death in Australia.[1] Clinically it manifests across a spectrum of subtypes, from ST-elevation myocardial infarction (STEMI) (the most severe), non-STEMI (NSTEMI), unstable angina, stable angina through to other chronic presentations. Accurate information on population trends in CHD event rates and its subtypes is essential for planning and evaluation of appropriate public health measures and clinical services. Until the late 1990s, it was possible to monitor acute CHD rates in the Australian population using a measure based on administrative data for myocardial infarction (MI) and CHD deaths.[2 3] However, the introduction of more sensitive cardiac biomarkers for MI diagnosis mean this measure is no longer a reliable population trend indicator.[4-6] The focus on MI alone fails to provide a complete understanding of the size of the problem of suspected CHD or its outcomes and reliable estimates of CHD events at the population level are predicated on accurate stratification of CHD subtypes, for which there are limited data in Australia.

Population hospital administrative data provides a valuable data source in this regard, where each admission is a separate record and diagnosis. However, admissions counts are susceptible to over-inflation if the patient is transferred or readmitted multiple times during their clinical course for essentially a single episode of care. This is especially true for the management of CHD which has historically been characterised with high rates of hospital transfers and early readmissions.[2] Indeed, contemporary Australian data has shown that around 18-30% of patients hospitalised for MI are transferred to another hospital,[7 8] often for highly specialised coronary artery procedures, most notably coronary angiography and revascularisation by percutaneous coronary intervention (PCI). These specialised coronary care services are generally located at major population centres, and many patients, especially those from non-urban areas, are transferred to one of these hospitals for treatment and management of their condition.[9] In addition, a significant number of MI patients are readmitted for

complications post-MI (such as repeat MI or heart failure), for elective procedures (such as coronary artery revascularisation or electrophysiological investigation), and to a lesser degree, for non-cardiac related admissions.[10 11]

Therefore, there is potential to overestimate hospitalisation rates and incidence of CHD and to under-estimate MI case fatality, as the latter uses hospital admission counts as denominators.[12] Hence, there is a need to test and develop more reliable methods for counting hospital admissions using linked administrative hospital data to monitor trends in CHD and its subtypes in the population. Our aims were to: (i) develop an approach to identify and categorise admissions for each CHD subtype accounting for hospital transfers from linked hospital data; (ii) compare counts of unlinked CHD admissions with linked data accounting for transfers and early readmissions; and (iii) examine whether the ratios of these counts show similar or disparate patterns over time and across age and sex groups for each CHD subtype.

METHODS

Data source and study population

We used person-linked administrative health data from the Hospital Morbidity Data Collection, one of the core datasets of the Western Australian Data Linkage System. Western Australia (WA) is representative of national sociodemographic and health indicators,[13] with an estimated resident population of 2.5 million in 2013.[14] The available dataset included all hospital records for any person hospitalised with CHD in WA from 1988 to 2013. We included all fatal and non-fatal admissions, with age restricted to 35-84 years. Variables available included demographic information, admission and discharge dates, principal and 20 secondary discharge diagnosis fields, and hospital locations.

Identification of CHD subtypes for individual (unlinked) admissions

All CHD admissions were identified from the principal discharge diagnosis field based on ICD-9-CM (1st January 1988 to 30th June 1999) and the International Statistical Classification of Diseases and Related Health Problems, Tenth Revision, Australian Modification (ICD-10-AM) (1st July 1999 to the present). CHD subtypes were defined as: transmural MI/STEMI (ICD-9-CM: 410.0-410.6, 410.8; ICD-10-AM: I21.0-I21.3) (hereafter STEMI), subendocardial MI/NSTEMI (410.7; I21.4) (hereafter NSTEMI), unspecified MI (410.9; I21.9), unstable angina (411.1; I20.0), stable angina (413; I20.1-I20.9), other CHD (411.0, 411.81, 411.89, 412, 414; I23-I25). Other CHD includes complications following MI and chronic ischaemic heart disease. An addition to the labelling of transmural or subendocardial MI was added in ICD-10-AM in 2004, with reference to STEMI ("transmural or STEMI") and NSTEMI ("subendocardial or NSTEMI") included. All MI is a combination of STEMI, NSTEMI and unspecified MI; acute coronary syndrome (ACS) is a combination of All MI and unstable angina; and All CHD is a combination of ACS, stable angina and Other CHD.

Identifying transfers and readmissions

An inter-hospital transfer occurs when a patient is discharged from one hospital and directly admitted to another hospital within one day. Patients can have multiple transfers related to the same presentation. We introduce the concept of a *contiguous admission* (CA) which may represent a single isolated admission or an uninterrupted continuous hospital stay as a result of one or more transfers between hospitals. The admission date for the CA is the admission date of the first admission in the sequence. We also define a *28-day episode of care*, which comprises an index CA and any subsequent CAs occuring within 28 days of the admission date of the index CA. A CA that begins more than 28 days after the

index CA is considered a new episode of care. The 28-day period is commonly used in epidemiological studies.[15-17]

Assigning principal diagnosis for CHD subtype to each CA and 28-day episode

Each admission in a CA has its own principal discharge diagnosis code that may vary between admissions. We have calculated CA counts based on four approaches described below.

Diagnosis hierarchy: This is based on the work of Sanfilippo et al,[6] and reflects the severity of the CHD subtypes from STEMI (most severe), NSTEMI, unstable angina, stable angina to Other CHD (least severe). For a CA with multiple principal diagnoses, the most severe diagnostic category is used.

Hospital hierarchy: The hierarchy is metropolitan tertiary hospital (specialised cardiac care, diagnostic angiography and PCI), private metropolitan hospital (with and without aforementioned tertiary care), metropolitan non-tertiary hospital and rural/remote hospital. During the study period, all three metropolitan tertiary and four private hospitals had a cardiac catheter laboratory.[18] None of the metropolitan non-tertiary or rural/remote hospitals had a cardiac catheter laboratory at the time of this study. For a CA with multiple principal diagnoses, the principal diagnosis from the hospital highest in the hierarchy is used.

First admission: The principal diagnosis recorded from the first admission in the CA is used.

Last admission: The principal diagnosis recorded from the last admission in the CA is used.

The diagnostic CHD subtype assigned to each 28-day episode was based on the diagnosis hierarchy approach. That is, the most severe subtype of all the CAs that comprise the 28-day episode is used. Table 1 illustrates how diagnoses (CHD subtypes) are assigned to CAs (four approaches) and to 28-day

episodes for a hypothetical patient with ten hospital admissions, grouped into four CAs and three 28-day episodes.

Table 1: Example of typical patient record (not a real patient) depicting the different approaches of assigning a diagnosis to contiguous admissions (CA) and 28-day episodes.

Record No.	Patient ID	Admission date	Discharge date	Hospital	Transfer	28-day readmission	CA No.	28-day episode No.	Principal diagnosis	Diagnosis approach at the CA-level				Diagnosis at 28-day episode level
										Diagnosis hierarchy	Hospital hierarchy	First admission	Last admission	
1	1	1 Feb 2005	2 Feb 2005	Rural			1	1	Stable angina	NSTEMI	Unstable angina	Stable angina	NSTEMI	STEMI
2	1	2 Feb 2005	4 Feb 2005	Metropolitan tertiary	1		1	1	Unstable angina					
3	1	4 Feb 2005	6 Feb 2005	Metropolitan non-tertiary	1		1	1	NSTEMI					
4	1	17 Feb 2005	18 Feb 2005	Metropolitan tertiary		1	2	1	STEMI	STEMI	STEMI	STEMI	Other CHD	-
5	1	18 Feb 2005	22 Feb2005	Private	1	1	2	1	Other CHD					
6	1	10 Oct 2005	11 Oct 2005	Metropolitan non-tertiary			3	2	Stable angina	NSTEMI	NSTEMI	Stable angina	NSTEMI	NSTEMI
7	1	11 Oct 2005	14 Oct 2005	Metropolitan tertiary	1		3	2	NSTEMI					
8	1	1 Dec 2005	2 Dec 2005	Rural			4	3	Non-CHD	Stable angina	Stable angina	Non-CHD	Non-CHD	Stable angina
9	1	2 Dec 2005	3 Dec 2005	Metropolitan tertiary	1		4	3	Stable angina					
10	1	3 Dec 2005	5 Dec 2005	Private	1		4	3	Non-CHD					

Key: CHD=coronary heart disease; CA=contiguous admission

Statistical analysis

Annual counts for each CHD subtype and combination subtypes are presented at the unlinked-, CA- and 28-day episode levels for 1988 to 2013. The ratio of unlinked admission count to CA count was calculated for each age-group (35-54 years, 55-74 years, 75-84 years) and gender in each year to determine the relative overestimation of each CHD subtype. To examine the impact on counts from using 28-day episodes, we calculated the ratio of 28-day episode to CA counts for each age-group and gender in each year, for each CHD subtype. Linear regression (with robust standard errors) was used to compare the ratios statistically across age-groups and gender, and assess trends over time. This analysis was restricted to the period 2000 to 2013 as CHD counts were more consistent during this time. All models included sex, age-group, sex*age-group interaction term and year. Models also included year squared (to accommodate trend curvature) where needed ($p<0.01$). Additional terms relating to differences in time trends by sex and age-group (i.e. sex*year, age-group*year, sex*age-group*year and the curvature equivalents) were tested but found not to be needed. Analyses were performed using Stata 13.1.

Ethics approval

This study was approved by the Human Research Ethics Committees of the Western Australian Department of Health and The University of Western Australia. The study was granted a waiver of informed consent.

RESULTS

There were 296,659 unlinked hospital admissions for CHD from 1988 to 2013 in WA (Table 2). The diagnosis hierarchy approach resulted in the highest count of CHD admissions (n=273,793) and the approach based on the diagnosis from last admission resulted in the lowest count (n=263,313). The number of 28-day episodes was 242,966. The counts at the unlinked, CA-level and 28-day episode level for each CHD subtype are shown in Table 2.

Table 2: Diagnosis counts at the unlinked-, contiguous admission (CA)- and 28-day episode levels for admission years 1988 to 2013.

	Unlinked-level	CA-level				28-day episode-level
		Diagnosis hierarchy	Hospital hierarchy	Diagnosis based on first admission	Diagnosis based on last admission	
Number of CHD records	296,659	273,793	269,614	267,389	263,313	242,966
Diagnosis:						
STEMI	37,457 (12.63%)	34,435 (12.58%)	33,313 (12.36%)	32,165 (12.03%)	32,014 (12.16%)	33,364 (13.73%)
NSTEMI	29,203 (9.84%)	24,734 (9.03%)	23,956 (8.89%)	21,868 (8.18%)	22,631 (8.59%)	23,738 (9.77%)
Unstable angina	72,223 (24.35%)	65,589 (23.96%)	63,301 (23.48%)	64,478 (24.11%)	60,333 (22.91%)	59,144 (24.34%)
Stable angina	77,076 (25.98%)	73,994 (27.03%)	73,898 (27.41%)	73,845 (27.62%)	73,037 (27.74%)	64,669 (26.62%)
Other CHD	69,070 (23.27%)	65,161 (23.80%)	65,751 (24.39%)	64,632 (24.17%)	66,148 (25.11%)	52,688 (21.68%)
All MI	78,315 (26.40%)	69,049 (25.22%)	66,664 (24.73%)	64,434 (24.10%)	63,818 (24.24%)	66,487 (27.36%)
ACS	150,538 (50.74%)	134,638 (49.18%)	129,965 (48.20%)	128,912 (48.21%)	124,151 (47.15%)	125,631 (51.71%)

Key: ACS=acute coronary syndrome; CHD=coronary heart disease; MI=myocardial infarction; NSTEMI=non ST-elevation myocardial infarction; STEMI=ST-elevation myocardial infarction.

Figure 1 shows trends in annual admission counts for each CHD subtype and combination subtypes at the CA-level, using the diagnosis hierarchy approach and the three alternative approaches. The diagnosis hierarchy approach resulted in highest counts for the more severe CHD subtypes compared to the three alternative approaches, but all methods had similar trends over time for each CHD subtype.

Figure 2 compares annual CHD counts at the unlinked, CA (using diagnosis hierarchy approach) and 28-day episode levels from 1988 to 2013. The use of unlinked records resulted in the highest counts of all subtypes while 28-day episode records resulted in the lowest counts. The difference between unlinked and CA counts tended to be greater in the latter half of the study period for STEMI, NSTEMI and unstable angina, while the reverse was apparent for Other CHD. The difference between unlinked and CA counts for NSTEMI, All MI and ACS increased from around 2000 onwards. The difference between CA and 28-day episode counts tended to increase from around 2000 onwards for NSTEMI but narrowed for STEMI and unstable angina.

Supplementary table 1 presents estimated ratios for unlinked to CA counts (based on diagnosis hierarchy approach) from fitted regression models by CHD subtype, sex and age-group for the period 2000 to 2013. In females aged 35-54 years, the ratio of unlinked to CA counts for NSTEMI admissions in 2000 was 1.10 (i.e. 10% higher in unlinked) and this increased in a linear fashion to 1.30 (i.e. 30% higher) in 2013 representing an increase of 0.0148 per year. Conversely, the over count for STEMI and All MI followed a curved (quadratic) trend. For subtypes with a linear trend, the trend coefficients were largest in the most severe CHD subtype (NSTEMI: increase of 0.0148/year) and smallest in the least severe subtype (Other CHD: non-significant increase of 0.0003/year). The sex*age-group interaction term was not significant in any individual or combination subtype but the ratios were significantly higher in the youngest age-group for STEMI, NSTEMI, stable angina and all

combination subtypes. Males had significantly higher ratios than females for unstable angina and ACS.

Supplementary table 2 presents the estimated ratios for CA versus 28-day episode counts. For example, in females aged 35-54 years, the ratio for STEMI was 1.10 in 2000 (i.e. 10% higher for CA counts) and this decreased to 1.01 in 2013 (i.e. 1% higher), representing a 0.0064 decrease per year. Ratios for unstable angina, stable angina, Other CHD and All CHD followed a curved (quadratic) trend. For example in females aged 35-54 years, the ratio for unstable angina was 1.15 in 2000 before levelling out at 1.09 from 2010 onwards. For unstable angina, stable angina, Other CHD, ACS and All CHD, the ratios were significantly higher in males than females. Differences in ratios between age-groups were seen for all CHD subtypes except for NSTEMI and other CHD.

DISCUSSION

We developed different approaches to assign CHD diagnoses to a sequence of consecutive admissions and 28-day episodes that account for transfers and readmissions, thereby avoiding the over-count that occurs with unlinked administrative data. Hospitalisation data from 1988 to 2013 show that for each CHD subtype, unlinked records over-counted the number of CHD hospitalisations relative to CA counts and 28-day episode counts. Our analyses of ratios from 2000-2013 showed a complex pattern of over-counting in unlinked data due to transfers and readmissions. In almost all CHD subtypes, the ratios changed in a linear or quadratic fashion over time and the coefficients of the trends differed across CHD subtypes. Further, for many CHD subtypes the ratios also differed by age-group and sex.

The development of the CA method accounts for transfers and allows for classification by CHD subtype where multiple admissions with differing discharge diagnoses are present. As each transfer and admission to the receiving hospital has its own principal discharge diagnosis, we compared four

approaches to assigning a single clinically relevant diagnosis for each CA. Of the four approaches to assigning diagnosis, we contend that diagnosis hierarchy is the most clinically relevant approach as it prioritises disease severity according to a physician's clinical judgement. Of the four approaches, diagnosis hierarchy results in the highest CHD counts and would therefore result in the most conservative differences between unlinked and CA. Hospital hierarchy is based on resourcing of hospitals with coronary care services and the level of resourcing may differ in other jurisdictions. The recent introduction of coronary care services in rural hospitals in WA, means that the hospital hierarchy method may become less applicable. Diagnosis based on first or last admission in a CA may not identify CHD-related admissions that occur in the middle of a CA, highlighted by the resulting low counts that occurred when using these methods to assign a diagnosis. A small number of patients have an MI during an admission for non-cardiac conditions,[19] and diagnosis based on first admission may not identify these CHD cases if they are subsequently transferred.

The ratios of unlinked versus CA counts for almost all subtypes (except STEMI and All MI) increased in a linear fashion, indicating a consistent increase in the over-inflation of admission numbers in unlinked data due to transfers. This likely reflects a complex mix of changes in clinical guidelines and practice, facilitated by direct transfers to hospitals with PCI capability for ACS cases and pre-hospital care protocols during this period. The widening difference between unlinked and CA counts for NSTEMI indicates an increasing rate of transfer for this group of patients. Given that NSTEMI patients are still at risk of future adverse events,[20] clinical guidelines now recommend that these patients undergo early coronary angiography and hospitalisation if indicated.[21] Patients who are not at a hospital with advanced coronary care services may be transferred as a priority to a hospital with such capabilities.

Furthermore, ratios were higher in the younger than older age-groups for all subtypes, indicating that older CHD patients were less likely to be transferred than younger patients. We also found

males had a higher ratio than females for unstable angina and ACS. These sex and age differences in transfers may partly reflect age and sex disparities in ACS care and especially invasive management reported in earlier studies,[22 23] although further studies are needed to support this theory.

28-day episodes have previously only been used to capture early MI readmissions following an index MI admission thus reducing overestimation of population rates for MI. Historically, early readmissions were often for coronary procedures or other management related to the initial MI admission. Our method ensures 28-day episodes capture any CHD readmission during this period. In general, our results show that early readmissions across all CHD subtypes have decreased, although the trend was not linear for unstable and stable angina, and Other CHD. This could indicate that most acute treatment is now managed during the initial admission or subsequent transfer, thus requiring fewer readmissions.

The findings of this study have important implications for monitoring population trends in MI and other CHD subtypes. The ratios of counts we presented would have been the same if we had used age-standardised rates as population denominators would have been the same in all three levels of counts. The trends in CA and 28-day episode counts for STEMI and NSTEMI are in accordance with other studies showing that hospital admissions for STEMI have decreased in Western countries while admissions for NSTEMI have increased.[4 24] The use of the CA and 28-day episode methods in linked data offsets over-counting of MI events which could potentially inflate trends in ASRs. In addition, it allows accurate representation of other subtypes of CHD, for which there are limited data at a whole-population level.

Although we have described an approach to dealing with transfers and defining episodes of care for use with CHD, these methods could be applied to other conditions that have high rates of transfer

and readmissions, such as major trauma and head injury where many patients are transferred from rural sites to major tertiary hospitals with intensive care and/or head injury units and rehabilitation.

Strengths and limitations

Strengths of our study include use of statewide data that captures all hospital admissions in WA. Record linkage allowed the identification of CAs to account for transfers and 28-day episodes. The limitations of this study include the validity of coding for CHD. An earlier WA study using linked data showed that the sensitivity of hospital coding for non-fatal MI was 76.9% in the 35-69 year olds.[6] The use of 28-day episodes may miss a small number of related readmissions which occur beyond 28 days. Furthermore, we did not adjust for confounders such as remoteness and Indigenous status which may influence transfer and readmission patterns.[9 25] Whilst the complex pattern of counts and ratios we presented are from a single jurisdiction in Australia, it is likely that the methods we have described will be generalisable to other states and territories.

Conclusions

Although unlinked data has its place in measurement of hospital health service utilisation, its use in epidemiological estimates of CHD hospitalisations overestimates CHD counts. We contend that CA (accounting for transfers) and 28-day episode (accounting for transfers and readmissions) counts are more aligned with epidemiological studies of CHD. The degree of overestimation of counts using only unlinked records varies in a complex manner with CHD subtype, time, sex and age-group, it is not possible to apply a simple correction factor to counts obtained from unlinked data.

ABBREVIATIONS

ACS: acute coronary syndrome; AM: Australian modification; ASR: age standardised rates; CA: contiguous admission; CHD: coronary heart disease; CM: clinical modification; ICD: International Classification of Diseases; MI: myocardial infarction; NSTEMI: non ST-elevation myocardial infarction;

PCI: percutaneous coronary intervention; STEMI: ST-elevation myocardial infarction; WA: Western Australia

ACKNOWLEDGEMENTS

The authors thank the staff at the Western Australian Data Linkage Branch and the Department of Health Inpatient Data Collections for the provision of linked data.

FUNDING

This work was supported by the National Health and Medical Research Council (NHMRC) of Australia project grant 1078978. The grant agency does not impose restrictions on conduct of analyses or dissemination of findings. LN is funded by a National Health and Medical Research Council of Australia Early Career Fellowship.

DATA SHARING

We will consider requests for data sharing on an individual basis, with an aim to sharing data whenever possible for appropriate research purposes. However the research project uses secondary (third party) data derived from Australian (State or Federal) government registries, which are ultimately governed by their ethics committees and data custodians. Therefore, any requests to share this data will be subject to formal approval from their ethics committees overseeing the use of these data sources, along with the data custodian(s) for the data of interest.

AUTHOR CONTRIBUTIONS

MSTH, FM, LN, MK, JH and TGB conceived the study. DL performed all the data and statistical analyses, with statistical advice from MK. All authors interpreted the results. DL constructed the figures and tables, and led the write-up of this manuscript. All authors have reviewed, commented and approved this manuscript for submission.

COMPETING INTERESTS

The authors have no competing interests to declare.

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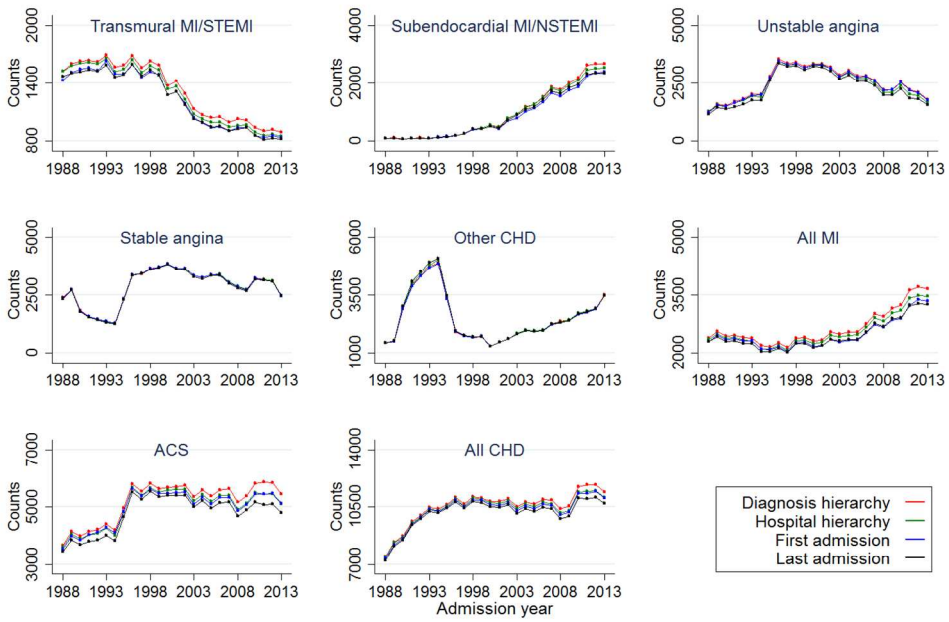

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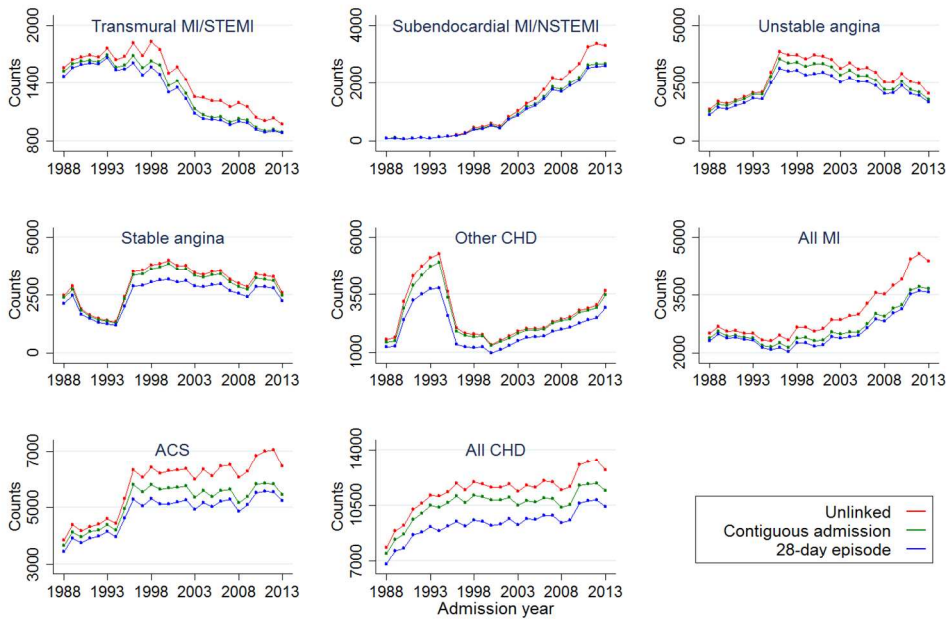

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Supplementary table 1: Estimated ratios of unlinked versus CA-level counts (diagnosis hierarchy approach) from 2000 to 2013: by CHD subtype, sex and age group

Diagnosis	Sex	Age group	Ratio (CI) in 2000	Ratio (CI) in 2013	Trend coefficient (p-value)		p-values for tests comparing		
					Year	Year squared	Sex[§]	Age group[§]	Sex*Age group
STEMI[†]	F	35-54	1.12 (1.09-1.15)	1.14 (1.11-1.18)	0.0174 (0.000)	-0.0012 (0.000)	0.946	0.000	0.945
	F	55-74	1.09 (1.06-1.11)	1.11 (1.08-1.14)	0.0174 (0.000)	-0.0012 (0.000)			
	F	75-84	1.05 (1.02-1.09)	1.07 (1.02-1.13)	0.0174 (0.000)	-0.0012 (0.000)			
	M	35-54	1.12 (1.10-1.15)	1.15 (1.11-1.19)	0.0174 (0.000)	-0.0012 (0.000)			
	M	55-74	1.08 (1.06-1.10)	1.10 (1.08-1.13)	0.0174 (0.000)	-0.0012 (0.000)			
	M	75-84	1.05 (1.03-1.08)	1.08 (1.04-1.11)	0.0174 (0.000)	-0.0012 (0.000)			
NSTEMI[‡]	F	35-54	1.10 (1.08-1.13)	1.30 (1.27-1.33)	0.0148 (0.000)		0.768	0.000	0.734
	F	55-74	1.08 (1.06-1.10)	1.27 (1.25-1.29)	0.0148 (0.000)				
	F	75-84	1.04 (1.02-1.06)	1.23 (1.21-1.25)	0.0148 (0.000)				
	M	35-54	1.12 (1.09-1.14)	1.31 (1.29-1.33)	0.0148 (0.000)				
	M	55-74	1.07 (1.06-1.09)	1.27 (1.25-1.28)	0.0148 (0.000)				
	M	75-84	1.03 (1.02-1.05)	1.23 (1.21-1.24)	0.0148 (0.000)				

Unstable angina‡	F	35-54	1.09 (1.07-1.10)	1.15 (1.13-1.16)	0.0047 (0.000)	0.000	0.010	0.445
	F	55-74	1.09 (1.07-1.10)	1.15 (1.14-1.16)	0.0047 (0.000)			
	F	75-84	1.07 (1.06-1.09)	1.14 (1.12-1.15)	0.0047 (0.000)			
	M	35-54	1.12 (1.10-1.13)	1.18 (1.16-1.20)	0.0047 (0.000)			
	M	55-74	1.10 (1.09-1.11)	1.16 (1.15-1.17)	0.0047 (0.000)			
	M	75-84	1.09 (1.08-1.11)	1.15 (1.14-1.17)	0.0047 (0.000)			
Stable angina‡	F	35-54	1.05 (1.04-1.06)	1.07 (1.06-1.08)	0.0015 (0.000)	0.031	0.000	0.776
	F	55-74	1.03 (1.03-1.04)	1.05 (1.05-1.06)	0.0015 (0.000)			
	F	75-84	1.03 (1.03-1.04)	1.05 (1.05-1.06)	0.0015 (0.000)			
	M	35-54	1.04 (1.04-1.05)	1.06 (1.05-1.07)	0.0015 (0.000)			
	M	55-74	1.03 (1.03-1.03)	1.05 (1.04-1.05)	0.0015 (0.000)			
	M	75-84	1.03 (1.02-1.04)	1.05 (1.04-1.06)	0.0015 (0.000)			
Other CHD‡	F	35-54	1.05 (1.03-1.07)	1.06 (1.03-1.08)	0.0003 (0.583)	0.057	0.072	0.630
	F	55-74	1.03 (1.02-1.04)	1.04 (1.03-1.05)	0.0003 (0.583)			
	F	75-84	1.04 (1.03-1.06)	1.05 (1.03-1.06)	0.0003 (0.583)			
	M	35-54	1.04 (1.03-1.05)	1.04 (1.03-1.05)	0.0003 (0.583)			

	M	55-74	1.03 (1.02-1.04)	1.03 (1.03-1.04)	0.0003 (0.583)				
	M	75-84	1.03 (1.02-1.04)	1.04 (1.03-1.05)	0.0003 (0.583)				
All MI[†]	F	35-54	1.15 (1.12-1.18)	1.27 (1.25-1.30)	0.0166 (0.000)	-0.0006 (0.002)	0.576	0.000	0.720
	F	55-74	1.10 (1.09-1.12)	1.22 (1.20-1.24)	0.0166 (0.000)	-0.0006 (0.002)			
	F	75-84	1.06 (1.04-1.07)	1.18 (1.16-1.20)	0.0166 (0.000)	-0.0006 (0.002)			
	M	35-54	1.14 (1.12-1.16)	1.26 (1.24-1.29)	0.0166 (0.000)	-0.0006 (0.002)			
	M	55-74	1.10 (1.09-1.12)	1.22 (1.20-1.24)	0.0166 (0.000)	-0.0006 (0.002)			
	M	75-84	1.06 (1.05-1.08)	1.18 (1.16-1.20)	0.0166 (0.000)	-0.0006 (0.002)			
ACS[‡]	F	35-54	1.12 (1.10-1.13)	1.22 (1.21-1.23)	0.0078 (0.000)				
	F	55-74	1.10 (1.09-1.10)	1.20 (1.18-1.21)	0.0078 (0.000)				
	F	75-84	1.07 (1.06-1.08)	1.17 (1.16-1.18)	0.0078 (0.000)		0.003	0.000	0.695
	M	35-54	1.14 (1.12-1.15)	1.24 (1.22-1.26)	0.0078 (0.000)				
	M	55-74	1.11 (1.10-1.11)	1.21 (1.20-1.22)	0.0078 (0.000)				
	M	75-84	1.08 (1.07-1.09)	1.18 (1.17-1.19)	0.0078 (0.000)				
All CHD[‡]	F	35-54	1.09 (1.08-1.10)	1.15 (1.14-1.15)	0.0043 (0.000)				
	F	55-74	1.06 (1.06-1.07)	1.12 (1.11-1.13)	0.0043 (0.000)				

	F	75-84	1.06 (1.06-1.07)	1.12 (1.11-1.12)	0.0043 (0.000)	0.684	0.000	0.152
	M	35-54	1.10 (1.09-1.11)	1.15 (1.15-1.16)	0.0043 (0.000)			
	M	55-74	1.06 (1.06-1.07)	1.12 (1.11-1.12)	0.0043 (0.000)			
	M	75-84	1.06 (1.05-1.06)	1.11 (1.11-1.12)	0.0043 (0.000)			

Key: ACS=acute coronary syndrome; CHD=coronary heart disease; CI=confidence interval; CA=contiguous admission; F=female; M=male; MI=myocardial infarction; NSTEMI=non ST-elevation myocardial infarction; STEMI=ST-elevation myocardial infarction.

† From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex + (admission year - 2000)^2

‡ From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex

§ p-values for sex and age group are from the respective models but without the age group*sex interaction term

Supplementary table 2: Estimated ratios of CA- versus 28-day episode-level counts (diagnosis hierarchy approach) from 2000 to 2013: by CHD subtype, sex and age group

Diagnosis	Sex	Age group	Ratio (CI) in 2000	Ratio (CI) in 2013	Trend coefficient (p-value)		p-values for tests comparing		
					Year	Year squared	Sex[#]	Age group[#]	Sex*Age group
STEMI[†]	F	35-54	1.10 (1.05-1.14)	1.01 (0.99-1.03)	-0.0064 (0.000)				
	F	55-74	1.08 (1.06-1.09)	1.01 (1.00-1.02)	-0.0064 (0.000)				
	F	75-84	1.05 (1.03-1.06)	1.03 (1.02-1.05)	-0.0064 (0.000)		0.946	0.000	0.799
	M	35-54	1.09 (1.06-1.11)	1.01 (0.98-1.03)	-0.0064 (0.000)				
	M	55-74	1.08 (1.07-1.09)	1.01 (1.00-1.02)	-0.0064 (0.000)				
	M	75-84	1.05 (1.04-1.06)	1.04 (1.02-1.06)	-0.0064 (0.000)				
NSTEMI[‡]	F	35-54	1.10 (1.06-1.14)	1.05 (1.03-1.08)	-0.0036 (0.000)				
	F	55-74	1.07 (1.06-1.09)	1.03 (1.01-1.04)	-0.0036 (0.000)				
	F	75-84	1.08 (1.06-1.10)	1.04 (1.02-1.05)	-0.0036 (0.000)		0.470	0.937	0.033
	M	35-54	1.08 (1.06-1.10)	1.03 (1.02-1.05)	-0.0036 (0.000)				
	M	55-74	1.10 (1.08-1.12)	1.05 (1.04-1.07)	-0.0036 (0.000)				
	M	75-84	1.09 (1.07-1.11)	1.04 (1.03-1.06)	-0.0036 (0.000)				

	F	35-54	1.15 (1.13-1.17)	1.09 (1.07-1.10)	-0.0124 (0.000)	0.0006 (0.001)			
	F	55-74	1.15 (1.14-1.17)	1.09 (1.08-1.10)	-0.0124 (0.000)	0.0006 (0.001)			
Unstable	F	75-84	1.17 (1.15-1.19)	1.11 (1.09-1.12)	-0.0124 (0.000)	0.0006 (0.001)	0.000	0.040	0.017
angina[§]	M	35-54	1.18 (1.16-1.20)	1.12 (1.10-1.14)	-0.0124 (0.000)	0.0006 (0.001)			
	M	55-74	1.21 (1.19-1.22)	1.15 (1.13-1.16)	-0.0124 (0.000)	0.0006 (0.001)			
	M	75-84	1.20 (1.18-1.21)	1.13 (1.12-1.15)	-0.0124 (0.000)	0.0006 (0.001)			
	F	35-54	1.14 (1.12-1.16)	1.08 (1.07-1.10)	-0.0115 (0.000)	0.0006 (0.004)			
	F	55-74	1.15 (1.14-1.17)	1.10 (1.09-1.11)	-0.0115 (0.000)	0.0006 (0.001)			
Stable	F	75-84	1.14 (1.12-1.16)	1.08 (1.07-1.10)	-0.0115 (0.000)	0.0006 (0.001)	0.000	0.009	0.097
angina[§]	M	35-54	1.20 (1.18-1.23)	1.15 (1.13-1.16)	-0.0115 (0.000)	0.0006 (0.001)			
	M	55-74	1.20 (1.18-1.22)	1.14 (1.13-1.15)	-0.0115 (0.000)	0.0006 (0.001)			
	M	75-84	1.18 (1.16-1.20)	1.13 (1.11-1.14)	-0.0115 (0.000)	0.0006 (0.001)			
	F	35-54	1.18 (1.15-1.22)	1.11 (1.08-1.14)	-0.0211 (0.000)	0.0012 (0.000)			
	F	55-74	1.19 (1.16-1.22)	1.12 (1.10-1.14)	-0.0211 (0.000)	0.0012 (0.000)			
Other CHD[§]	F	75-84	1.19 (1.16-1.21)	1.11 (1.09-1.13)	-0.0211 (0.000)	0.0012 (0.000)	0.000	0.359	0.542
	M	35-54	1.22 (1.20-1.25)	1.15 (1.13-1.17)	-0.0211 (0.000)	0.0012 (0.000)			

	M	55-74	1.23 (1.20-1.25)	1.15 (1.14-1.17)	-0.0211 (0.000)	0.0012 (0.000)			
	M	75-84	1.21 (1.19-1.24)	1.14 (1.12-1.15)	-0.0211 (0.000)	0.0012 (0.000)			
All MI[†]	F	35-54	1.10 (1.08-1.12)	1.03 (1.02-1.04)	-0.0052 (0.000)				
	F	55-74	1.08 (1.07-1.09)	1.03 (1.02-1.03)	-0.0052 (0.000)				
	F	75-84	1.06 (1.05-1.07)	1.05 (1.04-1.06)	-0.0052 (0.000)		0.077	0.000	0.112
	M	35-54	1.09 (1.08-1.11)	1.03 (1.01-1.04)	-0.0052 (0.000)				
	M	55-74	1.09 (1.08-1.10)	1.04 (1.03-1.05)	-0.0052 (0.000)				
	M	75-84	1.07 (1.06-1.08)	1.06 (1.04-1.07)	-0.0052 (0.000)				
ACS[†]	F	35-54	1.13 (1.11-1.14)	1.04 (1.03-1.06)	-0.0063 (0.000)				
	F	55-74	1.13 (1.12-1.14)	1.04 (1.03-1.05)	-0.0063 (0.000)				
	F	75-84	1.11 (1.10-1.12)	1.06 (1.06-1.07)	-0.0063 (0.000)		0.000	0.001	0.007
	M	35-54	1.13 (1.11-1.15)	1.05 (1.04-1.06)	-0.0063 (0.000)				
	M	55-74	1.16 (1.14-1.17)	1.06 (1.06-1.07)	-0.0063 (0.000)				
	M	75-84	1.12 (1.11-1.13)	1.08 (1.07-1.09)	-0.0063 (0.000)				
All CHD[‖]	F	35-54	1.14 (1.12-1.16)	1.07 (1.05-1.08)	-0.0125 (0.000)	0.0005 (0.000)			
	F	55-74	1.15 (1.14-1.17)	1.08 (1.07-1.09)	-0.0125 (0.000)	0.0005 (0.000)			

	F	75-84	1.12 (1.11-1.13)	1.08 (1.07-1.09)	-0.0125 (0.000)	0.0005 (0.000)	0.000	0.000	0.051
	M	35-54	1.17 (1.14-1.20)	1.09 (1.08-1.11)	-0.0125 (0.000)	0.0005 (0.000)			
	M	55-74	1.19 (1.18-1.20)	1.12 (1.11-1.12)	-0.0125 (0.000)	0.0005 (0.000)			
	M	75-84	1.14 (1.13-1.15)	1.11 (1.10-1.11)	-0.0125 (0.000)	0.0005 (0.000)			

Key: ACS=acute coronary syndrome; CHD=coronary heart disease; CI=confidence interval; F=female; M=male; MI=myocardial infarction; NSTEMI=non ST-elevation myocardial infarction; STEMI=ST-elevation myocardial infarction.

† From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex + age*(admission year-2000)

‡ From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex

§ From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex + $(\text{admission year-2000})^2$

‖ From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex + $(\text{admission year-2000})^2$ + age group*(admission year-2000)

p-values for sex and age group are from the respective models but without the age group*sex interaction term

BMJ Open

Exploring the effects of transfers and readmissions on trends in population counts of hospital admissions for coronary heart disease: a Western Australian data linkage study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2017-019226.R1
Article Type:	Research
Date Submitted by the Author:	29-Sep-2017
Complete List of Authors:	Lopez, Derrick; University of Western Australia, School of Population and Global Health Nedkoff, Lee; University of Western Australia, School of Population and Global Health Knuiman, Matthew; University of Western Australia, School of Population and Global Health Hobbs, Michael; University of Western Australia, School of Population and Global Health Briffa, Thomas; University of Western Australia, School of Population and Global Health Preen, David; The University of Western Australia, School of Population and Global Health Hung, Joseph; The University of Western Australia, School of Medicine Beilby, John; The University of Western Australia, School of Biomedical Sciences Mathur, Sushma; Australian Institute of Health and Welfare Reynolds, Anna; Australian Institute of Health and Welfare Sanfilippo, Frank; University of Western Australia, School of Population and Global Health
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Cardiovascular medicine, Research methods
Keywords:	Coronary heart disease < CARDIOLOGY, Cardiac Epidemiology < CARDIOLOGY, STATISTICS & RESEARCH METHODS

Title: Exploring the effects of transfers and readmissions on trends in population counts of hospital admissions for coronary heart disease: a Western Australian data linkage study

Type of manuscript: Original research article

Running title: Transfers, readmissions and heart disease counts

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Word count: 3,677 words

Abstract: 253 words

References: 24

Figures: 2

Tables: 4

Supplementary tables: 2

ABSTRACT

Objectives To develop a method for categorising coronary heart disease (CHD) subtype in linked data accounting for different CHD diagnoses across records, and to compare hospital admission numbers and ratios of unlinked versus linked data for each CHD subtype over time, and across age groups and sex.

Design Cohort study

Data source Person-linked hospital administrative data covering all admissions for CHD in Western Australia from 1988 to 2013.

Main outcome Ratios of (i) unlinked admission counts to contiguous admission (CA) counts (accounting for transfers), and (ii) 28-day episode counts (accounting for transfers and readmissions) to CA counts stratified by CHD subtype, sex and age-group.

Results In all CHD subtypes, the ratios changed in a linear or quadratic fashion over time and the coefficients of the trend term differed across CHD subtypes. Furthermore, for many CHD subtypes the ratios also differed by age-group and sex. For example, in females aged 35-54 years, the ratio of unlinked to CA counts for non-ST elevation myocardial infarction admissions in 2000 was 1.10 and this increased in a linear fashion to 1.30 in 2013, representing an annual increase of 0.0148.

Conclusion The use of unlinked counts in epidemiological estimates of CHD hospitalisations overestimates CHD counts. The CA and 28-day episode counts are more aligned with epidemiological studies of CHD. The degree of overestimation of counts using only unlinked counts varies in a complex manner with CHD subtype, time, sex and age-group and it is not possible to apply a simple correction factor to counts obtained from unlinked data.

Key words: coronary heart disease; transfers; readmissions; ratios; counts

Strengths and limitations of this study

- Use of statewide administrative data captures all hospital admissions in Western Australia.
- Record linkage allowed the identification of contiguous admissions to account for transfers and 28-day episodes to account for readmissions.
- Whilst the complex pattern of counts and ratios presented are from a single jurisdiction in Australia, it is likely that the methods described will be generalisable to other states and territories. However, the ratios obtained may be not be generalisable outside Western Australia (because of differences in healthcare systems) or beyond the study period.
- Another limitation is the validity of coding for coronary heart disease in administrative data.
- The use of 28-day episodes may miss a small number of related readmissions which occur beyond 28 days.

INTRODUCTION

Coronary heart disease (CHD) remains a major cause of death in Australia.[1] Clinically it manifests across a spectrum of subtypes, from ST-elevation myocardial infarction (STEMI) (the most severe), non-STEMI (NSTEMI), unstable angina, stable angina through to other chronic presentations. There is increasing evidence that less severe forms of CHD, such as stable angina, also have an increased risk of major adverse cardiovascular events.[2] Therefore, accurate information on population trends in CHD event rates and its subtypes is an indicator of the healthcare burden and essential for planning and evaluation of appropriate public health measures and clinical services. The focus on MI alone fails to provide a complete understanding of the size of the problem of suspected CHD or its outcomes and reliable estimates of CHD events at the population level are predicated on accurate stratification of CHD subtypes, for which there are limited data in Australia.

Population hospital administrative data provides a valuable data source in this regard where each admission is a separate record and diagnosis. However, this data source is not specifically designed for research purposes, and admission counts are susceptible to over-inflation if the patient is transferred or readmitted multiple times during their clinical course for essentially a single episode of care. Additionally, recording of CHD subtype can differ between records in the same episode of care, requiring consideration when categorising CHD subtype for the episode. This is especially true for the management of CHD which has historically been characterised with high rates of hospital transfers and early readmissions.[3] Indeed, contemporary Australian data has shown that around 18-30% of patients hospitalised for MI are transferred to another hospital,[4 5] often for highly specialised coronary artery procedures, most notably coronary angiography and revascularisation by percutaneous coronary intervention (PCI). These specialised coronary care services are generally located at major population centres, and many patients, especially those from non-urban areas, are transferred to one of these

hospitals for treatment and management of their condition.[6] In addition, a significant number of MI patients are readmitted for complications post-MI (such as repeat MI or heart failure), for elective procedures (such as coronary artery revascularisation or electrophysiological investigation), and to a lesser degree, for non-cardiac related admissions.[7 8]

There is a potential to overestimate hospitalisation rates of CHD subtypes using unlinked data because transfers and readmissions are not accounted for. This could differentially affect CHD subtype rates, depending on the use of different diagnosis codes when patients are transferred or for early readmissions. For jurisdictions where only unlinked data is available, it is important to understand the degree of overestimation of the number of admissions across subtypes, and whether this changes over time or by age-group and sex. Where person-linked hospital data is available, there is a need to assign a single relevant diagnosis to a group of admissions related by transfers or readmissions. To the best of our knowledge, approaches to these issues have not been addressed previously. Hence, our aims were to: (i) develop an approach to identify and categorise admissions for each CHD subtype accounting for different CHD diagnoses across hospital transfers and readmission records from linked hospital data; (ii) compare counts of unlinked CHD admissions with linked data accounting for transfers and readmissions; and (iii) examine whether the ratios of these counts show similar or disparate patterns over time and across age and sex groups for each CHD subtype.

METHODS

Data source and study population

For this cohort study, we used person-linked administrative health data from the Hospital Morbidity Data Collection, one of the core datasets of the Western Australian Data Linkage System. Western

Australia (WA) is representative of national sociodemographic and health indicators,[9] with an estimated resident population of 2.6 million in 2013.[10] The available dataset included all hospital records for any person hospitalised with CHD in WA from 1988 to 2013. We included all fatal and non-fatal admissions, with age restricted to 35-84 years. Variables available included demographic information, admission and discharge dates, principal and 20 secondary discharge diagnosis fields, and hospital locations.

Identification of CHD subtypes for individual (unlinked) admissions

All CHD admissions were identified from the principal discharge diagnosis field based on ICD-9-CM (1st January 1988 to 30th June 1999) and the International Statistical Classification of Diseases and Related Health Problems, Tenth Revision, Australian Modification (ICD-10-AM) (1st July 1999 to the present). CHD subtypes were defined as: transmural MI/STEMI (ICD-9-CM: 410.0-410.6, 410.8; ICD-10-AM: I21.0-I21.3) (hereafter STEMI), subendocardial MI/NSTEMI (410.7; I21.4) (hereafter NSTEMI), unspecified MI (410.9; I21.9), unstable angina (411.1; I20.0), stable angina (413; I20.1-I20.9), other CHD (411.0, 411.81, 411.89, 412, 414; I23-I25). Other CHD includes complications following MI and chronic ischaemic heart disease. An addition to the labelling of transmural or subendocardial MI was added in ICD-10-AM in 2004, with reference to STEMI ("transmural or STEMI") and NSTEMI ("subendocardial or NSTEMI") included. All MI is a combination of STEMI, NSTEMI and unspecified MI; acute coronary syndrome (ACS) is a combination of All MI and unstable angina; and All CHD is a combination of ACS, stable angina and Other CHD.

Identifying transfers and readmissions

An inter-hospital transfer occurs when a patient is discharged from one hospital and directly admitted to another hospital within one day. Patients can have multiple transfers related to the same presentation. We introduce the concept of a *contiguous admission* (CA) which may represent a single isolated

admission or an uninterrupted continuous hospital stay as a result of one or more transfers between hospitals. The admission date for the CA is the admission date of the first admission in the sequence. We also define a *28-day episode of care*, which comprises an index CA and any subsequent CAs occuring within 28 days of the admission date of the index CA. A CA that begins more than 28 days after the index CA is considered a new episode of care. The 28-day period is commonly used in epidemiological studies.[11-13]

Assigning principal diagnosis for CHD subtype to each CA and 28-day episode

Each admission in a CA has its own principal discharge diagnosis code that may vary between admissions. We have calculated CA counts based on four approaches described below.

Diagnosis hierarchy: This is based on the work of Sanfilippo et al,[14] and reflects the severity of the CHD subtypes from STEMI (most severe), NSTEMI, unstable angina, stable angina to Other CHD (least severe). For a CA with multiple principal diagnoses, the most severe diagnostic category is used.

Hospital hierarchy: The hierarchy is metropolitan tertiary hospital (specialised cardiac care, diagnostic angiography and PCI), private metropolitan hospital (with and without aforementioned tertiary care), metropolitan non-tertiary hospital and rural/remote hospital. During the study period, all three metropolitan tertiary and four private hospitals had a cardiac catheter laboratory.[15] None of the metropolitan non-tertiary or rural/remote hospitals had a cardiac catheter laboratory at the time of this study. For a CA with multiple principal diagnoses, the principal diagnosis from the hospital highest in the hierarchy is used.

First admission: The principal diagnosis recorded from the first admission in the CA is used. Given the acute nature of CHD, the first admission in a CA is presumed to be due to this condition while subsequent transfers are for procedures or resultant complications or cardiac rehabilitation.

Last admission: The principal diagnosis recorded from the last admission in the CA is used. The last hospital admission in the CA is presumed to be when the most definitive diagnosis is made amongst all admissions.

The diagnostic CHD subtype assigned to each 28-day episode was based on the diagnosis hierarchy approach. That is, the most severe subtype of all the CAs that comprise the 28-day episode is used. Table 1 illustrates how diagnoses (CHD subtypes) are assigned to CAs (four approaches) and to 28-day episodes for a hypothetical patient with ten hospital admissions, grouped into four CAs and three 28-day episodes.

Table 1: Example of typical patient record (not a real patient) depicting the different approaches of assigning a diagnosis to contiguous admissions (CA) and 28-day episodes.

Record No.	Patient ID	Admission date	Discharge date	Hospital	Transfer	28-day readmission	CA No.	28-day episode No.	Principal diagnosis	Diagnosis approach at the CA-level				Diagnosis at 28-day episode level
										Diagnosis hierarchy	Hospital hierarchy	First admission	Last admission	
1	1	1 Feb 2005	2 Feb 2005	Rural			1	1	Stable angina	NSTEMI	Unstable angina	Stable angina	NSTEMI	STEMI
2	1	2 Feb 2005	4 Feb 2005	Metropolitan tertiary	1		1	1	Unstable angina					
3	1	4 Feb 2005	6 Feb 2005	Metropolitan non-tertiary	1		1	1	NSTEMI					
4	1	17 Feb 2005	18 Feb 2005	Metropolitan tertiary		1	2	1	STEMI	STEMI	STEMI	STEMI	Other CHD	-
5	1	18 Feb 2005	22 Feb2005	Private	1	1	2	1	Other CHD					
6	1	10 Oct 2005	11 Oct 2005	Metropolitan non-tertiary			3	2	Stable angina	NSTEMI	NSTEMI	Stable angina	NSTEMI	NSTEMI
7	1	11 Oct 2005	14 Oct 2005	Metropolitan tertiary	1		3	2	NSTEMI					
8	1	1 Dec 2005	2 Dec 2005	Rural			4	3	Non-CHD	Stable angina	Stable angina	Non-CHD	Non-CHD	Stable angina
9	1	2 Dec 2005	3 Dec 2005	Metropolitan tertiary	1		4	3	Stable angina					
10	1	3 Dec 2005	5 Dec 2005	Private	1		4	3	Non-CHD					

Key: CHD=coronary heart disease; CA=contiguous admission

Statistical analysis

Annual counts for each CHD subtype and combination subtypes are presented at the unlinked-, CA- and 28-day episode levels for 1988 to 2013. The ratio of unlinked admission count to CA count was calculated for each age-group (35-54 years, 55-74 years, 75-84 years) and gender in each year to determine the relative overestimation of each CHD subtype. To examine the impact on counts from using 28-day episodes, we calculated the ratio of 28-day episode to CA counts for each age-group and gender in each year, for each CHD subtype. Linear regression (with robust standard errors) was used to compare the ratios statistically across age-groups and gender, and assess trends over time. This analysis was restricted to the period 2000 to 2013 as CHD counts were more consistent during this time. All models included sex, age-group, sex*age-group interaction term and year as a continuous variable and year squared was also included where a curved trend was indicated (Wald test $p<0.01$). We fitted extended models with time interaction terms to test if there were differences in time trends by sex and age-group (i.e. we tested sex*year, age-group*year, and sex*age-group*year for ratios without curved trends and, for ratios with curved trends, also tested sex*year squared, age-group*year squared and sex*age-group*year squared). Only a few of the time interaction tests had $p<0.01$ and in lieu of the large number of time interactions tested and the lack of any consistent pattern to these results, these were considered not to be real and were ignored (i.e. considered as false positive time interactions). Analyses were performed using Stata 13.1.

Ethics approval

This study was approved by the Human Research Ethics Committees of the Western Australian Department of Health and The University of Western Australia. The study was granted a waiver of informed consent.

RESULTS

There were 296,659 unlinked hospital admissions for CHD from 1988 to 2013 in WA (Table 2). The diagnosis hierarchy approach resulted in the highest count of CHD admissions (n=273,793) and the approach based on the diagnosis from last admission resulted in the lowest count (n=263,313). The number of 28-day episodes was 242,966. The counts at the unlinked, CA-level and 28-day episode level for each CHD subtype are shown in Table 2.

Table 2: Diagnosis counts at the unlinked-, contiguous admission (CA)- and 28-day episode levels for admission years 1988 to 2013.

	Unlinked-level	CA-level				28-day episode-level
		Diagnosis hierarchy	Hospital hierarchy	Diagnosis based on first admission	Diagnosis based on last admission	
Number of CHD records	296,659	273,793	269,614	267,389	263,313	242,966
Diagnosis:						
STEMI	37,457 (12.63%)	34,435 (12.58%)	33,313 (12.36%)	32,165 (12.03%)	32,014 (12.16%)	33,364 (13.73%)
NSTEMI	29,203 (9.84%)	24,734 (9.03%)	23,956 (8.89%)	21,868 (8.18%)	22,631 (8.59%)	23,738 (9.77%)
Unstable angina	72,223 (24.35%)	65,589 (23.96%)	63,301 (23.48%)	64,478 (24.11%)	60,333 (22.91%)	59,144 (24.34%)
Stable angina	77,076 (25.98%)	73,994 (27.03%)	73,898 (27.41%)	73,845 (27.62%)	73,037 (27.74%)	64,669 (26.62%)
Other CHD	69,070 (23.27%)	65,161 (23.80%)	65,751 (24.39%)	64,632 (24.17%)	66,148 (25.11%)	52,688 (21.68%)
All MI	78,315 (26.40%)	69,049 (25.22%)	66,664 (24.73%)	64,434 (24.10%)	63,818 (24.24%)	66,487 (27.36%)
ACS	150,538 (50.74%)	134,638 (49.18%)	129,965 (48.20%)	128,912 (48.21%)	124,151 (47.15%)	125,631 (51.71%)

Key: ACS=acute coronary syndrome; CHD=coronary heart disease; MI=myocardial infarction; NSTEMI=non ST-elevation myocardial infarction; STEMI=ST-elevation myocardial infarction.

Figure 1 shows trends in annual admission counts for each CHD subtype and combination subtypes at the CA-level, using the diagnosis hierarchy approach and the three alternative approaches. The diagnosis hierarchy approach resulted in highest counts for the more severe CHD subtypes compared to the three alternative approaches, but all methods had similar trends over time for each CHD subtype.

Figure 2 compares annual CHD counts at the unlinked, CA (using diagnosis hierarchy approach) and 28-day episode levels from 1988 to 2013. The use of unlinked records resulted in the highest counts of all subtypes while 28-day episode records resulted in the lowest counts. The difference between unlinked and CA counts tended to be greater in the latter half of the study period for STEMI, NSTEMI and unstable angina, while the reverse was apparent for Other CHD. The difference between unlinked and CA counts for NSTEMI, All MI and ACS increased from around 2000 onwards. The difference between CA and 28-day episode counts tended to increase from around 2000 onwards for NSTEMI but narrowed for STEMI and unstable angina.

Table 3 and supplementary table 1 present estimated ratios for unlinked to CA counts (based on diagnosis hierarchy approach) from fitted regression models by CHD subtype, sex and age-group for the period 2000 to 2013. In females aged 35-54 years, the ratio of unlinked to CA counts for NSTEMI admissions in 2000 was 1.10 (i.e. 10% higher in unlinked) and this increased in a linear fashion to 1.30 (i.e. 30% higher) in 2013 representing an increase of 0.0148 per year. Conversely, the over count for STEMI and All MI followed a curved (quadratic) trend. For subtypes with a linear trend, the trend coefficients were largest in the most severe CHD subtype (NSTEMI: increase of 0.0148/year) and smallest in the least severe subtype (Other CHD: non-significant increase of 0.0003/year). The sex*age-group interaction term was not significant in any individual or combination subtype but the ratios were significantly higher in the youngest age-group for STEMI, NSTEMI, stable angina and all

combination subtypes. Males had significantly higher ratios than females for unstable angina and ACS.

Table 3: Estimated ratios of unlinked versus CA-level counts (diagnosis hierarchy approach) from 2000 to 2013: by CHD subtype, sex and age-group

Diagnosis	Sex	Age-group	Ratio (CI) in 2000	Ratio (CI) in 2013	Trend coefficient (p-value)		p-values for tests comparing		
					Year	Year squared	Sex[§]	Age-group[§]	Sex*Age-group
STEMI[†]	F	35-54	1.12 (1.09-1.15)	1.14 (1.11-1.18)	0.0174 (0.000)	-0.0012 (0.000)	0.946	0.000	0.945
	F	55-74	1.09 (1.06-1.11)	1.11 (1.08-1.14)	0.0174 (0.000)	-0.0012 (0.000)			
	F	75-84	1.05 (1.02-1.09)	1.07 (1.02-1.13)	0.0174 (0.000)	-0.0012 (0.000)			
	M	35-54	1.12 (1.10-1.15)	1.15 (1.11-1.19)	0.0174 (0.000)	-0.0012 (0.000)			
	M	55-74	1.08 (1.06-1.10)	1.10 (1.08-1.13)	0.0174 (0.000)	-0.0012 (0.000)			
	M	75-84	1.05 (1.03-1.08)	1.08 (1.04-1.11)	0.0174 (0.000)	-0.0012 (0.000)			
NSTEMI[‡]	F	35-54	1.10 (1.08-1.13)	1.30 (1.27-1.33)	0.0148 (0.000)		0.768	0.000	0.734
	F	55-74	1.08 (1.06-1.10)	1.27 (1.25-1.29)	0.0148 (0.000)				
	F	75-84	1.04 (1.02-1.06)	1.23 (1.21-1.25)	0.0148 (0.000)				
	M	35-54	1.12 (1.09-1.14)	1.31 (1.29-1.33)	0.0148 (0.000)				
	M	55-74	1.07 (1.06-1.09)	1.27 (1.25-1.28)	0.0148 (0.000)				
	M	75-84	1.03 (1.02-1.05)	1.23 (1.21-1.24)	0.0148 (0.000)				
Unstable angina[‡]	F	35-54	1.09 (1.07-1.10)	1.15 (1.13-1.16)	0.0047 (0.000)		0.000	0.010	0.445
	F	55-74	1.09 (1.07-1.10)	1.15 (1.14-1.16)	0.0047 (0.000)				
	F	75-84	1.07 (1.06-1.09)	1.14 (1.12-1.15)	0.0047 (0.000)				
	M	35-54	1.12 (1.10-1.13)	1.18 (1.16-1.20)	0.0047 (0.000)				
	M	55-74	1.10 (1.09-1.11)	1.16 (1.15-1.17)	0.0047 (0.000)				
	M	75-84	1.09 (1.08-1.11)	1.15 (1.14-1.17)	0.0047 (0.000)				
Stable	F	35-54	1.05 (1.04-1.06)	1.07 (1.06-1.08)	0.0015 (0.000)				

angina‡	F	55-74	1.03 (1.03-1.04)	1.05 (1.05-1.06)	0.0015 (0.000)			
	F	75-84	1.03 (1.03-1.04)	1.05 (1.05-1.06)	0.0015 (0.000)	0.031	0.000	0.776
	M	35-54	1.04 (1.04-1.05)	1.06 (1.05-1.07)	0.0015 (0.000)			
	M	55-74	1.03 (1.03-1.03)	1.05 (1.04-1.05)	0.0015 (0.000)			
	M	75-84	1.03 (1.02-1.04)	1.05 (1.04-1.06)	0.0015 (0.000)			
Other CHD‡	F	35-54	1.05 (1.03-1.07)	1.06 (1.03-1.08)	0.0003 (0.583)			
	F	55-74	1.03 (1.02-1.04)	1.04 (1.03-1.05)	0.0003 (0.583)			
	F	75-84	1.04 (1.03-1.06)	1.05 (1.03-1.06)	0.0003 (0.583)	0.057	0.072	0.630
	M	35-54	1.04 (1.03-1.05)	1.04 (1.03-1.05)	0.0003 (0.583)			
	M	55-74	1.03 (1.02-1.04)	1.03 (1.03-1.04)	0.0003 (0.583)			
	M	75-84	1.03 (1.02-1.04)	1.04 (1.03-1.05)	0.0003 (0.583)			

Key: CHD=coronary heart disease; CI=confidence interval; CA=contiguous admission; F=female; M=male; MI=myocardial infarction; NSTEMI=non ST-elevation myocardial infarction; STEMI=ST-elevation myocardial infarction.

† From the model: ratio = constant + (admission year - 2000) + age-group + sex + age-group*sex + (admission year - 2000)^2

‡ From the model: ratio = constant + (admission year - 2000) + age-group + sex + age-group*sex

§ p-values for sex and age-group are from the respective models but without the age-group*sex interaction term

Table 4 and supplementary table 2 present the estimated ratios for CA versus 28-day episode counts. For example, in females aged 35-54 years, the ratio for STEMI was 1.10 in 2000 (i.e. 10% higher for CA counts) and this decreased to 1.01 in 2013 (i.e. 1% higher), representing a 0.0064 decrease per year. Ratios for unstable angina, stable angina, Other CHD and All CHD followed a curved (quadratic) trend. For example in females aged 35-54 years, the ratio for unstable angina was 1.15 in 2000 before levelling out at 1.09 from 2010 onwards. For unstable angina, stable angina, Other CHD, ACS and All CHD, the ratios were significantly higher in males than females. Differences in ratios between age-groups were seen for all CHD subtypes except for NSTEMI and other CHD.

Table 4: Estimated ratios of CA- versus 28-day episode-level counts (diagnosis hierarchy approach) from 2000 to 2013: by CHD subtype, sex and age-group

Diagnosis	Sex	Age-group	Ratio (CI) in 2000	Ratio (CI) in 2013	Trend coefficient (p-value)		p-values for tests comparing		
					Year	Year squared	Sex[#]	Age-group[#]	Sex*Age-group
STEMI[†]	F	35-54	1.10 (1.05-1.14)	1.01 (0.99-1.03)	-0.0064 (0.000)				
	F	55-74	1.08 (1.06-1.09)	1.01 (1.00-1.02)	-0.0064 (0.000)				
	F	75-84	1.05 (1.03-1.06)	1.03 (1.02-1.05)	-0.0064 (0.000)		0.946	0.000	0.799
	M	35-54	1.09 (1.06-1.11)	1.01 (0.98-1.03)	-0.0064 (0.000)				
	M	55-74	1.08 (1.07-1.09)	1.01 (1.00-1.02)	-0.0064 (0.000)				
	M	75-84	1.05 (1.04-1.06)	1.04 (1.02-1.06)	-0.0064 (0.000)				
NSTEMI[‡]	F	35-54	1.10 (1.06-1.14)	1.05 (1.03-1.08)	-0.0036 (0.000)				
	F	55-74	1.07 (1.06-1.09)	1.03 (1.01-1.04)	-0.0036 (0.000)				
	F	75-84	1.08 (1.06-1.10)	1.04 (1.02-1.05)	-0.0036 (0.000)		0.470	0.937	0.033
	M	35-54	1.08 (1.06-1.10)	1.03 (1.02-1.05)	-0.0036 (0.000)				
	M	55-74	1.10 (1.08-1.12)	1.05 (1.04-1.07)	-0.0036 (0.000)				
	M	75-84	1.09 (1.07-1.11)	1.04 (1.03-1.06)	-0.0036 (0.000)				
Unstable angina[§]	F	35-54	1.15 (1.13-1.17)	1.09 (1.07-1.10)	-0.0124 (0.000)	0.0006 (0.001)			
	F	55-74	1.15 (1.14-1.17)	1.09 (1.08-1.10)	-0.0124 (0.000)	0.0006 (0.001)			
	F	75-84	1.17 (1.15-1.19)	1.11 (1.09-1.12)	-0.0124 (0.000)	0.0006 (0.001)	0.000	0.040	0.017
	M	35-54	1.18 (1.16-1.20)	1.12 (1.10-1.14)	-0.0124 (0.000)	0.0006 (0.001)			
	M	55-74	1.21 (1.19-1.22)	1.15 (1.13-1.16)	-0.0124 (0.000)	0.0006 (0.001)			
	M	75-84	1.20 (1.18-1.21)	1.13 (1.12-1.15)	-0.0124 (0.000)	0.0006 (0.001)			

Stable angina[§]	F	35-54	1.14 (1.12-1.16)	1.08 (1.07-1.10)	-0.0115 (0.000)	0.0006 (0.004)	0.000	0.009	0.097
	F	55-74	1.15 (1.14-1.17)	1.10 (1.09-1.11)	-0.0115 (0.000)	0.0006 (0.001)			
	F	75-84	1.14 (1.12-1.16)	1.08 (1.07-1.10)	-0.0115 (0.000)	0.0006 (0.001)			
	M	35-54	1.20 (1.18-1.23)	1.15 (1.13-1.16)	-0.0115 (0.000)	0.0006 (0.001)			
	M	55-74	1.20 (1.18-1.22)	1.14 (1.13-1.15)	-0.0115 (0.000)	0.0006 (0.001)			
	M	75-84	1.18 (1.16-1.20)	1.13 (1.11-1.14)	-0.0115 (0.000)	0.0006 (0.001)			
Other CHD[§]	F	35-54	1.18 (1.15-1.22)	1.11 (1.08-1.14)	-0.0211 (0.000)	0.0012 (0.000)	0.000	0.359	0.542
	F	55-74	1.19 (1.16-1.22)	1.12 (1.10-1.14)	-0.0211 (0.000)	0.0012 (0.000)			
	F	75-84	1.19 (1.16-1.21)	1.11 (1.09-1.13)	-0.0211 (0.000)	0.0012 (0.000)			
	M	35-54	1.22 (1.20-1.25)	1.15 (1.13-1.17)	-0.0211 (0.000)	0.0012 (0.000)			
	M	55-74	1.23 (1.20-1.25)	1.15 (1.14-1.17)	-0.0211 (0.000)	0.0012 (0.000)			
	M	75-84	1.21 (1.19-1.24)	1.14 (1.12-1.15)	-0.0211 (0.000)	0.0012 (0.000)			

Key: CHD=coronary heart disease; CI=confidence interval; F=female; M=male; MI=myocardial infarction; NSTEMI=non ST-elevation myocardial infarction; STEMI=ST-elevation myocardial infarction.

† From the model: ratio = constant + (admission year - 2000) + age-group + sex + age-group*sex + age*(admission year-2000)

‡ From the model: ratio = constant + (admission year - 2000) + age-group + sex + age-group*sex

§ From the model: ratio = constant + (admission year - 2000) + age-group + sex + age-group*sex + (admission year-2000)^2

‖ From the model: ratio = constant + (admission year - 2000) + age-group + sex + age-group*sex + (admission year-2000)^2 + age-group*(admission year-2000)

p-values for sex and age-group are from the respective models but without the age-group*sex interaction term

DISCUSSION

We developed different approaches to assign CHD diagnoses to a sequence of consecutive admissions and 28-day episodes that account for transfers and readmissions, thereby avoiding the over-count that occurs with unlinked administrative data. Hospitalisation data from 1988 to 2013 show that for each CHD subtype, unlinked records over-counted the number of CHD hospitalisations relative to CA counts and 28-day episode counts. Our analyses of ratios from 2000-2013 showed a complex pattern of over-counting in unlinked data due to transfers and readmissions. In almost all CHD subtypes, the ratios changed in a linear or quadratic fashion over time and the coefficients of the trends differed across CHD subtypes. Further, for many CHD subtypes the ratios also differed by age-group and sex.

The development of the CA method accounts for transfers and allows for classification by CHD subtype where multiple admissions with differing discharge diagnoses are present. As each transfer and admission to the receiving hospital has its own principal discharge diagnosis, we compared four approaches to assigning a single clinically relevant diagnosis for each CA. Of the four approaches to assigning diagnosis, we contend that diagnosis hierarchy is the most clinically relevant approach and indicator of healthcare burden as it prioritises disease severity according to a physician's clinical judgement. Of the four approaches, diagnosis hierarchy results in the highest CHD counts and would therefore result in the most conservative differences between unlinked and CA. Hospital hierarchy is based on resourcing of hospitals with coronary care services and the level of resourcing may differ in other jurisdictions. The recent introduction of coronary care services in rural hospitals in WA, means that the hospital hierarchy method may become less applicable. Diagnosis based on first or last admission in a CA may not identify CHD-related admissions that occur in the middle of a CA, highlighted by the resulting low counts that occurred when using these methods to assign a diagnosis. A small number of patients have an MI during an admission for non-cardiac conditions,[16]

and diagnosis based on first admission may not identify these CHD cases if they are subsequently transferred.

The ratios of unlinked versus CA counts for almost all subtypes (except STEMI and All MI) increased in a linear fashion, indicating a consistent increase in the over-inflation of admission numbers in unlinked data due to transfers. This likely reflects a complex mix of changes in clinical guidelines and practice, facilitated by direct transfers to hospitals with PCI capability for ACS cases and pre-hospital care protocols during this period. The widening difference between unlinked and CA counts for NSTEMI indicates an increasing rate of transfer for this group of patients. Given that NSTEMI patients are still at risk of future adverse events, clinical guidelines now recommend that these patients undergo early coronary angiography and hospitalisation if indicated. [2 17] Patients who are not at a hospital with advanced coronary care services may be transferred as a priority to a hospital with such capabilities. These findings show that the use of unlinked data would bias temporal trends in NSTEMI hospitalisation rates upwards and that linked data, using the described methods, would provide more reliable trend estimates for hospitalisation rates of NSTEMI in particular.

Furthermore, ratios were higher in the younger than older age-groups for all subtypes, indicating that older CHD patients were less likely to be transferred than younger patients. We also found males had a higher ratio than females for unstable angina and ACS. These sex and age differences in transfers may partly reflect age and sex disparities in ACS care and especially invasive management reported in earlier studies,[18 19] although further studies are needed to support this theory.

28-day episodes have previously only been used to capture early MI readmissions following an index MI admission thus reducing overestimation of population rates for MI. Historically, early readmissions were often for coronary procedures or other management related to the initial MI admission. Our method ensures 28-day episodes capture any CHD readmission during this period.

In general, our results show that early readmissions across all CHD subtypes have decreased, although the trend was not linear for unstable and stable angina, and Other CHD. This could indicate that most acute treatment is now managed during the initial admission or subsequent transfer, thus requiring fewer readmissions.

The findings of this study have important implications for monitoring population trends in MI and other CHD subtypes. The ratios of counts we presented would have been the same if we had used age-standardised rates (ASRs) as population denominators would have been the same in all three levels of counts. The trends in CA and 28-day episode counts for STEMI and NSTEMI are in accordance with other studies showing that hospital admissions for STEMI have decreased in Western countries while admissions for NSTEMI have increased.[20 21] The use of the CA and 28-day episode methods in linked data offsets over-counting of MI events which could potentially inflate trends in ASRs. The effect of overestimation of MI hospitalisation numbers due to transfers and readmissions could also artificially reduce case fatality because of the impact on case fatality denominators. In addition, it allows accurate representation of other subtypes of CHD, for which there are limited data at a whole-population level.

There are a number of jurisdictions including Australia where linked data is not available at a national/population level, for example, the United States, where studies reporting nation-wide trends on MI or CHD rely on unlinked data (e.g. Nationwide Inpatient Sample), or where the more recent introduction of national linked data necessitates use of unlinked data where long-term trends are required (e.g. Hospital Episode Statistics data in England).[22 23] Therefore we contend our methods and data will be of interest to countries outside of Australia. Although we have described an approach to dealing with transfers and defining episodes of care for use with CHD, these methods could be applied to other conditions that have high rates of transfer and readmissions, such as major

trauma and head injury where many patients are transferred from rural sites to major tertiary hospitals with intensive care and/or head injury units and rehabilitation.

Strengths and limitations

Strengths of our study include use of statewide data that captures all hospital admissions in WA. Record linkage allowed the identification of CAs to account for transfers and 28-day episodes. The limitations of this study include the validity of coding for CHD. An earlier WA study using linked data showed that the sensitivity of hospital coding for MI was 76.9% in the 35-69 year olds.[14] The use of 28-day episodes may miss a small number of related readmissions which occur beyond 28 days. Furthermore, we did not adjust for confounders such as remoteness and Indigenous status which may influence transfer and readmission patterns.[6 24] The complex pattern of counts and ratios we presented are from WA for 2000 to 2013 and may not be generalisable to other jurisdictions (because of different healthcare systems) or beyond the study period, however the methods we described are generalisable to other states and territories.

Conclusions

Although unlinked data has its place in measurement of hospital health service utilisation, its use in epidemiological estimates of CHD hospitalisations overestimates CHD counts. We contend that CA (accounting for transfers) and 28-day episode (accounting for transfers and readmissions) counts are more aligned with epidemiological studies of CHD. The degree of overestimation of counts using only unlinked records varies in a complex manner with CHD subtype, time, sex and age-group, it is not possible to apply a simple correction factor to counts obtained from unlinked data.

ABBREVIATIONS

ACS: acute coronary syndrome; AM: Australian modification; ASR: age standardised rates; CA: contiguous admission; CHD: coronary heart disease; CM: clinical modification; ICD: International

Classification of Diseases; MI: myocardial infarction; NSTEMI: non ST-elevation myocardial infarction; PCI: percutaneous coronary intervention; STEMI: ST-elevation myocardial infarction; WA: Western Australia

ACKNOWLEDGEMENTS

The authors thank the staff at the Western Australian Data Linkage Branch and the Department of Health Inpatient Data Collections for the provision of linked data.

FUNDING

This work was supported by the National Health and Medical Research Council (NHMRC) of Australia project grant 1078978. The grant agency does not impose restrictions on conduct of analyses or dissemination of findings. LN is funded by a National Health and Medical Research Council of Australia Early Career Fellowship.

DATA SHARING

We will consider requests for data sharing on an individual basis, with an aim to sharing data whenever possible for appropriate research purposes. However the research project uses secondary (third party) data derived from Australian (State or Federal) government registries, which are ultimately governed by their ethics committees and data custodians. Therefore, any requests to share this data will be subject to formal approval from their ethics committees overseeing the use of these data sources, along with the data custodian(s) for the data of interest.

AUTHOR CONTRIBUTIONS

MSTH, FM, LN, MK, JH and TGB conceived the study. DL performed all the data and statistical analyses, with statistical advice from MK. All authors interpreted the results. DL constructed the

figures and tables, and led the write-up of this manuscript. All authors have reviewed, commented and approved this manuscript for submission.

COMPETING INTERESTS

The authors have no competing interests to declare.

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Figure legends

Figure 1

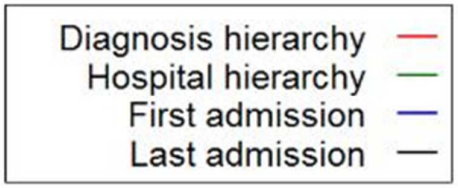
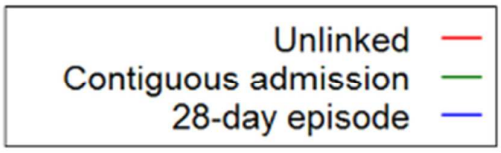


Figure 2



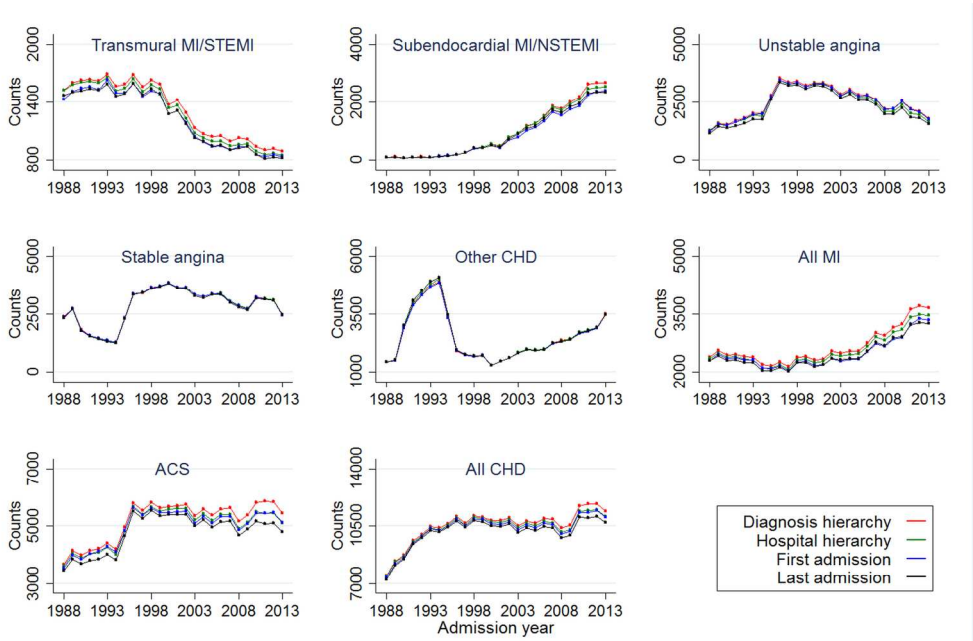


Figure 1: Comparison of CHD counts from 1988 to 2013 using four different approaches at the contiguous admission (CA) level (key: ACS=acute coronary syndrome; CHD=coronary heart disease; MI=myocardial infarction; NSTEMI=non ST-elevation myocardial infarction; CA=contiguous admission; STEMI=ST-elevation myocardial infarction)

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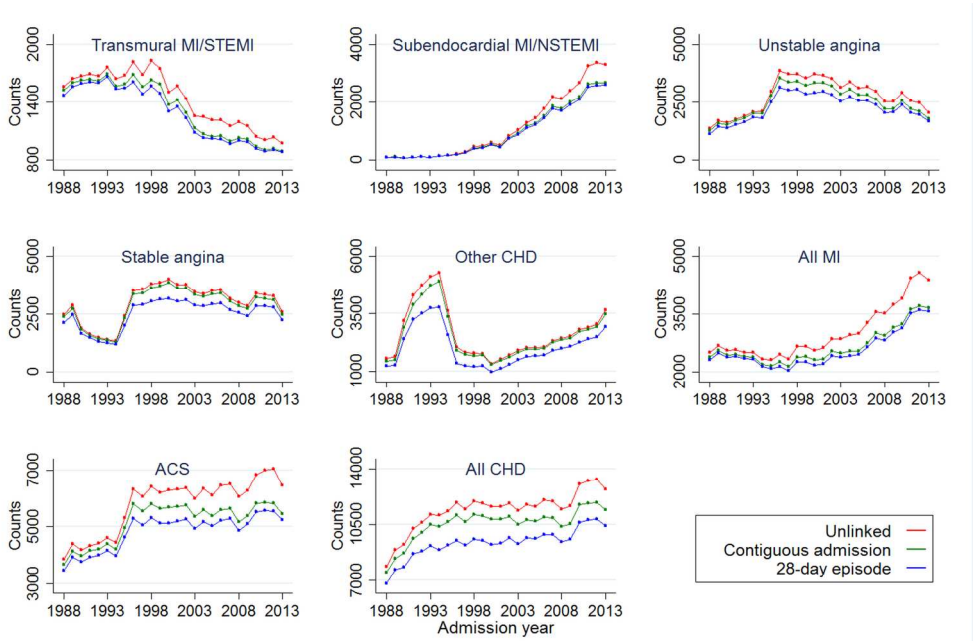

Figure 2: Comparison of CHD counts at the unlinked-, CA (diagnosis hierarchy approach) and 28-day episode levels from 1988 to 2013 (key: ACS=acute coronary syndrome; CHD=coronary heart disease; MI=myocardial infarction; NSTEMI=non ST-elevation myocardial infarction; CA=contiguous admission; STEMI=ST-elevation myocardial infarction)

162x108mm (300 x 300 DPI)

Supplementary table 1: Estimated ratios of unlinked versus CA-level counts (diagnosis hierarchy approach) from 2000 to 2013: by CHD subtype, sex and age group

Diagnosis	Sex	Age group	Ratio (CI) in 2000	Ratio (CI) in 2013	Trend coefficient (p-value)		p-values for tests comparing		
					Year	Year squared	Sex[§]	Age group[§]	Sex*Age group
STEMI[†]	F	35-54	1.12 (1.09-1.15)	1.14 (1.11-1.18)	0.0174 (0.000)	-0.0012 (0.000)	0.946	0.000	0.945
	F	55-74	1.09 (1.06-1.11)	1.11 (1.08-1.14)	0.0174 (0.000)	-0.0012 (0.000)			
	F	75-84	1.05 (1.02-1.09)	1.07 (1.02-1.13)	0.0174 (0.000)	-0.0012 (0.000)			
	M	35-54	1.12 (1.10-1.15)	1.15 (1.11-1.19)	0.0174 (0.000)	-0.0012 (0.000)			
	M	55-74	1.08 (1.06-1.10)	1.10 (1.08-1.13)	0.0174 (0.000)	-0.0012 (0.000)			
	M	75-84	1.05 (1.03-1.08)	1.08 (1.04-1.11)	0.0174 (0.000)	-0.0012 (0.000)			
NSTEMI[‡]	F	35-54	1.10 (1.08-1.13)	1.30 (1.27-1.33)	0.0148 (0.000)		0.768	0.000	0.734
	F	55-74	1.08 (1.06-1.10)	1.27 (1.25-1.29)	0.0148 (0.000)				
	F	75-84	1.04 (1.02-1.06)	1.23 (1.21-1.25)	0.0148 (0.000)				
	M	35-54	1.12 (1.09-1.14)	1.31 (1.29-1.33)	0.0148 (0.000)				
	M	55-74	1.07 (1.06-1.09)	1.27 (1.25-1.28)	0.0148 (0.000)				
	M	75-84	1.03 (1.02-1.05)	1.23 (1.21-1.24)	0.0148 (0.000)				

Unstable angina‡	F	35-54	1.09 (1.07-1.10)	1.15 (1.13-1.16)	0.0047 (0.000)	0.000	0.010	0.445
	F	55-74	1.09 (1.07-1.10)	1.15 (1.14-1.16)	0.0047 (0.000)			
	F	75-84	1.07 (1.06-1.09)	1.14 (1.12-1.15)	0.0047 (0.000)			
	M	35-54	1.12 (1.10-1.13)	1.18 (1.16-1.20)	0.0047 (0.000)			
	M	55-74	1.10 (1.09-1.11)	1.16 (1.15-1.17)	0.0047 (0.000)			
	M	75-84	1.09 (1.08-1.11)	1.15 (1.14-1.17)	0.0047 (0.000)			
Stable angina‡	F	35-54	1.05 (1.04-1.06)	1.07 (1.06-1.08)	0.0015 (0.000)	0.031	0.000	0.776
	F	55-74	1.03 (1.03-1.04)	1.05 (1.05-1.06)	0.0015 (0.000)			
	F	75-84	1.03 (1.03-1.04)	1.05 (1.05-1.06)	0.0015 (0.000)			
	M	35-54	1.04 (1.04-1.05)	1.06 (1.05-1.07)	0.0015 (0.000)			
	M	55-74	1.03 (1.03-1.03)	1.05 (1.04-1.05)	0.0015 (0.000)			
	M	75-84	1.03 (1.02-1.04)	1.05 (1.04-1.06)	0.0015 (0.000)			
Other CHD‡	F	35-54	1.05 (1.03-1.07)	1.06 (1.03-1.08)	0.0003 (0.583)	0.057	0.072	0.630
	F	55-74	1.03 (1.02-1.04)	1.04 (1.03-1.05)	0.0003 (0.583)			
	F	75-84	1.04 (1.03-1.06)	1.05 (1.03-1.06)	0.0003 (0.583)			
	M	35-54	1.04 (1.03-1.05)	1.04 (1.03-1.05)	0.0003 (0.583)			

	M	55-74	1.03 (1.02-1.04)	1.03 (1.03-1.04)	0.0003 (0.583)				
	M	75-84	1.03 (1.02-1.04)	1.04 (1.03-1.05)	0.0003 (0.583)				
All MI†	F	35-54	1.15 (1.12-1.18)	1.27 (1.25-1.30)	0.0166 (0.000)	-0.0006 (0.002)	0.576	0.000	0.720
	F	55-74	1.10 (1.09-1.12)	1.22 (1.20-1.24)	0.0166 (0.000)	-0.0006 (0.002)			
	F	75-84	1.06 (1.04-1.07)	1.18 (1.16-1.20)	0.0166 (0.000)	-0.0006 (0.002)			
	M	35-54	1.14 (1.12-1.16)	1.26 (1.24-1.29)	0.0166 (0.000)	-0.0006 (0.002)			
	M	55-74	1.10 (1.09-1.12)	1.22 (1.20-1.24)	0.0166 (0.000)	-0.0006 (0.002)			
	M	75-84	1.06 (1.05-1.08)	1.18 (1.16-1.20)	0.0166 (0.000)	-0.0006 (0.002)			
ACS‡	F	35-54	1.12 (1.10-1.13)	1.22 (1.21-1.23)	0.0078 (0.000)		0.003	0.000	0.695
	F	55-74	1.10 (1.09-1.10)	1.20 (1.18-1.21)	0.0078 (0.000)				
	F	75-84	1.07 (1.06-1.08)	1.17 (1.16-1.18)	0.0078 (0.000)				
	M	35-54	1.14 (1.12-1.15)	1.24 (1.22-1.26)	0.0078 (0.000)				
	M	55-74	1.11 (1.10-1.11)	1.21 (1.20-1.22)	0.0078 (0.000)				
	M	75-84	1.08 (1.07-1.09)	1.18 (1.17-1.19)	0.0078 (0.000)				
All CHD‡	F	35-54	1.09 (1.08-1.10)	1.15 (1.14-1.15)	0.0043 (0.000)				
	F	55-74	1.06 (1.06-1.07)	1.12 (1.11-1.13)	0.0043 (0.000)				

	F	75-84	1.06 (1.06-1.07)	1.12 (1.11-1.12)	0.0043 (0.000)	0.684	0.000	0.152
	M	35-54	1.10 (1.09-1.11)	1.15 (1.15-1.16)	0.0043 (0.000)			
	M	55-74	1.06 (1.06-1.07)	1.12 (1.11-1.12)	0.0043 (0.000)			
	M	75-84	1.06 (1.05-1.06)	1.11 (1.11-1.12)	0.0043 (0.000)			

Key: ACS=acute coronary syndrome; CHD=coronary heart disease; CI=confidence interval; CA=contiguous admission; F=female; M=male; MI=myocardial infarction; NSTEMI=non ST-elevation myocardial infarction; STEMI=ST-elevation myocardial infarction.

† From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex + (admission year - 2000)^2

‡ From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex

§ p-values for sex and age group are from the respective models but without the age group*sex interaction term

Supplementary table 2: Estimated ratios of CA- versus 28-day episode-level counts (diagnosis hierarchy approach) from 2000 to 2013: by CHD subtype, sex and age group

Diagnosis	Sex	Age group	Ratio (CI) in 2000	Ratio (CI) in 2013	Trend coefficient (p-value)		p-values for tests comparing		
					Year	Year squared	Sex[#]	Age group[#]	Sex*Age group
STEMI[†]	F	35-54	1.10 (1.05-1.14)	1.01 (0.99-1.03)	-0.0064 (0.000)		0.946	0.000	0.799
	F	55-74	1.08 (1.06-1.09)	1.01 (1.00-1.02)	-0.0064 (0.000)				
	F	75-84	1.05 (1.03-1.06)	1.03 (1.02-1.05)	-0.0064 (0.000)				
	M	35-54	1.09 (1.06-1.11)	1.01 (0.98-1.03)	-0.0064 (0.000)				
	M	55-74	1.08 (1.07-1.09)	1.01 (1.00-1.02)	-0.0064 (0.000)				
	M	75-84	1.05 (1.04-1.06)	1.04 (1.02-1.06)	-0.0064 (0.000)				
NSTEMI[‡]	F	35-54	1.10 (1.06-1.14)	1.05 (1.03-1.08)	-0.0036 (0.000)		0.470	0.937	0.033
	F	55-74	1.07 (1.06-1.09)	1.03 (1.01-1.04)	-0.0036 (0.000)				
	F	75-84	1.08 (1.06-1.10)	1.04 (1.02-1.05)	-0.0036 (0.000)				
	M	35-54	1.08 (1.06-1.10)	1.03 (1.02-1.05)	-0.0036 (0.000)				
	M	55-74	1.10 (1.08-1.12)	1.05 (1.04-1.07)	-0.0036 (0.000)				
	M	75-84	1.09 (1.07-1.11)	1.04 (1.03-1.06)	-0.0036 (0.000)				

	F	35-54	1.15 (1.13-1.17)	1.09 (1.07-1.10)	-0.0124 (0.000)	0.0006 (0.001)			
	F	55-74	1.15 (1.14-1.17)	1.09 (1.08-1.10)	-0.0124 (0.000)	0.0006 (0.001)			
Unstable	F	75-84	1.17 (1.15-1.19)	1.11 (1.09-1.12)	-0.0124 (0.000)	0.0006 (0.001)	0.000	0.040	0.017
angina[§]	M	35-54	1.18 (1.16-1.20)	1.12 (1.10-1.14)	-0.0124 (0.000)	0.0006 (0.001)			
	M	55-74	1.21 (1.19-1.22)	1.15 (1.13-1.16)	-0.0124 (0.000)	0.0006 (0.001)			
	M	75-84	1.20 (1.18-1.21)	1.13 (1.12-1.15)	-0.0124 (0.000)	0.0006 (0.001)			
	F	35-54	1.14 (1.12-1.16)	1.08 (1.07-1.10)	-0.0115 (0.000)	0.0006 (0.004)			
	F	55-74	1.15 (1.14-1.17)	1.10 (1.09-1.11)	-0.0115 (0.000)	0.0006 (0.001)			
Stable	F	75-84	1.14 (1.12-1.16)	1.08 (1.07-1.10)	-0.0115 (0.000)	0.0006 (0.001)	0.000	0.009	0.097
angina[§]	M	35-54	1.20 (1.18-1.23)	1.15 (1.13-1.16)	-0.0115 (0.000)	0.0006 (0.001)			
	M	55-74	1.20 (1.18-1.22)	1.14 (1.13-1.15)	-0.0115 (0.000)	0.0006 (0.001)			
	M	75-84	1.18 (1.16-1.20)	1.13 (1.11-1.14)	-0.0115 (0.000)	0.0006 (0.001)			
	F	35-54	1.18 (1.15-1.22)	1.11 (1.08-1.14)	-0.0211 (0.000)	0.0012 (0.000)			
	F	55-74	1.19 (1.16-1.22)	1.12 (1.10-1.14)	-0.0211 (0.000)	0.0012 (0.000)			
Other CHD[§]	F	75-84	1.19 (1.16-1.21)	1.11 (1.09-1.13)	-0.0211 (0.000)	0.0012 (0.000)	0.000	0.359	0.542
	M	35-54	1.22 (1.20-1.25)	1.15 (1.13-1.17)	-0.0211 (0.000)	0.0012 (0.000)			

	M	55-74	1.23 (1.20-1.25)	1.15 (1.14-1.17)	-0.0211 (0.000)	0.0012 (0.000)			
	M	75-84	1.21 (1.19-1.24)	1.14 (1.12-1.15)	-0.0211 (0.000)	0.0012 (0.000)			
All MI†	F	35-54	1.10 (1.08-1.12)	1.03 (1.02-1.04)	-0.0052 (0.000)				
	F	55-74	1.08 (1.07-1.09)	1.03 (1.02-1.03)	-0.0052 (0.000)				
	F	75-84	1.06 (1.05-1.07)	1.05 (1.04-1.06)	-0.0052 (0.000)		0.077	0.000	0.112
	M	35-54	1.09 (1.08-1.11)	1.03 (1.01-1.04)	-0.0052 (0.000)				
	M	55-74	1.09 (1.08-1.10)	1.04 (1.03-1.05)	-0.0052 (0.000)				
	M	75-84	1.07 (1.06-1.08)	1.06 (1.04-1.07)	-0.0052 (0.000)				
ACS†	F	35-54	1.13 (1.11-1.14)	1.04 (1.03-1.06)	-0.0063 (0.000)				
	F	55-74	1.13 (1.12-1.14)	1.04 (1.03-1.05)	-0.0063 (0.000)				
	F	75-84	1.11 (1.10-1.12)	1.06 (1.06-1.07)	-0.0063 (0.000)		0.000	0.001	0.007
	M	35-54	1.13 (1.11-1.15)	1.05 (1.04-1.06)	-0.0063 (0.000)				
	M	55-74	1.16 (1.14-1.17)	1.06 (1.06-1.07)	-0.0063 (0.000)				
	M	75-84	1.12 (1.11-1.13)	1.08 (1.07-1.09)	-0.0063 (0.000)				
All CHD‖	F	35-54	1.14 (1.12-1.16)	1.07 (1.05-1.08)	-0.0125 (0.000)	0.0005 (0.000)			
	F	55-74	1.15 (1.14-1.17)	1.08 (1.07-1.09)	-0.0125 (0.000)	0.0005 (0.000)			

	F	75-84	1.12 (1.11-1.13)	1.08 (1.07-1.09)	-0.0125 (0.000)	0.0005 (0.000)	0.000	0.000	0.051
	M	35-54	1.17 (1.14-1.20)	1.09 (1.08-1.11)	-0.0125 (0.000)	0.0005 (0.000)			
	M	55-74	1.19 (1.18-1.20)	1.12 (1.11-1.12)	-0.0125 (0.000)	0.0005 (0.000)			
	M	75-84	1.14 (1.13-1.15)	1.11 (1.10-1.11)	-0.0125 (0.000)	0.0005 (0.000)			

Key: ACS=acute coronary syndrome; CHD=coronary heart disease; CI=confidence interval; F=female; M=male; MI=myocardial infarction; NSTEMI=non ST-elevation myocardial infarction; STEMI=ST-elevation myocardial infarction.

† From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex + age*(admission year-2000)

‡ From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex

§ From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex + (admission year-2000)^2

‖ From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex + (admission year-2000)^2 + age group*(admission year-2000)

p-values for sex and age group are from the respective models but without the age group*sex interaction term

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No.	Recommendation	Page No.	Relevant text from manuscript
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2	Title: Exploring the effects of transfers and readmissions on trends in population counts of hospital admissions for coronary heart disease: a Western Australian data linkage study
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	4	ABSTRACT Objectives To (i) develop an approach to identify and categorise admissions for each coronary heart disease (CHD) subtype accounting for hospital transfers and readmissions from linked hospital data; (ii) compare counts of unlinked CHD admissions with linked data accounting for transfers and early readmissions; and (iii) examine whether the ratios of these counts show similar or disparate patterns over time and across age and sex groups for each CHD subtype……
Introduction				
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	6-7	INTRODUCTION Coronary heart disease (CHD) remains a major cause of death in Australia.[1] Clinically it manifests across a spectrum of subtypes, from ST-elevation myocardial infarction (STEMI) (the most severe), non-STEMI (NSTEMI), unstable angina, stable angina through to other

				chronic presentations……
Objectives	3	State specific objectives, including any prespecified hypotheses	7	There is a potential to overestimate hospitalisation counts of CHD using unlinked data where essentially each admission record is treated as a different patient. On the other hand the issues with person-linked hospital data is the need to group admissions related by transfers or readmissions into a single admission and to assign a single relevant diagnosis. To the best of our knowledge, approaches to these issues have not been addressed previously. Hence, our aims were to: (i) develop an approach to identify and categorise admissions for each CHD subtype accounting for hospital transfers and readmissions from linked hospital data; (ii) compare counts of unlinked CHD admissions with linked data accounting for transfers and readmissions; and (iii) examine whether the ratios of these counts show similar or disparate patterns over time and across age and sex groups for each CHD subtype.
Methods				
Study design	4	Present key elements of study design early in the paper	7	For this cohort study, we used person-linked administrative health data from the Hospital Morbidity Data Collection, one of the core datasets of the Western Australian Data

				Linkage System.
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7-8	Western Australia (WA) is representative of national sociodemographic and health indicators,[9] with an estimated resident population of 2.6 million in 2013.[10] The available dataset included all hospital records for any person hospitalised with CHD in WA from 1988 to 2013. We included all fatal and non-fatal admissions, with age restricted to 35-84 years.
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	8	The available dataset included all hospital records for any person hospitalised with CHD in WA from 1988 to 2013. We included all fatal and non-fatal admissions, with age restricted to 35-84 years.
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case		Not applicable
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8	Variables available included demographic information, admission and discharge dates, principal and 20 secondary discharge diagnosis fields, and hospital locations.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7-8	For this cohort study, we used person-linked administrative health data from the Hospital Morbidity Data Collection, one of the core datasets of the

				Western Australian Data Linkage System. Western Australia (WA) is representative of national sociodemographic and health indicators,[9] with an estimated resident population of 2.6 million in 2013.[10] The available dataset included all hospital records for any person hospitalised with CHD in WA from 1988 to 2013. We included all fatal and non-fatal admissions, with age restricted to 35-84 years. Variables available included demographic information, admission and discharge dates, principal and 20 secondary discharge diagnosis fields, and hospital locations.
Bias	9	Describe any efforts to address potential sources of bias		Not relevant as this is not an outcomes study by a methodological study.
Study size	10	Explain how the study size was arrived at		Not relevant as this is a population-based study.
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	12	All models included sex, age-group, sex*age-group interaction term and year as a continuous variable and year squared was also included where a curved trend was indicated (Wald test p<0.01).
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	12	Annual counts for each CHD subtype and combination subtypes are presented at the unlinked-, CA- and 28-day episode levels for 1988 to 2013. The ratio of unlinked admission count to CA count was

			calculated for each age-group (35-54 years, 55-74 years, 75-84 years) and gender in each year to determine the relative overestimation of each CHD subtype. To examine the impact on counts from using 28-day episodes, we calculated the ratio of 28-day episode to CA counts for each age-group and gender in each year, for each CHD subtype. Linear regression (with robust standard errors) was used to compare the ratios statistically across age-groups and gender, and assess trends over time.
	(*b*) Describe any methods used to examine subgroups and interactions	12	This analysis was restricted to the period 2000 to 2013 as CHD counts were more consistent during this time. All models included sex, age-group, sex*age-group interaction term and year as a continuous variable and year squared was also included where a curved trend was indicated (Wald test p<0.01). We fitted extended models with time interaction terms to test if there were differences in time trends by sex and age-group (i.e. we tested sex*year, age-group*year, and sex*age-group*year for ratios without curved trends and, for ratios with curved trends, also tested sex*year squared, age-group*year squared and sex*age-group*year squared). Only a few of the time interaction tests had p<0.01 and in lieu of the large number of time interactions tested and the lack of any consistent pattern to these results, these were

				considered not to be real and were ignored (i.e. considered as false positive time interactions)
		(*c*) Explain how missing data were addressed		Not relevant as this is population-based study from administrative data.
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy		Not relevant as this is a methodological study.
		(*e*) Describe any sensitivity analyses		
Results				
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	13	Not relevant as this is a methodological study on hospital admission counts rather than person counts. However, we have described the numbers of hospital admissions on Page 11 as such: There were 296,659 unlinked hospital admissions for CHD from 1988 to 2013 in WA (Table 2). The diagnosis hierarchy approach resulted in the highest count of CHD admissions (n=273,793) and the approach based on the diagnosis from last admission resulted in the lowest count (n=263,313). The number of 28-day episodes was 242,966. The counts at the unlinked, CA-level and 28-day episode level for each CHD subtype are shown in Table 2.
		(b) Give reasons for non-participation at each stage		
		(c) Consider use of a flow diagram		
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on		As per Question 13 above.

		exposures and potential confounders	
		(b) Indicate number of participants with missing data for each variable of interest	
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	Not relevant as this is not an outcomes study but rather a methodological study.
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Not relevant given this is a methodological study. Our linear regressions include age-group, year, sex as variables of interest rather than confounders. Results are presented in Tables 3 (Pages 16-17) and 4 (Pages 19-20).
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	

Continued on next page

Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses		We report analyses of CHD subgroups in Tables 3 (pages 15-16) and 4 (Pages 18-19), and in Supplementary Tables 1 and 2.
Discussion				
Key results	18	Summarise key results with reference to study objectives	22	We developed different approaches to assign CHD diagnoses to a sequence of consecutive admissions and 28-day episodes that account for transfers and readmissions, thereby avoiding the over-count that occurs with unlinked administrative data. Hospitalisation data from 1988 to 2013 show that for each CHD subtype, unlinked records over-counted the number of CHD hospitalisations relative to CA counts and 28-day episode counts. Our analyses of ratios from 2000-2013 showed a complex pattern of over-counting in unlinked data due to transfers and readmissions. In almost all CHD subtypes, the ratios changed in a linear or quadratic fashion over time and the coefficients of the trends differed across CHD subtypes. Further, for many CHD subtypes the ratios also differed by age-group and sex.
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	25	The limitations of this study include the validity of coding for CHD. An earlier WA study using linked data showed that the sensitivity of hospital coding for MI was 76.9% in the 35-69 year olds.[14] The use of 28-day episodes may miss a small number of related readmissions which occur beyond 28 days. Furthermore, we did not adjust for

				confounders such as remoteness and Indigenous status which may influence transfer and readmission patterns.[6 22] The complex pattern of counts and ratios we presented are from WA for 2000 to 2013 and may not be generalisable to other jurisdictions (because of different healthcare systems) or beyond the study period, however the methods we described are generalisable to other states and territories.
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	25	Although unlinked data has its place in measurement of hospital health service utilisation, its use in epidemiological estimates of CHD hospitalisations overestimates CHD counts. We contend that CA (accounting for transfers) and 28-day episode (accounting for transfers and readmissions) counts are more aligned with epidemiological studies of CHD. The degree of overestimation of counts using only unlinked records varies in a complex manner with CHD subtype, time, sex and age-group, it is not possible to apply a simple correction factor to counts obtained from unlinked data.
Generalisability	21	Discuss the generalisability (external validity) of the study results	25	The complex pattern of counts and ratios we presented are from WA for 2000 to 2013 and may not be generalisable to other jurisdictions (because of different healthcare systems) or beyond the study period, however the methods we described are generalisable to other states and territories.

				The degree of overestimation of counts using only unlinked records varies in a complex manner with CHD subtype, time, sex and age-group, it is not possible to apply a simple correction factor to counts obtained from unlinked data.
Other information				
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	26	This work was supported by the National Health and Medical Research Council (NHMRC) of Australia project grant 1078978. The grant agency does not impose restrictions on conduct of analyses or dissemination of findings. LN is funded by a National Health and Medical Research Council of Australia Early Career Fellowship.

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Exploring the effects of transfers and readmissions on trends in population counts of hospital admissions for coronary heart disease: a Western Australian data linkage study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2017-019226.R2
Article Type:	Research
Date Submitted by the Author:	13-Oct-2017
Complete List of Authors:	Lopez, Derrick; University of Western Australia, School of Population and Global Health Nedkoff, Lee; University of Western Australia, School of Population and Global Health Knuiman, Matthew; University of Western Australia, School of Population and Global Health Hobbs, Michael; University of Western Australia, School of Population and Global Health Briffa, Thomas; University of Western Australia, School of Population and Global Health Preen, David; The University of Western Australia, School of Population and Global Health Hung, Joseph; The University of Western Australia, School of Medicine Beilby, John; The University of Western Australia, School of Biomedical Sciences Mathur, Sushma; Australian Institute of Health and Welfare Reynolds, Anna; Australian Institute of Health and Welfare Sanfilippo, Frank; University of Western Australia, School of Population and Global Health
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Cardiovascular medicine, Research methods
Keywords:	Coronary heart disease < CARDIOLOGY, Cardiac Epidemiology < CARDIOLOGY, STATISTICS & RESEARCH METHODS

Title: Exploring the effects of transfers and readmissions on trends in population counts of hospital admissions for coronary heart disease: a Western Australian data linkage study

Type of manuscript: Original research article

Running title: Transfers, readmissions and heart disease counts

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Word count: 3,677 words

Abstract: 253 words

References: 24

Figures: 2

Tables: 4

Supplementary tables: 2

ABSTRACT

Objectives To develop a method for categorising coronary heart disease (CHD) subtype in linked data accounting for different CHD diagnoses across records, and to compare hospital admission numbers and ratios of unlinked versus linked data for each CHD subtype over time, and across age groups and sex.

Design Cohort study

Data source Person-linked hospital administrative data covering all admissions for CHD in Western Australia from 1988 to 2013.

Main outcome Ratios of (i) unlinked admission counts to contiguous admission (CA) counts (accounting for transfers), and (ii) 28-day episode counts (accounting for transfers and readmissions) to CA counts stratified by CHD subtype, sex and age-group.

Results In all CHD subtypes, the ratios changed in a linear or quadratic fashion over time and the coefficients of the trend term differed across CHD subtypes. Furthermore, for many CHD subtypes the ratios also differed by age-group and sex. For example, in females aged 35-54 years, the ratio of unlinked to CA counts for non-ST elevation myocardial infarction admissions in 2000 was 1.10 and this increased in a linear fashion to 1.30 in 2013, representing an annual increase of 0.0148.

Conclusion The use of unlinked counts in epidemiological estimates of CHD hospitalisations overestimates CHD counts. The CA and 28-day episode counts are more aligned with epidemiological studies of CHD. The degree of overestimation of counts using only unlinked counts varies in a complex manner with CHD subtype, time, sex and age-group and it is not possible to apply a simple correction factor to counts obtained from unlinked data.

Key words: coronary heart disease; transfers; readmissions; ratios; counts

Strengths and limitations of this study

- Use of statewide administrative data captures all hospital admissions in Western Australia.
- Record linkage allowed the identification of contiguous admissions to account for transfers and 28-day episodes to account for readmissions.
- Whilst the complex pattern of counts and ratios presented are from a single jurisdiction in Australia, it is likely that the methods described will be generalisable to other states and territories. However, the ratios obtained may be not be generalisable outside Western Australia (because of differences in healthcare systems) or beyond the study period.
- Another limitation is the validity of coding for coronary heart disease in administrative data.
- The use of 28-day episodes may miss a small number of related readmissions which occur beyond 28 days.

INTRODUCTION

Coronary heart disease (CHD) remains a major cause of death in Australia.[1] Clinically it manifests across a spectrum of subtypes, from ST-elevation myocardial infarction (STEMI) (the most severe), non-STEMI (NSTEMI), unstable angina, stable angina through to other chronic presentations. There is increasing evidence that less severe forms of CHD, such as stable angina, also have an increased risk of major adverse cardiovascular events.[2] Therefore, accurate information on population trends in CHD event rates and its subtypes is an indicator of the healthcare burden and essential for planning and evaluation of appropriate public health measures and clinical services. The focus on MI alone fails to provide a complete understanding of the size of the problem of suspected CHD or its outcomes and reliable estimates of CHD events at the population level are predicated on accurate stratification of CHD subtypes, for which there are limited data in Australia.

Population hospital administrative data provides a valuable data source in this regard where each admission is a separate record and diagnosis. However, this data source is not specifically designed for research purposes, and admission counts are susceptible to over-inflation if the patient is transferred or readmitted multiple times during their clinical course for essentially a single episode of care. Additionally, recording of CHD subtype can differ between records in the same episode of care, requiring consideration when categorising CHD subtype for the episode. This is especially true for the management of CHD which has historically been characterised with high rates of hospital transfers and early readmissions.[3] Indeed, contemporary Australian data has shown that around 18-30% of patients hospitalised for MI are transferred to another hospital,[4 5] often for highly specialised coronary artery procedures, most notably coronary angiography and revascularisation by percutaneous coronary intervention (PCI). These specialised coronary care services are generally located at major population centres, and many patients, especially those from non-urban areas, are transferred to one of these

hospitals for treatment and management of their condition.[6] In addition, a significant number of MI patients are readmitted for complications post-MI (such as repeat MI or heart failure), for elective procedures (such as coronary artery revascularisation or electrophysiological investigation), and to a lesser degree, for non-cardiac related admissions.[7 8]

There is a potential to overestimate hospitalisation rates of CHD subtypes using unlinked data because transfers and readmissions are not accounted for. This could differentially affect CHD subtype rates, depending on the use of different diagnosis codes when patients are transferred or for early readmissions. For jurisdictions where only unlinked data is available, it is important to understand the degree of overestimation of the number of admissions across subtypes, and whether this changes over time or by age-group and sex. Where person-linked hospital data is available, there is a need to assign a single relevant diagnosis to a group of admissions related by transfers or readmissions. To the best of our knowledge, approaches to these issues have not been addressed previously. Hence, our aims were to: (i) develop an approach to identify and categorise admissions for each CHD subtype accounting for different CHD diagnoses across hospital transfers and readmission records from linked hospital data; (ii) compare counts of unlinked CHD admissions with linked data accounting for transfers and readmissions; and (iii) examine whether the ratios of these counts show similar or disparate patterns over time and across age and sex groups for each CHD subtype.

METHODS

Data source and study population

For this cohort study, we used person-linked administrative health data from the Hospital Morbidity Data Collection, one of the core datasets of the Western Australian Data Linkage System. Western

Australia (WA) is representative of national sociodemographic and health indicators,[9] with an estimated resident population of 2.6 million in 2013.[10] The available dataset included all hospital records for any person hospitalised with CHD in WA from 1988 to 2013. We included all fatal and non-fatal admissions, with age restricted to 35-84 years. Variables available included demographic information, admission and discharge dates, principal and 20 secondary discharge diagnosis fields, and hospital locations.

Identification of CHD subtypes for individual (unlinked) admissions

All CHD admissions were identified from the principal discharge diagnosis field based on ICD-9-CM (1st January 1988 to 30th June 1999) and the International Statistical Classification of Diseases and Related Health Problems, Tenth Revision, Australian Modification (ICD-10-AM) (1st July 1999 to the present). CHD subtypes were defined as: transmural MI/STEMI (ICD-9-CM: 410.0-410.6, 410.8; ICD-10-AM: I21.0-I21.3) (hereafter STEMI), subendocardial MI/NSTEMI (410.7; I21.4) (hereafter NSTEMI), unspecified MI (410.9; I21.9), unstable angina (411.1; I20.0), stable angina (413; I20.1-I20.9), other CHD (411.0, 411.81, 411.89, 412, 414; I23-I25). Other CHD includes complications following MI and chronic ischaemic heart disease. An addition to the labelling of transmural or subendocardial MI was added in ICD-10-AM in 2004, with reference to STEMI ("transmural or STEMI") and NSTEMI ("subendocardial or NSTEMI") included. All MI is a combination of STEMI, NSTEMI and unspecified MI; acute coronary syndrome (ACS) is a combination of All MI and unstable angina; and All CHD is a combination of ACS, stable angina and Other CHD.

Identifying transfers and readmissions

An inter-hospital transfer occurs when a patient is discharged from one hospital and directly admitted to another hospital within one day. Patients can have multiple transfers related to the same presentation. We introduce the concept of a *contiguous admission* (CA) which may represent a single isolated

admission or an uninterrupted continuous hospital stay as a result of one or more transfers between hospitals. The admission date for the CA is the admission date of the first admission in the sequence. We also define a *28-day episode of care*, which comprises an index CA and any subsequent CAs occuring within 28 days of the admission date of the index CA. A CA that begins more than 28 days after the index CA is considered a new episode of care. The 28-day period is commonly used in epidemiological studies.[11-13]

Assigning principal diagnosis for CHD subtype to each CA and 28-day episode

Each admission in a CA has its own principal discharge diagnosis code that may vary between admissions. We have calculated CA counts based on four approaches described below.

Diagnosis hierarchy: This is based on the work of Sanfilippo et al,[14] and reflects the severity of the CHD subtypes from STEMI (most severe), NSTEMI, unstable angina, stable angina to Other CHD (least severe). For a CA with multiple principal diagnoses, the most severe diagnostic category is used.

Hospital hierarchy: The hierarchy is metropolitan tertiary hospital (specialised cardiac care, diagnostic angiography and PCI), private metropolitan hospital (with and without aforementioned tertiary care), metropolitan non-tertiary hospital and rural/remote hospital. During the study period, all three metropolitan tertiary and four private hospitals had a cardiac catheter laboratory.[15] None of the metropolitan non-tertiary or rural/remote hospitals had a cardiac catheter laboratory at the time of this study. For a CA with multiple principal diagnoses, the principal diagnosis from the hospital highest in the hierarchy is used.

First admission: The principal diagnosis recorded from the first admission in the CA is used. Given the acute nature of CHD, the first admission in a CA is presumed to be due to this condition while subsequent transfers are for procedures or resultant complications or cardiac rehabilitation.

Last admission: The principal diagnosis recorded from the last admission in the CA is used. The last hospital admission in the CA is presumed to be when the most definitive diagnosis is made amongst all admissions.

The diagnostic CHD subtype assigned to each 28-day episode was based on the diagnosis hierarchy approach. That is, the most severe subtype of all the CAs that comprise the 28-day episode is used. Table 1 illustrates how diagnoses (CHD subtypes) are assigned to CAs (four approaches) and to 28-day episodes for a hypothetical patient with ten hospital admissions, grouped into four CAs and three 28-day episodes.

Table 1: Example of typical patient record (not a real patient) depicting the different approaches of assigning a diagnosis to contiguous admissions (CA) and 28-day episodes.

Record No.	Patient ID	Admission date	Discharge date	Hospital	Transfer	28-day readmission	CA No.	28-day episode No.	Principal diagnosis	Diagnosis approach at the CA-level				Diagnosis at 28-day episode level
										Diagnosis hierarchy	Hospital hierarchy	First admission	Last admission	
1	1	1 Feb 2005	2 Feb 2005	Rural			1	1	Stable angina	NSTEMI	Unstable angina	Stable angina	NSTEMI	STEMI
2	1	2 Feb 2005	4 Feb 2005	Metropolitan tertiary	1		1	1	Unstable angina					
3	1	4 Feb 2005	6 Feb 2005	Metropolitan non-tertiary	1		1	1	NSTEMI					
4	1	17 Feb 2005	18 Feb 2005	Metropolitan tertiary		1	2	1	STEMI	STEMI	STEMI	STEMI	Other CHD	-
5	1	18 Feb 2005	22 Feb2005	Private	1	1	2	1	Other CHD					
6	1	10 Oct 2005	11 Oct 2005	Metropolitan non-tertiary			3	2	Stable angina	NSTEMI	NSTEMI	Stable angina	NSTEMI	NSTEMI
7	1	11 Oct 2005	14 Oct 2005	Metropolitan tertiary	1		3	2	NSTEMI					
8	1	1 Dec 2005	2 Dec 2005	Rural			4	3	Non-CHD	Stable angina	Stable angina	Non-CHD	Non-CHD	Stable angina
9	1	2 Dec 2005	3 Dec 2005	Metropolitan tertiary	1		4	3	Stable angina					
10	1	3 Dec 2005	5 Dec 2005	Private	1		4	3	Non-CHD					

Key: CHD=coronary heart disease; CA=contiguous admission

Statistical analysis

Annual counts for each CHD subtype and combination subtypes are presented at the unlinked-, CA- and 28-day episode levels for 1988 to 2013. The ratio of unlinked admission count to CA count was calculated for each age-group (35-54 years, 55-74 years, 75-84 years) and gender in each year to determine the relative overestimation of each CHD subtype. To examine the impact on counts from using 28-day episodes, we calculated the ratio of 28-day episode to CA counts for each age-group and gender in each year, for each CHD subtype. Linear regression (with robust standard errors) was used to compare the ratios statistically across age-groups and gender, and assess trends over time. This analysis was restricted to the period 2000 to 2013 as CHD counts were more consistent during this time. All models included sex, age-group, sex*age-group interaction term and year as a continuous variable and year squared was also included where a curved trend was indicated (Wald test $p<0.01$). We fitted extended models with time interaction terms to test if there were differences in time trends by sex and age-group (i.e. we tested sex*year, age-group*year, and sex*age-group*year for ratios without curved trends and, for ratios with curved trends, also tested sex*year squared, age-group*year squared and sex*age-group*year squared). Only a few of the time interaction tests had $p<0.01$ and in lieu of the large number of time interactions tested and the lack of any consistent pattern to these results, these were considered not to be real and were ignored (i.e. considered as false positive time interactions). Analyses were performed using Stata 13.1.

Ethics approval

This study was approved by the Human Research Ethics Committees of the Western Australian Department of Health and The University of Western Australia. The study was granted a waiver of informed consent.

RESULTS

There were 296,659 unlinked hospital admissions for CHD from 1988 to 2013 in WA (Table 2). The diagnosis hierarchy approach resulted in the highest count of CHD admissions (n=273,793) and the approach based on the diagnosis from last admission resulted in the lowest count (n=263,313). The number of 28-day episodes was 242,966. The counts at the unlinked, CA-level and 28-day episode level for each CHD subtype are shown in Table 2.

Table 2: Diagnosis counts at the unlinked-, contiguous admission (CA)- and 28-day episode levels for admission years 1988 to 2013.

	Unlinked-level	CA-level				28-day episode-level
		Diagnosis hierarchy	Hospital hierarchy	Diagnosis based on first admission	Diagnosis based on last admission	
Number of CHD records	296,659	273,793	269,614	267,389	263,313	242,966
Diagnosis:						
STEMI	37,457 (12.63%)	34,435 (12.58%)	33,313 (12.36%)	32,165 (12.03%)	32,014 (12.16%)	33,364 (13.73%)
NSTEMI	29,203 (9.84%)	24,734 (9.03%)	23,956 (8.89%)	21,868 (8.18%)	22,631 (8.59%)	23,738 (9.77%)
Unstable angina	72,223 (24.35%)	65,589 (23.96%)	63,301 (23.48%)	64,478 (24.11%)	60,333 (22.91%)	59,144 (24.34%)
Stable angina	77,076 (25.98%)	73,994 (27.03%)	73,898 (27.41%)	73,845 (27.62%)	73,037 (27.74%)	64,669 (26.62%)
Other CHD	69,070 (23.27%)	65,161 (23.80%)	65,751 (24.39%)	64,632 (24.17%)	66,148 (25.11%)	52,688 (21.68%)
All MI	78,315 (26.40%)	69,049 (25.22%)	66,664 (24.73%)	64,434 (24.10%)	63,818 (24.24%)	66,487 (27.36%)
ACS	150,538 (50.74%)	134,638 (49.18%)	129,965 (48.20%)	128,912 (48.21%)	124,151 (47.15%)	125,631 (51.71%)

Key: ACS=acute coronary syndrome; CHD=coronary heart disease; MI=myocardial infarction; NSTEMI=non ST-elevation myocardial infarction; STEMI=ST-elevation myocardial infarction.

Figure 1 shows trends in annual admission counts for each CHD subtype and combination subtypes at the CA-level, using the diagnosis hierarchy approach and the three alternative approaches. The diagnosis hierarchy approach resulted in highest counts for the more severe CHD subtypes compared to the three alternative approaches, but all methods had similar trends over time for each CHD subtype.

Figure 2 compares annual CHD counts at the unlinked, CA (using diagnosis hierarchy approach) and 28-day episode levels from 1988 to 2013. The use of unlinked records resulted in the highest counts of all subtypes while 28-day episode records resulted in the lowest counts. The difference between unlinked and CA counts tended to be greater in the latter half of the study period for STEMI, NSTEMI and unstable angina, while the reverse was apparent for Other CHD. The difference between unlinked and CA counts for NSTEMI, All MI and ACS increased from around 2000 onwards. The difference between CA and 28-day episode counts tended to increase from around 2000 onwards for NSTEMI but narrowed for STEMI and unstable angina.

Table 3 and supplementary table 1 present estimated ratios for unlinked to CA counts (based on diagnosis hierarchy approach) from fitted regression models by CHD subtype, sex and age-group for the period 2000 to 2013. In females aged 35-54 years, the ratio of unlinked to CA counts for NSTEMI admissions in 2000 was 1.10 (i.e. 10% higher in unlinked) and this increased in a linear fashion to 1.30 (i.e. 30% higher) in 2013 representing an increase of 0.0148 per year. Conversely, the over count for STEMI and All MI followed a curved (quadratic) trend. For subtypes with a linear trend, the trend coefficients were largest in the most severe CHD subtype (NSTEMI: increase of 0.0148/year) and smallest in the least severe subtype (Other CHD: non-significant increase of 0.0003/year). The sex*age-group interaction term was not significant in any individual or combination subtype but the ratios were significantly higher in the youngest age-group for STEMI, NSTEMI, stable angina and all

combination subtypes. Males had significantly higher ratios than females for unstable angina and ACS.

Table 3: Estimated ratios of unlinked versus CA-level counts (diagnosis hierarchy approach) from 2000 to 2013: by CHD subtype, sex and age-group

Diagnosis	Sex	Age-group	Ratio (CI) in 2000	Ratio (CI) in 2013	Trend coefficient (p-value)		p-values for tests comparing		
					Year	Year squared	Sex[§]	Age-group[§]	Sex*Age-group
STEMI[†]	F	35-54	1.12 (1.09-1.15)	1.14 (1.11-1.18)	0.0174 (0.000)	-0.0012 (0.000)	0.946	0.000	0.945
	F	55-74	1.09 (1.06-1.11)	1.11 (1.08-1.14)	0.0174 (0.000)	-0.0012 (0.000)			
	F	75-84	1.05 (1.02-1.09)	1.07 (1.02-1.13)	0.0174 (0.000)	-0.0012 (0.000)			
	M	35-54	1.12 (1.10-1.15)	1.15 (1.11-1.19)	0.0174 (0.000)	-0.0012 (0.000)			
	M	55-74	1.08 (1.06-1.10)	1.10 (1.08-1.13)	0.0174 (0.000)	-0.0012 (0.000)			
	M	75-84	1.05 (1.03-1.08)	1.08 (1.04-1.11)	0.0174 (0.000)	-0.0012 (0.000)			
NSTEMI[‡]	F	35-54	1.10 (1.08-1.13)	1.30 (1.27-1.33)	0.0148 (0.000)		0.768	0.000	0.734
	F	55-74	1.08 (1.06-1.10)	1.27 (1.25-1.29)	0.0148 (0.000)				
	F	75-84	1.04 (1.02-1.06)	1.23 (1.21-1.25)	0.0148 (0.000)				
	M	35-54	1.12 (1.09-1.14)	1.31 (1.29-1.33)	0.0148 (0.000)				
	M	55-74	1.07 (1.06-1.09)	1.27 (1.25-1.28)	0.0148 (0.000)				
	M	75-84	1.03 (1.02-1.05)	1.23 (1.21-1.24)	0.0148 (0.000)				
Unstable angina[‡]	F	35-54	1.09 (1.07-1.10)	1.15 (1.13-1.16)	0.0047 (0.000)		0.000	0.010	0.445
	F	55-74	1.09 (1.07-1.10)	1.15 (1.14-1.16)	0.0047 (0.000)				
	F	75-84	1.07 (1.06-1.09)	1.14 (1.12-1.15)	0.0047 (0.000)				
	M	35-54	1.12 (1.10-1.13)	1.18 (1.16-1.20)	0.0047 (0.000)				
	M	55-74	1.10 (1.09-1.11)	1.16 (1.15-1.17)	0.0047 (0.000)				
	M	75-84	1.09 (1.08-1.11)	1.15 (1.14-1.17)	0.0047 (0.000)				
Stable	F	35-54	1.05 (1.04-1.06)	1.07 (1.06-1.08)	0.0015 (0.000)				

angina‡	F	55-74	1.03 (1.03-1.04)	1.05 (1.05-1.06)	0.0015 (0.000)			
	F	75-84	1.03 (1.03-1.04)	1.05 (1.05-1.06)	0.0015 (0.000)	0.031	0.000	0.776
	M	35-54	1.04 (1.04-1.05)	1.06 (1.05-1.07)	0.0015 (0.000)			
	M	55-74	1.03 (1.03-1.03)	1.05 (1.04-1.05)	0.0015 (0.000)			
	M	75-84	1.03 (1.02-1.04)	1.05 (1.04-1.06)	0.0015 (0.000)			
Other CHD‡	F	35-54	1.05 (1.03-1.07)	1.06 (1.03-1.08)	0.0003 (0.583)			
	F	55-74	1.03 (1.02-1.04)	1.04 (1.03-1.05)	0.0003 (0.583)			
	F	75-84	1.04 (1.03-1.06)	1.05 (1.03-1.06)	0.0003 (0.583)	0.057	0.072	0.630
	M	35-54	1.04 (1.03-1.05)	1.04 (1.03-1.05)	0.0003 (0.583)			
	M	55-74	1.03 (1.02-1.04)	1.03 (1.03-1.04)	0.0003 (0.583)			
	M	75-84	1.03 (1.02-1.04)	1.04 (1.03-1.05)	0.0003 (0.583)			

Key: CHD=coronary heart disease; CI=confidence interval; CA=contiguous admission; F=female; M=male; MI=myocardial infarction; NSTEMI=non ST-elevation myocardial infarction; STEMI=ST-elevation myocardial infarction.

† From the model: ratio = constant + (admission year - 2000) + age-group + sex + age-group*sex + (admission year - 2000)^2

‡ From the model: ratio = constant + (admission year - 2000) + age-group + sex + age-group*sex

§ p-values for sex and age-group are from the respective models but without the age-group*sex interaction term

Table 4 and supplementary table 2 present the estimated ratios for CA versus 28-day episode counts. For example, in females aged 35-54 years, the ratio for STEMI was 1.10 in 2000 (i.e. 10% higher for CA counts) and this decreased to 1.01 in 2013 (i.e. 1% higher), representing a 0.0064 decrease per year. Ratios for unstable angina, stable angina, Other CHD and All CHD followed a curved (quadratic) trend. For example in females aged 35-54 years, the ratio for unstable angina was 1.15 in 2000 before levelling out at 1.09 from 2010 onwards. For unstable angina, stable angina, Other CHD, ACS and All CHD, the ratios were significantly higher in males than females. Differences in ratios between age-groups were seen for all CHD subtypes except for NSTEMI and other CHD.

Table 4: Estimated ratios of CA- versus 28-day episode-level counts (diagnosis hierarchy approach) from 2000 to 2013: by CHD subtype, sex and age-group

Diagnosis	Sex	Age-group	Ratio (CI) in 2000	Ratio (CI) in 2013	Trend coefficient (p-value)		p-values for tests comparing		
					Year	Year squared	Sex[#]	Age-group[#]	Sex*Age-group
STEMI[†]	F	35-54	1.10 (1.05-1.14)	1.01 (0.99-1.03)	-0.0064 (0.000)				
	F	55-74	1.08 (1.06-1.09)	1.01 (1.00-1.02)	-0.0064 (0.000)				
	F	75-84	1.05 (1.03-1.06)	1.03 (1.02-1.05)	-0.0064 (0.000)		0.946	0.000	0.799
	M	35-54	1.09 (1.06-1.11)	1.01 (0.98-1.03)	-0.0064 (0.000)				
	M	55-74	1.08 (1.07-1.09)	1.01 (1.00-1.02)	-0.0064 (0.000)				
	M	75-84	1.05 (1.04-1.06)	1.04 (1.02-1.06)	-0.0064 (0.000)				
NSTEMI[‡]	F	35-54	1.10 (1.06-1.14)	1.05 (1.03-1.08)	-0.0036 (0.000)				
	F	55-74	1.07 (1.06-1.09)	1.03 (1.01-1.04)	-0.0036 (0.000)				
	F	75-84	1.08 (1.06-1.10)	1.04 (1.02-1.05)	-0.0036 (0.000)		0.470	0.937	0.033
	M	35-54	1.08 (1.06-1.10)	1.03 (1.02-1.05)	-0.0036 (0.000)				
	M	55-74	1.10 (1.08-1.12)	1.05 (1.04-1.07)	-0.0036 (0.000)				
	M	75-84	1.09 (1.07-1.11)	1.04 (1.03-1.06)	-0.0036 (0.000)				
Unstable angina[§]	F	35-54	1.15 (1.13-1.17)	1.09 (1.07-1.10)	-0.0124 (0.000)	0.0006 (0.001)			
	F	55-74	1.15 (1.14-1.17)	1.09 (1.08-1.10)	-0.0124 (0.000)	0.0006 (0.001)			
	F	75-84	1.17 (1.15-1.19)	1.11 (1.09-1.12)	-0.0124 (0.000)	0.0006 (0.001)	0.000	0.040	0.017
	M	35-54	1.18 (1.16-1.20)	1.12 (1.10-1.14)	-0.0124 (0.000)	0.0006 (0.001)			
	M	55-74	1.21 (1.19-1.22)	1.15 (1.13-1.16)	-0.0124 (0.000)	0.0006 (0.001)			
	M	75-84	1.20 (1.18-1.21)	1.13 (1.12-1.15)	-0.0124 (0.000)	0.0006 (0.001)			

Stable angina[§]	F	35-54	1.14 (1.12-1.16)	1.08 (1.07-1.10)	-0.0115 (0.000)	0.0006 (0.004)	0.000	0.009	0.097
	F	55-74	1.15 (1.14-1.17)	1.10 (1.09-1.11)	-0.0115 (0.000)	0.0006 (0.001)			
	F	75-84	1.14 (1.12-1.16)	1.08 (1.07-1.10)	-0.0115 (0.000)	0.0006 (0.001)			
	M	35-54	1.20 (1.18-1.23)	1.15 (1.13-1.16)	-0.0115 (0.000)	0.0006 (0.001)			
	M	55-74	1.20 (1.18-1.22)	1.14 (1.13-1.15)	-0.0115 (0.000)	0.0006 (0.001)			
	M	75-84	1.18 (1.16-1.20)	1.13 (1.11-1.14)	-0.0115 (0.000)	0.0006 (0.001)			
Other CHD[§]	F	35-54	1.18 (1.15-1.22)	1.11 (1.08-1.14)	-0.0211 (0.000)	0.0012 (0.000)	0.000	0.359	0.542
	F	55-74	1.19 (1.16-1.22)	1.12 (1.10-1.14)	-0.0211 (0.000)	0.0012 (0.000)			
	F	75-84	1.19 (1.16-1.21)	1.11 (1.09-1.13)	-0.0211 (0.000)	0.0012 (0.000)			
	M	35-54	1.22 (1.20-1.25)	1.15 (1.13-1.17)	-0.0211 (0.000)	0.0012 (0.000)			
	M	55-74	1.23 (1.20-1.25)	1.15 (1.14-1.17)	-0.0211 (0.000)	0.0012 (0.000)			
	M	75-84	1.21 (1.19-1.24)	1.14 (1.12-1.15)	-0.0211 (0.000)	0.0012 (0.000)			

Key: CHD=coronary heart disease; CI=confidence interval; F=female; M=male; MI=myocardial infarction; NSTEMI=non ST-elevation myocardial infarction; STEMI=ST-elevation myocardial infarction.

† From the model: ratio = constant + (admission year - 2000) + age-group + sex + age-group*sex + age*(admission year-2000)

‡ From the model: ratio = constant + (admission year - 2000) + age-group + sex + age-group*sex

§ From the model: ratio = constant + (admission year - 2000) + age-group + sex + age-group*sex + (admission year-2000)^2

‖ From the model: ratio = constant + (admission year - 2000) + age-group + sex + age-group*sex + (admission year-2000)^2 + age-group*(admission year-2000)

p-values for sex and age-group are from the respective models but without the age-group*sex interaction term

DISCUSSION

We developed different approaches to assign CHD diagnoses to a sequence of consecutive admissions and 28-day episodes that account for transfers and readmissions, thereby avoiding the over-count that occurs with unlinked administrative data. Hospitalisation data from 1988 to 2013 show that for each CHD subtype, unlinked records over-counted the number of CHD hospitalisations relative to CA counts and 28-day episode counts. Our analyses of ratios from 2000-2013 showed a complex pattern of over-counting in unlinked data due to transfers and readmissions. In almost all CHD subtypes, the ratios changed in a linear or quadratic fashion over time and the coefficients of the trends differed across CHD subtypes. Further, for many CHD subtypes the ratios also differed by age-group and sex.

The development of the CA method accounts for transfers and allows for classification by CHD subtype where multiple admissions with differing discharge diagnoses are present. As each transfer and admission to the receiving hospital has its own principal discharge diagnosis, we compared four approaches to assigning a single clinically relevant diagnosis for each CA. Of the four approaches to assigning diagnosis, we contend that diagnosis hierarchy is the most clinically relevant approach and indicator of healthcare burden as it prioritises disease severity according to a physician's clinical judgement. Of the four approaches, diagnosis hierarchy results in the highest CHD counts and would therefore result in the most conservative differences between unlinked and CA. Hospital hierarchy is based on resourcing of hospitals with coronary care services and the level of resourcing may differ in other jurisdictions. The recent introduction of coronary care services in rural hospitals in WA, means that the hospital hierarchy method may become less applicable. Diagnosis based on first or last admission in a CA may not identify CHD-related admissions that occur in the middle of a CA, highlighted by the resulting low counts that occurred when using these methods to assign a diagnosis. A small number of patients have an MI during an admission for non-cardiac conditions,[16]

and diagnosis based on first admission may not identify these CHD cases if they are subsequently transferred.

The ratios of unlinked versus CA counts for almost all subtypes (except STEMI and All MI) increased in a linear fashion, indicating a consistent increase in the over-inflation of admission numbers in unlinked data due to transfers. This likely reflects a complex mix of changes in clinical guidelines and practice, facilitated by direct transfers to hospitals with PCI capability for ACS cases and pre-hospital care protocols during this period. The widening difference between unlinked and CA counts for NSTEMI indicates an increasing rate of transfer for this group of patients. Given that NSTEMI patients are still at risk of future adverse events, clinical guidelines now recommend that these patients undergo early coronary angiography and hospitalisation if indicated. [2 17] Patients who are not at a hospital with advanced coronary care services may be transferred as a priority to a hospital with such capabilities. These findings show that the use of unlinked data would bias temporal trends in NSTEMI hospitalisation rates upwards and that linked data, using the described methods, would provide more reliable trend estimates for hospitalisation rates of NSTEMI in particular.

Furthermore, ratios were higher in the younger than older age-groups for all subtypes, indicating that older CHD patients were less likely to be transferred than younger patients. We also found males had a higher ratio than females for unstable angina and ACS. These sex and age differences in transfers may partly reflect age and sex disparities in ACS care and especially invasive management reported in earlier studies,[18 19] although further studies are needed to support this theory.

28-day episodes have previously only been used to capture early MI readmissions following an index MI admission thus reducing overestimation of population rates for MI. Historically, early readmissions were often for coronary procedures or other management related to the initial MI admission. Our method ensures 28-day episodes capture any CHD readmission during this period.

In general, our results show that early readmissions across all CHD subtypes have decreased, although the trend was not linear for unstable and stable angina, and Other CHD. This could indicate that most acute treatment is now managed during the initial admission or subsequent transfer, thus requiring fewer readmissions.

The findings of this study have important implications for monitoring population trends in MI and other CHD subtypes. The ratios of counts we presented would have been the same if we had used age-standardised rates (ASRs) as population denominators would have been the same in all three levels of counts. The trends in CA and 28-day episode counts for STEMI and NSTEMI are in accordance with other studies showing that hospital admissions for STEMI have decreased in Western countries while admissions for NSTEMI have increased.[20 21] The use of the CA and 28-day episode methods in linked data offsets over-counting of MI events which could potentially inflate trends in ASRs. The effect of overestimation of MI hospitalisation numbers due to transfers and readmissions could also artificially reduce case fatality because of the impact on case fatality denominators. In addition, it allows accurate representation of other subtypes of CHD, for which there are limited data at a whole-population level.

There are a number of jurisdictions including Australia where linked data is not available at a national/population level, for example, the United States, where studies reporting nation-wide trends on MI or CHD rely on unlinked data (e.g. Nationwide Inpatient Sample), or where the more recent introduction of national linked data necessitates use of unlinked data where long-term trends are required (e.g. Hospital Episode Statistics data in England).[22 23] Therefore we contend our methods and data will be of interest to countries outside of Australia. Although we have described an approach to dealing with transfers and defining episodes of care for use with CHD, these methods could be applied to other conditions that have high rates of transfer and readmissions, such as major

trauma and head injury where many patients are transferred from rural sites to major tertiary hospitals with intensive care and/or head injury units and rehabilitation.

Strengths and limitations

Strengths of our study include use of statewide data that captures all hospital admissions in WA. Record linkage allowed the identification of CAs to account for transfers and 28-day episodes. The limitations of this study include the validity of coding for CHD. An earlier WA study using linked data showed that the sensitivity of hospital coding for MI was 76.9% in the 35-69 year olds.[14] The use of 28-day episodes may miss a small number of related readmissions which occur beyond 28 days. Furthermore, we did not adjust for confounders such as remoteness and Indigenous status which may influence transfer and readmission patterns.[6 24] The complex pattern of counts and ratios we presented are from WA for 2000 to 2013 and may not be generalisable to other jurisdictions (because of different healthcare systems) or beyond the study period, however the methods we described are generalisable to other states and territories.

Conclusions

Although unlinked data has its place in measurement of hospital health service utilisation, its use in epidemiological estimates of CHD hospitalisations overestimates CHD counts. We contend that CA (accounting for transfers) and 28-day episode (accounting for transfers and readmissions) counts are more aligned with epidemiological studies of CHD. The degree of overestimation of counts using only unlinked records varies in a complex manner with CHD subtype, time, sex and age-group, it is not possible to apply a simple correction factor to counts obtained from unlinked data.

ABBREVIATIONS

ACS: acute coronary syndrome; AM: Australian modification; ASR: age standardised rates; CA: contiguous admission; CHD: coronary heart disease; CM: clinical modification; ICD: International

Classification of Diseases; MI: myocardial infarction; NSTEMI: non ST-elevation myocardial infarction; PCI: percutaneous coronary intervention; STEMI: ST-elevation myocardial infarction; WA: Western Australia

ACKNOWLEDGEMENTS

The authors thank the staff at the Western Australian Data Linkage Branch and the Department of Health Inpatient Data Collections for the provision of linked data.

FUNDING

This work was supported by the National Health and Medical Research Council (NHMRC) of Australia project grant 1078978. The grant agency does not impose restrictions on conduct of analyses or dissemination of findings. LN is funded by a National Health and Medical Research Council of Australia Early Career Fellowship.

DATA SHARING

We will consider requests for data sharing on an individual basis, with an aim to sharing data whenever possible for appropriate research purposes. However the research project uses secondary (third party) data derived from Australian (State or Federal) government registries, which are ultimately governed by their ethics committees and data custodians. Therefore, any requests to share this data will be subject to formal approval from their ethics committees overseeing the use of these data sources, along with the data custodian(s) for the data of interest.

AUTHOR CONTRIBUTIONS

MSTH, FMS, LN and MK conceived the study. MSTH, FMS, LN, MK, JH, JB and TGB contributed to protocol development study design and methods. DL performed all the data and statistical analyses, with statistical advice from MK. DL constructed the figures and tables, and led the write-up of this

manuscript. SM and AR provided advice on monitoring and linked data methods. DL, LN, MK, MSTH, TGB, DBP, JH, JB, SM, AR and FMS have interpreted the results, reviewed and approved this manuscript for submission.

COMPETING INTERESTS

The authors have no competing interests to declare.

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Figure legends

Figure 1

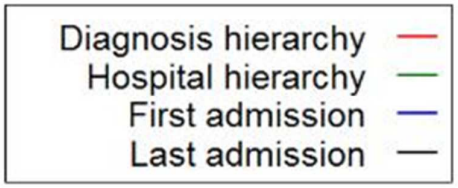
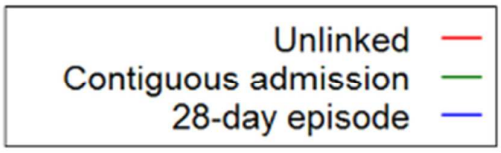


Figure 2



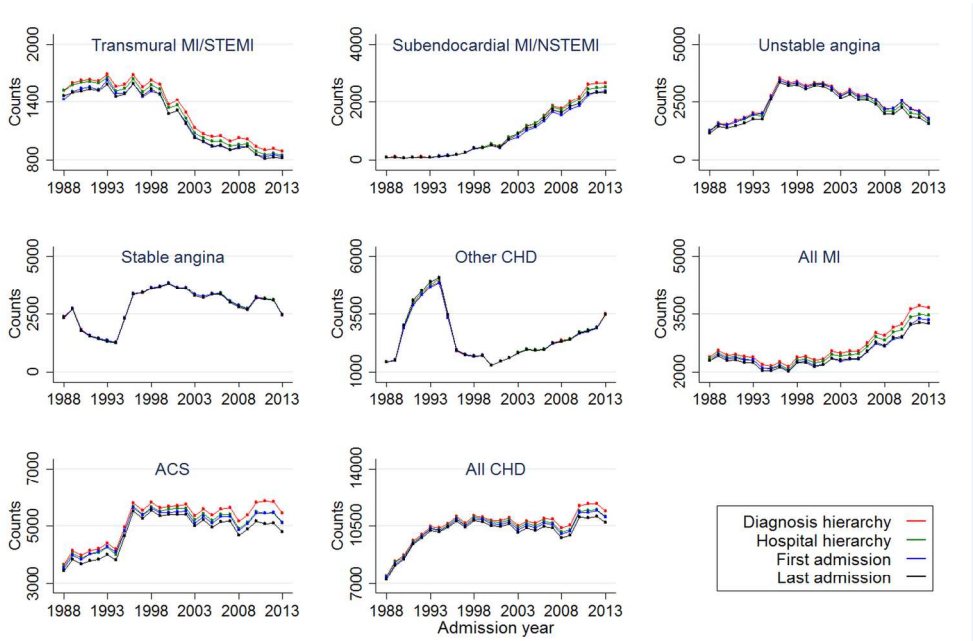


Figure 1: Comparison of CHD counts from 1988 to 2013 using four different approaches at the contiguous admission (CA) level (key: ACS=acute coronary syndrome; CHD=coronary heart disease; MI=myocardial infarction; NSTEMI=non ST-elevation myocardial infarction; CA=contiguous admission; STEMI=ST-elevation myocardial infarction)

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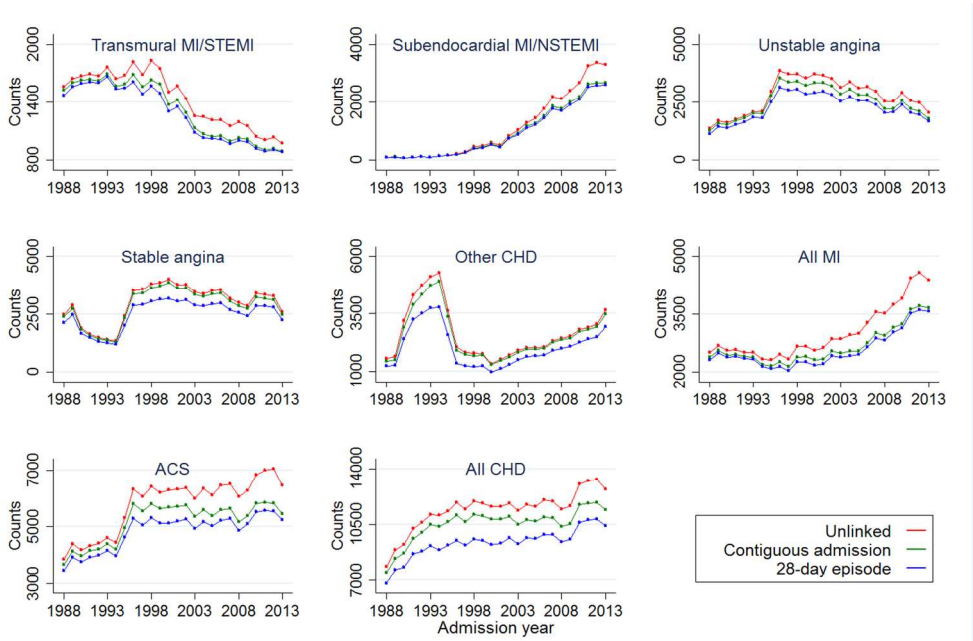

Figure 2: Comparison of CHD counts at the unlinked-, CA (diagnosis hierarchy approach) and 28-day episode levels from 1988 to 2013 (key: ACS=acute coronary syndrome; CHD=coronary heart disease; MI=myocardial infarction; NSTEMI=non ST-elevation myocardial infarction; CA=contiguous admission; STEMI=ST-elevation myocardial infarction)

162x108mm (300 x 300 DPI)

Supplementary table 1: Estimated ratios of unlinked versus CA-level counts (diagnosis hierarchy approach) from 2000 to 2013 for combination subtypes: by CHD subtype, sex and age group

Diagnosis	Sex	Age group	Ratio (CI) in 2000	Ratio (CI) in 2013	Trend coefficient (p-value)		p-values for tests comparing		
					Year	Year squared	Sex[§]	Age group[§]	Sex*Age group
All MI[†]	F	35-54	1.15 (1.12-1.18)	1.27 (1.25-1.30)	0.0166 (0.000)	-0.0006 (0.002)	0.576	0.000	0.720
	F	55-74	1.10 (1.09-1.12)	1.22 (1.20-1.24)	0.0166 (0.000)	-0.0006 (0.002)			
	F	75-84	1.06 (1.04-1.07)	1.18 (1.16-1.20)	0.0166 (0.000)	-0.0006 (0.002)			
	M	35-54	1.14 (1.12-1.16)	1.26 (1.24-1.29)	0.0166 (0.000)	-0.0006 (0.002)			
	M	55-74	1.10 (1.09-1.12)	1.22 (1.20-1.24)	0.0166 (0.000)	-0.0006 (0.002)			
	M	75-84	1.06 (1.05-1.08)	1.18 (1.16-1.20)	0.0166 (0.000)	-0.0006 (0.002)			
ACS[‡]	F	35-54	1.12 (1.10-1.13)	1.22 (1.21-1.23)	0.0078 (0.000)		0.003	0.000	0.695
	F	55-74	1.10 (1.09-1.10)	1.20 (1.18-1.21)	0.0078 (0.000)				
	F	75-84	1.07 (1.06-1.08)	1.17 (1.16-1.18)	0.0078 (0.000)				
	M	35-54	1.14 (1.12-1.15)	1.24 (1.22-1.26)	0.0078 (0.000)				
	M	55-74	1.11 (1.10-1.11)	1.21 (1.20-1.22)	0.0078 (0.000)				
	M	75-84	1.08 (1.07-1.09)	1.18 (1.17-1.19)	0.0078 (0.000)				

All CHD‡	F	35-54	1.09 (1.08-1.10)	1.15 (1.14-1.15)	0.0043 (0.000)	0.684	0.000	0.152
	F	55-74	1.06 (1.06-1.07)	1.12 (1.11-1.13)	0.0043 (0.000)			
	F	75-84	1.06 (1.06-1.07)	1.12 (1.11-1.12)	0.0043 (0.000)			
	M	35-54	1.10 (1.09-1.11)	1.15 (1.15-1.16)	0.0043 (0.000)			
	M	55-74	1.06 (1.06-1.07)	1.12 (1.11-1.12)	0.0043 (0.000)			
	M	75-84	1.06 (1.05-1.06)	1.11 (1.11-1.12)	0.0043 (0.000)			

Key: ACS=acute coronary syndrome; CHD=coronary heart disease; CI=confidence interval; CA=contiguous admission; F=female; M=male; MI=myocardial infarction.

† From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex + (admission year - 2000)^2

‡ From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex

§ p-values for sex and age group are from the respective models but without the age group*sex interaction term

Supplementary table 2: Estimated ratios of CA- versus 28-day episode-level counts (diagnosis hierarchy approach) from 2000 to 2013 for combination subtypes: by CHD subtype, sex and age group

Diagnosis	Sex	Age group	Ratio (CI) in 2000	Ratio (CI) in 2013	Trend coefficient (p-value)		p-values for tests comparing		
					Year	Year squared	Sex[#]	Age group[#]	Sex*Age group
All MI[†]	F	35-54	1.10 (1.08-1.12)	1.03 (1.02-1.04)	-0.0052 (0.000)		0.077	0.000	0.112
	F	55-74	1.08 (1.07-1.09)	1.03 (1.02-1.03)	-0.0052 (0.000)				
	F	75-84	1.06 (1.05-1.07)	1.05 (1.04-1.06)	-0.0052 (0.000)				
	M	35-54	1.09 (1.08-1.11)	1.03 (1.01-1.04)	-0.0052 (0.000)				
	M	55-74	1.09 (1.08-1.10)	1.04 (1.03-1.05)	-0.0052 (0.000)				
	M	75-84	1.07 (1.06-1.08)	1.06 (1.04-1.07)	-0.0052 (0.000)				
ACS[†]	F	35-54	1.13 (1.11-1.14)	1.04 (1.03-1.06)	-0.0063 (0.000)		0.000	0.001	0.007
	F	55-74	1.13 (1.12-1.14)	1.04 (1.03-1.05)	-0.0063 (0.000)				
	F	75-84	1.11 (1.10-1.12)	1.06 (1.06-1.07)	-0.0063 (0.000)				
	M	35-54	1.13 (1.11-1.15)	1.05 (1.04-1.06)	-0.0063 (0.000)				
	M	55-74	1.16 (1.14-1.17)	1.06 (1.06-1.07)	-0.0063 (0.000)				
	M	75-84	1.12 (1.11-1.13)	1.08 (1.07-1.09)	-0.0063 (0.000)				

All CHD‖	F	35-54	1.14 (1.12-1.16)	1.07 (1.05-1.08)	-0.0125 (0.000)	0.0005 (0.000)	0.000	0.000	0.051
	F	55-74	1.15 (1.14-1.17)	1.08 (1.07-1.09)	-0.0125 (0.000)	0.0005 (0.000)			
	F	75-84	1.12 (1.11-1.13)	1.08 (1.07-1.09)	-0.0125 (0.000)	0.0005 (0.000)			
	M	35-54	1.17 (1.14-1.20)	1.09 (1.08-1.11)	-0.0125 (0.000)	0.0005 (0.000)			
	M	55-74	1.19 (1.18-1.20)	1.12 (1.11-1.12)	-0.0125 (0.000)	0.0005 (0.000)			
	M	75-84	1.14 (1.13-1.15)	1.11 (1.10-1.11)	-0.0125 (0.000)	0.0005 (0.000)			

Key: ACS=acute coronary syndrome; CHD=coronary heart disease; CI=confidence interval; F=female; M=male; MI=myocardial infarction.

† From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex + age*(admission year-2000)

‡ From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex

§ From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex + $(\text{admission year-2000})^2$

‖ From the model: ratio = constant + (admission year - 2000) + age group + sex + age group*sex + $(\text{admission year-2000})^2$ + age group*(admission year-2000)

p-values for sex and age group are from the respective models but without the age group*sex interaction term

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No.	Recommendation	Page No.	Relevant text from manuscript
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2	Title: Exploring the effects of transfers and readmissions on trends in population counts of hospital admissions for coronary heart disease: a Western Australian data linkage study
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	4	ABSTRACT Objectives To (i) develop an approach to identify and categorise admissions for each coronary heart disease (CHD) subtype accounting for hospital transfers and readmissions from linked hospital data; (ii) compare counts of unlinked CHD admissions with linked data accounting for transfers and early readmissions; and (iii) examine whether the ratios of these counts show similar or disparate patterns over time and across age and sex groups for each CHD subtype……
Introduction				
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	6-7	INTRODUCTION Coronary heart disease (CHD) remains a major cause of death in Australia.[1] Clinically it manifests across a spectrum of subtypes, from ST-elevation myocardial infarction (STEMI) (the most severe), non-STEMI (NSTEMI), unstable angina, stable angina through to other

				chronic presentations……
Objectives	3	State specific objectives, including any prespecified hypotheses	7	There is a potential to overestimate hospitalisation counts of CHD using unlinked data where essentially each admission record is treated as a different patient. On the other hand the issues with person-linked hospital data is the need to group admissions related by transfers or readmissions into a single admission and to assign a single relevant diagnosis. To the best of our knowledge, approaches to these issues have not been addressed previously. Hence, our aims were to: (i) develop an approach to identify and categorise admissions for each CHD subtype accounting for hospital transfers and readmissions from linked hospital data; (ii) compare counts of unlinked CHD admissions with linked data accounting for transfers and readmissions; and (iii) examine whether the ratios of these counts show similar or disparate patterns over time and across age and sex groups for each CHD subtype.
Methods				
Study design	4	Present key elements of study design early in the paper	7	For this cohort study, we used person-linked administrative health data from the Hospital Morbidity Data Collection, one of the core datasets of the Western Australian Data

				Linkage System.
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7-8	Western Australia (WA) is representative of national sociodemographic and health indicators,[9] with an estimated resident population of 2.6 million in 2013.[10] The available dataset included all hospital records for any person hospitalised with CHD in WA from 1988 to 2013. We included all fatal and non-fatal admissions, with age restricted to 35-84 years.
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	8	The available dataset included all hospital records for any person hospitalised with CHD in WA from 1988 to 2013. We included all fatal and non-fatal admissions, with age restricted to 35-84 years.
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case		Not applicable
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8	Variables available included demographic information, admission and discharge dates, principal and 20 secondary discharge diagnosis fields, and hospital locations.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7-8	For this cohort study, we used person-linked administrative health data from the Hospital Morbidity Data Collection, one of the core datasets of the

				Western Australian Data Linkage System. Western Australia (WA) is representative of national sociodemographic and health indicators,[9] with an estimated resident population of 2.6 million in 2013.[10] The available dataset included all hospital records for any person hospitalised with CHD in WA from 1988 to 2013. We included all fatal and non-fatal admissions, with age restricted to 35-84 years. Variables available included demographic information, admission and discharge dates, principal and 20 secondary discharge diagnosis fields, and hospital locations.
Bias	9	Describe any efforts to address potential sources of bias		Not relevant as this is not an outcomes study by a methodological study.
Study size	10	Explain how the study size was arrived at		Not relevant as this is a population-based study.
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	12	All models included sex, age-group, sex*age-group interaction term and year as a continuous variable and year squared was also included where a curved trend was indicated (Wald test p<0.01).
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	12	Annual counts for each CHD subtype and combination subtypes are presented at the unlinked-, CA- and 28-day episode levels for 1988 to 2013. The ratio of unlinked admission count to CA count was

			calculated for each age-group (35-54 years, 55-74 years, 75-84 years) and gender in each year to determine the relative overestimation of each CHD subtype. To examine the impact on counts from using 28-day episodes, we calculated the ratio of 28-day episode to CA counts for each age-group and gender in each year, for each CHD subtype. Linear regression (with robust standard errors) was used to compare the ratios statistically across age-groups and gender, and assess trends over time.
	(*b*) Describe any methods used to examine subgroups and interactions	12	This analysis was restricted to the period 2000 to 2013 as CHD counts were more consistent during this time. All models included sex, age-group, sex*age-group interaction term and year as a continuous variable and year squared was also included where a curved trend was indicated (Wald test $p<0.01$). We fitted extended models with time interaction terms to test if there were differences in time trends by sex and age-group (i.e. we tested sex*year, age-group*year, and sex*age-group*year for ratios without curved trends and, for ratios with curved trends, also tested sex*year squared, age-group*year squared and sex*age-group*year squared). Only a few of the time interaction tests had $p<0.01$ and in lieu of the large number of time interactions tested and the lack of any consistent pattern to these results, these were

				considered not to be real and were ignored (i.e. considered as false positive time interactions)
		(*c*) Explain how missing data were addressed		Not relevant as this is population-based study from administrative data.
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy		Not relevant as this is a methodological study.
		(*e*) Describe any sensitivity analyses		
Results				
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	13	Not relevant as this is a methodological study on hospital admission counts rather than person counts. However, we have described the numbers of hospital admissions on Page 11 as such: There were 296,659 unlinked hospital admissions for CHD from 1988 to 2013 in WA (Table 2). The diagnosis hierarchy approach resulted in the highest count of CHD admissions (n=273,793) and the approach based on the diagnosis from last admission resulted in the lowest count (n=263,313). The number of 28-day episodes was 242,966. The counts at the unlinked, CA-level and 28-day episode level for each CHD subtype are shown in Table 2.
		(b) Give reasons for non-participation at each stage		
		(c) Consider use of a flow diagram		
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on		As per Question 13 above.

		exposures and potential confounders	
		(b) Indicate number of participants with missing data for each variable of interest	
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	Not relevant as this is not an outcomes study but rather a methodological study.
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Not relevant given this is a methodological study. Our linear regressions include age-group, year, sex as variables of interest rather than confounders. Results are presented in Tables 3 (Pages 16-17) and 4 (Pages 19-20).
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	

Continued on next page

Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses		We report analyses of CHD subgroups in Tables 3 (pages 15-16) and 4 (Pages 18-19), and in Supplementary Tables 1 and 2.
Discussion				
Key results	18	Summarise key results with reference to study objectives	22	We developed different approaches to assign CHD diagnoses to a sequence of consecutive admissions and 28-day episodes that account for transfers and readmissions, thereby avoiding the over-count that occurs with unlinked administrative data. Hospitalisation data from 1988 to 2013 show that for each CHD subtype, unlinked records over-counted the number of CHD hospitalisations relative to CA counts and 28-day episode counts. Our analyses of ratios from 2000-2013 showed a complex pattern of over-counting in unlinked data due to transfers and readmissions. In almost all CHD subtypes, the ratios changed in a linear or quadratic fashion over time and the coefficients of the trends differed across CHD subtypes. Further, for many CHD subtypes the ratios also differed by age-group and sex.
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	25	The limitations of this study include the validity of coding for CHD. An earlier WA study using linked data showed that the sensitivity of hospital coding for MI was 76.9% in the 35-69 year olds.[14] The use of 28-day episodes may miss a small number of related readmissions which occur beyond 28 days. Furthermore, we did not adjust for

				confounders such as remoteness and Indigenous status which may influence transfer and readmission patterns.[6 22] The complex pattern of counts and ratios we presented are from WA for 2000 to 2013 and may not be generalisable to other jurisdictions (because of different healthcare systems) or beyond the study period, however the methods we described are generalisable to other states and territories.
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	25	Although unlinked data has its place in measurement of hospital health service utilisation, its use in epidemiological estimates of CHD hospitalisations overestimates CHD counts. We contend that CA (accounting for transfers) and 28-day episode (accounting for transfers and readmissions) counts are more aligned with epidemiological studies of CHD. The degree of overestimation of counts using only unlinked records varies in a complex manner with CHD subtype, time, sex and age-group, it is not possible to apply a simple correction factor to counts obtained from unlinked data.
Generalisability	21	Discuss the generalisability (external validity) of the study results	25	The complex pattern of counts and ratios we presented are from WA for 2000 to 2013 and may not be generalisable to other jurisdictions (because of different healthcare systems) or beyond the study period, however the methods we described are generalisable to other states and territories.

				The degree of overestimation of counts using only unlinked records varies in a complex manner with CHD subtype, time, sex and age-group, it is not possible to apply a simple correction factor to counts obtained from unlinked data.
Other information				
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	26	This work was supported by the National Health and Medical Research Council (NHMRC) of Australia project grant 1078978. The grant agency does not impose restrictions on conduct of analyses or dissemination of findings. LN is funded by a National Health and Medical Research Council of Australia Early Career Fellowship.

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.