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Factors driving computed tomography utilisation in tertiary hospitals: A decomposition analysis using linked administrative data in Western Australia

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Abstract

Objectives: This study aimed to examine the contribution of demographic and clinical characteristics to the changing use of CT among people admitted to tertiary hospitals in Western Australia (WA).

Design: An observational cross-sectional study from 2003 to 2015

Setting: Linked administrative health service data at individual level from WA

Participants: A total of 2,375,787 tertiary hospital admissions of people aged 18 years or older

Main outcome measure: Number of CT's performed during tertiary hospital admission.

Methods: A multivariable decomposition for nonlinear response model was used to decompose the increasing use of CT into variation of (i) the distribution and (ii) the effect of the observed characteristics.

Results: The rate of CT scanning increased by 112 CT scans per 1000 tertiary admissions between the two periods. The variation in distribution of the observed demographic and clinical factors explained nearly two thirds (62.7%) of the growth of CT use in which unplanned admissions accounted for the largest proportion (50%). However, when the analysis is restricted to unplanned admissions, the variation in distribution of the observed factors only explained 17% of the growth of CT use and the rest was explained by change in the likelihood of having CT scan. Interestingly, compared with the past period, the likelihood of having CT scan in population such as young adults (-2.8%), people living in the rural/remote areas (-0.8%) and people transferred from secondary hospitals (-0.8%) were significant lower in the recent period.

Conclusions: Our study highlights a potential improvement in practice towards reducing medical radiation exposure in certain high risk population. Given change in the likelihood of having CT scan explained for a major component of the growth in CT use, this warrants more in-depth investigations

in clinical practices to better inform health policies promoting appropriate use of diagnostic imaging tests.

Strengths and limitations of this study

- This study utilised a large linked administrative data over the period of 13 years that allowed to measure the contribution of changes in demographic and clinical characteristics to the changing use of CT.
- With a rich source of individual level data, this study identified a wide range of demographic and clinical factors driving the use of CT scan in tertiary hospitals.
- Since the decomposition analysis methods only quantified the contribution of observed factors, contribution of any unobserved factors to the change of CT use was summed in the constant coefficient.
- Our data did not fully capture the use of CT in all secondary hospitals, hence, this study was limited to assess the factors driving the use of CT scan in tertiary hospitals.

Introduction

Computed tomography (CT) is one of the most important technical developments in medicine and is now an essential part of clinical practice (1, 2). In Australia, CT accounted for 13% of diagnostic imaging tests with an average of 134 scans per 1000 people in 2017/18 (3, 4). It is estimated that diagnostic imaging tests increased the annual effective ionising radiation dose on the Australian population by 50% (5). In acknowledgement of the relatively high radiation burden of diagnostic imaging, Australia introduced Diagnostic reference levels (DRL) in 2011 providing a benchmark to facilitate monitoring and comparison of radiation dose between facilities (6).

Despite the advanced technology leading to significant contribution in healthcare, its increasing use has raised a concern about inappropriate use. Approximately one third of diagnostic imaging tests are estimated to be unnecessary or inappropriate, with the potential to do more harm than good and represent a waste of health care resources (7, 8). In the case of CT the potential harm includes exposure to ionising radiation and the associated risk of cancer to population. A previous study found a high rate of inappropriate CT among older patients and those with multi-morbidity (9).

In response to concerns of inappropriate utilisation of the advanced diagnostic technique, since early 2000, the Royal Australian and New Zealand College of Radiologists (RANZCR) have provided the standards of practice for clinical radiology (10). In Western Australia (WA), Diagnostic Imaging Pathways has been deployed to promote appropriate use of imaging (11, 12). Most recently, in 2015 NPS MedicineWise launched the Australian “Choosing Wisely” campaigns promoting discussion on reducing low value care (13), changing health care provider behaviour and increasing patient knowledge. The overall intention is to improve patient safety and efficiency in health service utilisation (13).

While substantial effort is under way to promote appropriate use of imaging tests, current data reporting variation in potentially avoidable diagnostic imaging tests, particularly for CT over the last decade are limited (9, 14, 15). Recent studies mainly focus on examining the prevalence of low value

care (16), the early trend of procedure uptake in hospital settings (17) and selected spinal imaging (18) following Choosing Wisely campaigns. Therefore, better understanding of changes in the use of CT scanning over the past decade and demographic and clinical factors driving the change in the use of CT are necessary to support monitoring the use of CT scanning and to guide future research and public health interventions. The aim of this study is to use decomposition analysis to examine factors driving changes in CT use between two periods of time in tertiary hospitals in WA: recent (2013 to 2015) and past (2003 to 2005).

Methods

We conducted a retrospective observational cohort study of CT use in WA between 2003 and 2015 using linked administrative heath data at the individual patient level. Reporting follows the Reporting of studies Conducted using Observational Routinely-collected health Data (RECORD) guidelines (19).

Data sources

The data sources included three datasets:

(i) WA Hospital Morbidity Data system (January 2003- May 2016) providing information on diagnosis, date of admission and discharge from all hospitals in WA, and basic socio-demographic and clinical characteristics.

(ii) WA Emergency Department (ED) presentation data (January 2003- December 2016) providing details of presentation time and date, presentation type, triage code, major diagnostic group and basic socio-demographic characteristics.

(iii) WA Picture archiving and communication system (PACS) data (January 2003 to May 2016) providing documentation on all computed tomography (CT) scans conducted in tertiary including date of the scan, and the CT protocols used. All the datasets were linked using probabilistic matching algorithms with a level of data accuracy up to 99.9% (20, 21).

Details of data linkage process is presented in the website of Western Australia Data Linkage (https://www.datalinkage-wa.org.au/dlb-services/linkage/).

Study population

The study population consisted of all hospital admissions in the three tertiary hospitals in WA between 2003 and 2015 inclusive, for people aged 18 years and older. The study population was then constructed into two study periods; past period (2003-2005) and recent period (2013-2015). To avoid over-counting hospital admissions, for example where a patient was transferred between hospitals, consecutive tertiary hospital admission records for an individual were aggregated into a single hospital admission where admission or discharge dates were nested or overlapping, or where an admission date was within one day of the discharge date. A tertiary hospital admission was counted from the first date of admission in a tertiary hospital–or where applicable– the date of a prior associated tertiary ED presentation so long as it resulted in an admission, to the last discharge date in tertiary hospitals.

Outcome measures

The outcome measure of this study was the number of CT scans performed within a tertiary hospital admission. The number of CT scans was counted from the first day admitted to a tertiary hospital/presentation to a tertiary ED until the last date of discharge for that admission. To avoid over-counting the use of CT, multiple CT records with the same day and same anatomic areas were collapsed into one CT event (22).

Independent measures

This study measured basic demographic and socioeconomic characteristics including age (18-44, 45-64, 65-74, and 75+ years), sex, indigenous status, residential remoteness classified according to Accessibility Remoteness of Australia index (ARIA) (23) (major cities, inner regional areas, outer regional areas, remote and very remote), and quintiles of the Census-specific Socio-economic Indexes for Areas (SEIFA) index of relative socioeconomic disadvantage (24) (least disadvantage, less disadvantage, moderate disadvantage, high disadvantage, and highest disadvantage).

Clinical characteristics included major clinical diagnostic groups and the number of morbidities. Major clinical diagnostic groups included mental and behavioural disorders, circulatory system, digestive system, endocrine, nutritional and metabolic diseases, musculoskeletal system, respiratory system, injuries, and neoplasms. The conditions were identified in the principal diagnostic field of the hospital morbidity data record using ICD-AM-10 (the International Statistical Classification of Diseases and Related Health Problems, 10th Revision, Australian Modification). Multimorbidity was ascertained using the Multipurpose Australian Comorbidity Scoring system (25) using ICD-AM-10 across all diagnostic fields and was classified into 0-1, 2-5 and 6+ comorbidities. In addition, an admission was classified as having had a surgical procedure where the principal procedure field included one of the 20 most common surgical procedure as per ACHI codes (the Australian classification of health intervention) (26). Other independent measures included funding source (public or private), admission type (elective or unplanned admission) and admission with/without a transfer from secondary hospitals.

Statistical analysis

Descriptive analysis was conducted to examine the distribution of socio-demographic and clinical characteristics of the study population over two study periods; past period (2003-2005) and recent period (2013-2015) as well as the whole study population (2003-2015). Multivariable decomposition for nonlinear response models, an extension of Oaxaca-Blinder decomposition analysis (27), was conducted to decompose the differential rate of CT use between the two study periods into subcomponents attributable to observed factors. Using this method, the differences in the number of CT scans per admission between the two study periods were broken down or “decomposed” into two components; endowment and effect:

(1) The Endowment component depicts how much of the difference in the rate of CT use (between the past and recent period) can be attributed to change in the distribution of all observed factors such as socio-demographic and clinical characteristic in total and at the

individual factor level; the coefficient with 95% confidence interval in each factor quantifies the contribution of the specific factor and is expressed in percentage of its contribution.

(2) The Effect component describes how much of the difference in the rate of CT use (between the past and recent period) can be attributed to a change in the likelihood of having CT in total and for each of the observed characteristics. The coefficient with 95% confidence interval in each factor indicates the contribution of the specific factor.

The advantage of the multivariable decomposition approach is that it can account for variation due to a change in the order of variables entering the model and provide standard errors to indicate a significant contribution of the observed characteristics (28). We conducted decomposition analyses for all tertiary admissions and for unplanned tertiary admissions separately using STATA SE 14 (27).

Results

Characteristics of tertiary admissions with CT scan by study periods

Of a total of 2,375,787 tertiary hospital admissions over the 12 year period (2003-2015), 303,439 admissions (12.8%) had at least one CT scan. The proportion of admissions incorporating CT increased from 8.9% in the past period (2003-2005) to 16.6% in the recent period (2013-2015) (Table 1).Overall, there was a small change in the distribution of both demographic and clinical characteristics among admissions that included CT between the two study periods. For example, the proportion of the patients who had a CT scan and were in the older ager group (75+ years) increased from 30.3% to 32.7% and people living in major cities with CT increased from 82.5% to 88.3% between the past and recent period. Similarly within clinical characteristics, multi-morbidity (6+ morbidities) accounted for 27.8% of admissions with CT in the past period compared to 28.8% in the recent period. Among major diagnostic groups in the past period, injuries, circulatory system, cancer and digestive system accounted for 15.5%, 15.2%, 11.7% and 10.9% of admissions with CT, compared to 18.8%, 13.1%, 7.9% and 11.2% in recent period. For other characteristics, admission

with CT in the recent period had a higher proportion of unplanned admission (90.1% vs. 86.8%) and private funding sources (21.0% vs. 7.7%) compared with the past period.

Decomposition results for the use of CT over the two periods

The results of the decomposition analysis of the difference in average number of CT scans between the two periods for all tertiary admissions and unplanned at the aggregated level are presented in Figure 1 (detail in Appendix- Table 1A-B). The difference in number of CT scans between two periods was 112 scans per 1000 admissions for all tertiary admission and 117 scans per 1000 admissions for unplanned tertiary admissions. While the change in the number of CT scans per admission across the two analyses were not substantially different, a marked difference in the results of the decomposition analysis was observed. Figure 1 shows that 62.7% of the difference in CT use for all tertiary admission was explained by variation in the distribution of all observed characteristics of which unplanned admissions were accounting for 50%. The rest of the difference in CT usage was attributable to variation in the likelihood of having CT in each observed characteristics and unobserved factors (constant coefficient).

In contrast, when the analysis was restricted to unplanned admissions, the variation in the distribution of the observed characteristics explained only 17% of the difference in CT use between two periods while 82.7% was due to variation in the likelihood of having CT according to observed and unobserved factors included in the model.

Details of decomposition analysis for all tertiary admissions

Figure 2 presents decomposition analysis in details of all observed demographic and clinical characteristics. Overall, changes in the distribution of the demographic characteristics including sex, indigenous status, age, SEIFA and ARIA explained only -0.8% of the change in CT use. Change in the distribution of the clinical characteristics including major principal diagnoses and groups of morbidities accounted for 12.4% of the change in CT use. Half of this change (6.1%) was attributable to multi-morbidity (6 or more morbidities) and 4.7% was due to injuries.

The effect components of the observed demographic characteristics summed to 6.8% while the observed clinical characteristics was -2.6%. Interestingly, the negative coefficient in the young age group suggests that in the most recent time period, the likelihood of having a CT scan for those with young age was significantly lower than in the past period contributing -2.8% to the difference in the number of CT scan per admission between the two periods. In addition, the likelihood of having CT was higher for those identified as living in major cities in the recent period compared to the past period, and lower for people from remote/very remote areas in the recent period compared to the past period. The contribution of each component to the difference in the number of CT's per admission between the two periods was 5.5% (p-value=0.02) and -0.8% (p-values<0.001), respectively.

For clinical characteristics, the results indicated a lower likelihood of having CT scanning during a tertiary admission in the recent period than in the past period for all the diagnostic groups, with the exception of those admitted for injuries and endocrine disorders. The increase in patients with multi-morbidities (2-5 comorbidities) contributed 3.2% to the difference between the two periods.

For other factors, the likelihood of having a CT scan following transfer from a secondary hospital in the recent period was significantly lower than in the past period, contributing -0.8% to the difference between the two periods. A lower likelihood of having a CT scan in the recent period compared with the past period for unplanned admission contributed -4.9% to the difference in CT use between the two periods. Unobserved factors captured in the constant coefficient contributed to 41.8% of the difference in CT usage between the two periods.

Details of decomposition analysis for unplanned tertiary admissions

Figure 3 presents the results of decomposition analysis for unplanned admissions. Similar to the results in all tertiary admissions, the results for unplanned admission indicate that a substantial proportion of variation in CT use between the two study periods (10.0%) was attributable to the observed clinical characteristics including multimorbidity and major diagnostic groups. However,

variation in the distribution of the observed demographic characteristics such as age, sex and accessibility between two periods only explained a total of -0.5% the difference in CT use.

For the specific effect component, a similar finding to all tertiary admission was observed in unplanned admissions. Specifically, a negative coefficient was also observed in young age groups (18-44 years) that suggests a lower likelihood of having CT scan in this age group in the recent period compared with the past. Likewise, a lower likelihood of having CT scan in the recent period compared with the past period was observed among admissions with condition such as circulatory, cancer, and respiratory; this accounted for -3.8%, -3.7%, and -2.7% of the difference between CT use. The likelihood of having a CT scan after transfer from a secondary hospital in the recent period was lower than in the past, contributing -7.5% to the difference in the number of CT scans between the two periods.

Discussion

This is the first study to examine the contribution of demographic and clinical characteristics to changes in the rate of CT scanning in tertiary hospitals using multivariable decomposition analysis of linked health administrative data over an extended period of time. We found that nearly two thirds of the increase in the use of CT was attributable to changes in the distribution of observed characteristics, with changes in proportion of unplanned admissions accounting for the largest component. However when the analysis was restricted to unplanned admissions, changes in distribution of the observed characteristics only explained about a fifth of the difference in CT usage and the rest was explained by the effect component. In both decomposition analyses, clinical characteristics (12.4% in all admissions and 10% in unplanned admissions) including major diagnostic groups and comorbidities rather than demographic characteristics contributed substantially to explain the variation in CT use between the two periods. Interestingly, our study observed a lower likelihood of having a CT scan in the recent period (2013-2015) compared with the past period (2003-2005) in two subgroups: young adults, which may reflect a movement towards minimising

medical radiation exposure in the high risk population, and admissions transferred from secondary hospitals, reflecting either a reduction in inappropriate repeat imaging tests or greater access to CT in non-tertiary hospitals.

A recent study examined factors driving the increasing use of CT scan in Australia with a focus on the use of CT outside of public hospital settings (29). Although the study also used the decomposition analysis approach, the only endowment component captured in this study was changes in the population age structure; the rest of the difference in CT use was captured in the number of CT scans per capita. The study found that a change in the number of CT scans per capita, interpreted as a "scope shift", rather than changes in the population age structure accounted for a major component in the change of CT use outside hospital settings over the period 1993 to 2013(29). The previous study used changes in age structure as a marker of changes in need (eg an ageing population), which had been postulated as the reason for increasing CT scanning rates. The finding that changes in the age structure was responsible for only a small proportion of the rate of CT use suggested that "scope shift" (i.e. changes in the practice of CT) was driving the rate of use. However, the previous study was unable to determine what form these practice changes took. By using multivariable decomposition analysis, our study provides a more comprehensive picture of the contribution of demographic, clinical and other observed factors driving the change in CT use in the hospital setting. This is because our analysis was able to differentiate the influence of changes in the distribution (endowment component) from changes in the likelihood of CT (effect component) across a large range of observed factors. While the setting was different, in line with the previous study, we found a minimal contribution of changes in demographic characteristics on the variation in the use of CT in tertiary hospitals.

Our study found that while many observed factors drive the increase of CT use, the change in the likelihood of having CT scan in the young age group and in those with admissions transferred from secondary hospitals (once the variation in the distribution of these factors was accounted for)

reduced the use of CT in the recent period compared with the past period. These finding are encouraging as they confirm a reduction in two groups where there has been concern regarding inappropriate imaging. The results coincide with the goals of education campaigns to raise provider awareness of the risk of ionising radiation, especially among children and young adults (30-32). Since children and young adults are more sensitive and have more years to develop radiation-induced cancer (30, 31), radiologists have become more cautious and may have taken care to minimise unnecessary CT scanning.

Despite challenges due to the vast geographical spread of Australia, over the last 15 years diagnostic imaging services have become more accessible to patients in both major cities and rural areas within a timely and a reasonable distance from their home (31). A report in 2012 shows that more than 90% of Australians can get access to a comprehensive diagnostic imaging facility within a distance of 100km from their residential areas (31) and up to 80% of patients have access to a CT machine within 10 km (31). Between 2003 and 2018, Australia increased the rate of CT equipment per head of population from 40.6 to 67 per million (33, 34). The government also provided a diagnostic imaging bulk billing incentive from November 2009 that increased the accessibility to the service through improving patient affordability. In addition, the government endorsed the diagnostic imaging review reform package in 2011 and implemented it between 2011 and 2016, funded through the Medicare Benefits Schedule. One of the package objectives was to ensure accessibility to quality diagnostic imaging services for people in rural and remote areas. In addition, the package also aimed to promote for effective communication between practitioners and imaging service to ensure appropriate imaging (31). The increasing availability and accessibility of diagnostic imaging, in particular to CT scanners, raised concerns of potential overuse of CT scans increasing radiation exposure to patients and contributing additional costs to the health care system (15). However, we found that the likelihood of having CT scan in tertiary hospitals for people living in remote and very remote areas in the recent period was less than in the past period. Although the magnitude of the variation was small, it accounts for significantly lower use of CT scan in tertiary hospitals. Likewise,

the rate of CT scan among admissions transferred from the secondary hospital in the recent period was also less than in the past period. This would be consistent with government efforts to ensure accessibility of diagnostic imaging service in rural and remote areas as well as improved information transfer between hospitals. Previous studies have highlighted the important role of image sharing technology in improving provider access and avoiding duplication of investigations (35-37). However, a recent study found that repeat CT scanning is relatively common for patients already imaged prior to transfer to a tertiary hospital, although there was a valid clinical reason for repeat scanning in the majority of cases (15). Despite signs of improvement in our study, further detailed exploration is required to establish the proportion of avoidable repeat scans and therefore the potential benefit in terms of reduced radiation exposure and costs.

This study has a number of limitations, largely due to the nature of linked administrative data. This study only decomposed the difference in CT use between the two study periods based on the available observed characteristics available in the administrative data. Thus, the contribution of unobserved factors was not addressed in this study, although they are captured in the constant value. This study only captured the use of CT in tertiary hospitals because we did not have comprehensive data on CT use in non-tertiary settings, limiting our ability to determine whether the lower likelihood of having CT in the recent period in some subgroups was due to changes in practice or increasing accessibility of CT in other health care settings. While the linked administrative data can comprehensively capture use of health services over time without loss to follow up, information about clinical information is limited to relatively high-level diagnostic codes recorded in the HMDS. Therefore, our study cannot provide information about the proportion of scans that were justified.

In conclusion, the use of CT in tertiary hospitals increased between the two study periods and this is in keeping with international trends. The majority of the difference was explained by variation in the distribution of the observed characteristics, particularly unplanned admissions and the clinical characteristics of presenting patients. When the data were restricted to unplanned admissions,

changes in the likelihood of scanning were the major drivers of CT use, with the largest component of this relating to unobserved factors. In both results, clinical characteristics appear to be substantial component driving the growth of CT usage in tertiary hospital settings while the role of demographic characteristics was minimal. Our study also highlights a potential improvement in practice towards reducing medial radiation exposure through a decrease CTs in subpopulations such as young adults and in those admitted via transfer admission from other hospitals. While the finding is limited to tertiary settings, the method used in our study can be applied in a broader context to characterise major factors driving the use of CT scanning as well as the use of diagnostic imaging tests. Our study may assist to identify areas worthy of more in-depth investigations to better inform health policy makers and interventions promoting appropriate use of diagnostic imaging tests.

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Competing interests

The authors have no competing interest to declare. The institutions of RM, NH, DY, MB and DM received grant funding from the National Medical Research Council of Australia for investigator-initiated research. The funding agreement ensured author independence in designing the study, interpreting the data, writing and publishing the report.

Authors' contributions

RM, MB, JD, DM, PO, JSl, SM, NTH conceived the idea and study design for the manuscript. NTH, RM, SM conducted data analyses and drafted the manuscript. RM, SM, NTH, MB contributed to statistical expertise. RM, MB, JD, DM, PO, JSl, SM, NTH contributed in analysis, interpreting the results, drafting and revising critically for important intellectual content of the manuscript. RM, MB,

JD, DM, PO, JSl secured funding for the study. All authors read and approved the final version of the manuscript for publication. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

Ethics approval and consent to participate

Human research ethics approval was obtained from Curtin University Human Research Ethics Committee (SMEC-80-10) and the WA Department of Health Human Research Ethics Committee (2011/97) which exempted the study from requiring individual consent.

Patient and public involvement

A consumer representative was involved in the design of the grant used to fund this research.

Patient consent

Not applicable

Data sharing statement

Data access is limited to only authors who require it for data analysis - the remaining authors do not have access to the data but did have full access to the results of the data analysis. The data that support the findings of this study are available from the relevant data custodians of the study datasets. Restrictions by the data custodians mean that the data are not publicly available or able to be provided by the authors. Researchers wishing to access the datasets used in this study should refer to the WA data linkage application process (https://www.datalinkage-wa.org.au/access-and-application).

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List of tables

Figures

Table 2. Characteristics of the study population by study period and CT scan status

	Study period								All years 2003-2015 (2,375,787)			
	The past period (2003-2005) (N=519,286)				The recent period (2013-2015) (N=572,642)							
	Without CT scan		With CT scan		Without CT scan		With CT scan		Without CT scan		With CT scan	
	N	%	N	%	N	%	N	%	N	%	N	%
N	473,120	91.1	46,166	8.9	477,462	83.4	95,180	16.6	2,072,348	87.2	303,439	12.8
Female	237,021	50.1	21,232	46.0	248,412	52.0	43,865	46.1	1,057,280	51.0	137,988	45.5
Age groups												
18-44years	134,467	28.4	10,954	23.7	145,181	30.4	20,075	21.1	621,452	30.0	67,456	22.2
45-64 years	144,820	30.6	12,797	27.7	150,139	31.4	27,225	28.6	651,941	31.5	87,319	28.8
65-74 years	91,075	19.2	8,447	18.3	83,797	17.6	16,798	17.6	368,070	17.8	53,332	17.6
75+ years	102,758	21.7	13,968	30.3	98,345	20.6	31,082	32.7	430,885	20.8	95,332	31.4
Indigenous status	31,708	6.7	2,111	4.6	32,061	6.7	4,540	4.8	137,806	6.6	14,156	4.7
SEIFA												
Least disadvantage	129,988	27.5	12,522	27.1	130,427	27.3	27,885	29.3	595,921	28.8	90,660	29.9
Less disadvantage	89,310	18.9	8,495	18.4	87,703	18.4	17,850	18.8	364,787	17.6	53,241	17.5
Moderate disadvantage	91,594	19.4	9,112	19.7	99,533	20.8	19,549	20.5	449,532	21.7	65,203	21.5
High disadvantage	89,421	18.9	8,923	19.3	95,607	20.0	18,104	19.0	388,311	18.7	57,090	18.8
Highest disadvantage	70,595	14.9	6,900	14.9	61,291	12.8	11,344	11.9	262,172	12.7	35,691	11.8
unknown	2,212	0.5	214	0.5	2,901	0.6	448	0.5	11,625	0.6	1,554	0.5
ARIA												
Major cities	411,062	86.9	38,086	82.5	416,708	87.3	84,046	88.3	1,807,380	87.2	261,292	86.1
Inner regional areas	29,622	6.3	3,663	7.9	19,675	4.1	3,508	3.7	108,562	5.2	15,908	5.2
Outer regional areas	16,251	3.4	2,155	4.7	19,417	4.1	3,814	4.0	75,935	3.7	13,210	4.4
Remote	8,968	1.9	1,283	2.8	10,654	2.2	1,901	2.0	44,727	2.2	7,336	2.4
Very Remote	6,205	1.3	894	1.9	8,167	1.7	1,458	1.5	28,389	1.4	4,731	1.6
Unknown	1,012	0.2	85	0.2	2,841	0.6	453	0.5	7,355	0.4	962	0.3
Number of morbidity (MACSS) (Median – IQR)	2	2-3	4	2-6	2	2-3	4	2-6	2	2-3	3	2-6
Major clinical conditions												

	Study period								All years 2003-2015 (2,375,787)			
	The past period (2003-2005) (N=519,286)				The recent period (2013-2015) (N=572,642)							
	Without CT scan		With CT scan		Without CT scan		With CT scan		Without CT scan		With CT scan	
	N	%	N	%	N	%	N	%	N	%	N	%
Mental and behaviour disorders	11,065	2.3	2,015	4.4	15,514	3.2	3,296	3.5	61,756	3.0	11,109	3.7
Circulatory system	35,636	7.5	7,038	15.2	38,534	8.1	12,434	13.1	162,138	7.8	41,737	13.8
Digestive system	31,437	6.6	5,026	10.9	38,055	8.0	10,678	11.2	150,492	7.3	32,897	10.8
Endocrine	9,160	1.9	823	1.8	11,074	2.3	1,381	1.5	46,268	2.2	5,165	1.7
Musculoskeletal system	21,153	4.5	1,532	3.3	21,477	4.5	2,819	3.0	93,520	4.5	9,231	3.0
Respiratory system	15,013	3.2	2,918	6.3	17,001	3.6	5,241	5.5	68,859	3.3	17,149	5.7
Injury	23,483	5.0	7,165	15.5	31,608	6.6	17,913	18.8	126,703	6.1	53,420	17.6
Cancer	21,608	4.6	5,389	11.7	22,465	4.7	7,520	7.9	96,232	4.6	28,783	9.5
Funding sources												
Public	447,927	94.7	42,612	92.3	416,248	87.2	75,202	79.0	1,894,581	91.4	258,126	85.1
Private	25,193	5.3	3,554	7.7	61,214	12.8	19,978	21.0	177,767	8.6	45,313	14.9
Unplanned admissions												
No	316,762	67.0	6,089	13.2	259,764	54.4	9,387	9.9	1,245,273	60.1	34,058	11.2
Yes	156,358	33.0	40,077	86.8	217,698	45.6	85,793	90.1	827,075	39.9	269,381	88.8
Transferred from secondary hospitals												
No	459,539	97.1	41,742	90.4	455,496	95.4	88,480	93.0	1,990,570	96.1	277,994	91.6
Yes	13,581	2.9	4,424	9.6	21,966	4.6	6,700	7.0	81,778	3.9	25,445	8.4
Surgical procedure												
No	457,900	96.8	42,803	92.7	449,708	94.2	87,721	92.2	1,975,259	95.3	280,008	92.3
Yes	15,220	3.2	3,363	7.3	27,754	5.8	7,459	7.8	97,089	4.7	23,431	7.7
Morbidity group												
0-1	103,369	21.85	6,165	13.35	116,826	24.47	13,361	14.04	514,216	24.81	46,686	15.4
2-5	349,557	73.88	27,175	58.86	329,844	69.08	54,377	57.13	1,452,109	70.07	175,377	57.8
6+	20,194	4.27	12,826	27.78	30,792	6.45	27,442	28.83	106,023	5.12	81,376	26.82

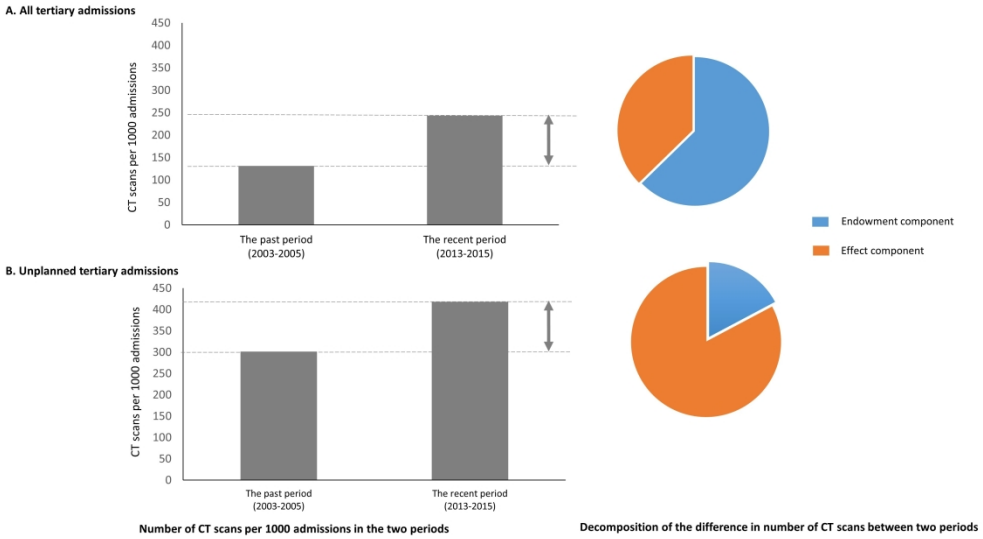

Figure 1

338x190mm (300 x 300 DPI)

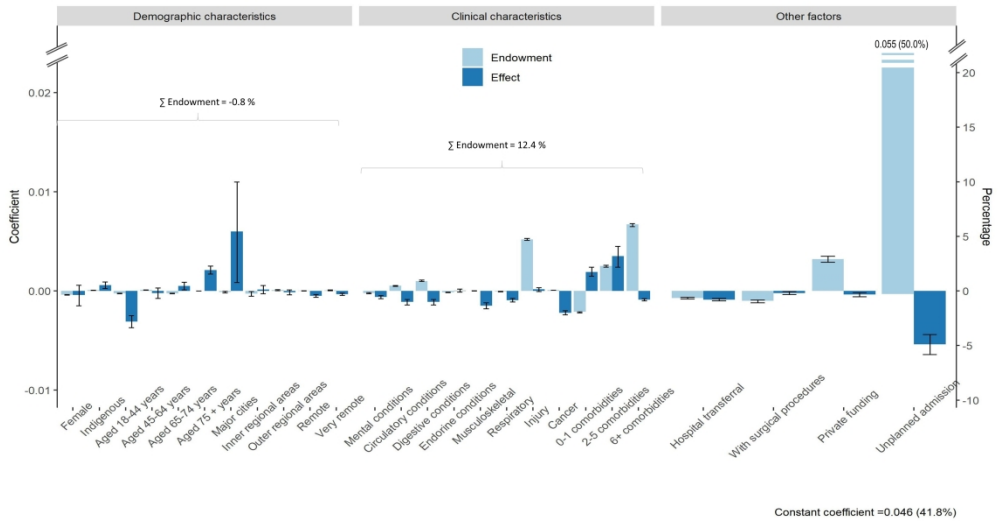

Figure 2

338x190mm (300 x 300 DPI)

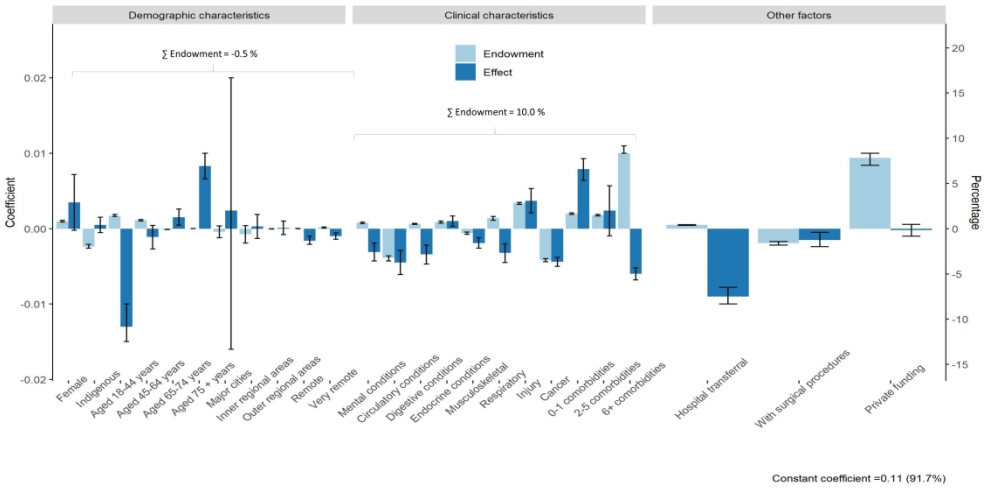

Figure 3

338x190mm (300 x 300 DPI)

Table 1A. Decomposition of the difference in the use of CT of all tertiary admissions between two periods

	Number of CT per admission	95% CI	
The use of CT			
The past period	0.131	0.129; 0.132	
The recent period	0.243	0.241; 0.245	
Difference	0.112	0.110; 0.114	
Decomposition output	Coefficient	95% CI	Percentage
Endowment component	0.069***	0.068; 0.070	62.7
Effect component	0.043***	0.041; 0.045	37.3
1. Specific endowment component			
Sex	-0.00039***	-0.00043; -0.00036	-0.4
Indigenous	0.000074***	0.000066; 0.000081	0.1
Age groups			
18-44 years	-0.00025***	-0.00027; -0.00023	-0.2
45-64 years	0.00010***	0.000089; 0.00011	0.1
65-74 years	-0.00025***	-0.00029; -0.00021	-0.2
75 + years	-0.0000039**	-0.0000066; -0.0000012	-0.004
SEIFA			
Least disadvantage	0.0000081	-0.0000085; 0.000025	0.01
Less disadvantage	-0.000020	-0.000053; 0.000013	-0.02
Moderate disadvantage	0.000056	-0.000060; 0.00017	0.1
High disadvantage	0.000061	-0.000015; 0.00014	0.1
Highest disadvantage	-0.00010	-0.00029; 0.000086	-0.1
Unknown	-0.000028	-0.000075; 0.000018	-0.2
ARIA			
Major cities	-0.00012**	-0.00020; -0.000034	-0.1
Inner regional areas	-0.00029*	-0.00052; -0.000055	-0.3
Outer regional areas	0.000076**	0.000027; 0.00013	0.1
Remote	0.000014	-0.0000095; 0.000037	0.01
Very Remote	0.000065**	0.000028; 0.00010	0.1
Unknown	-0.00015*	-0.00030; -0.0000086	-0.1
Major principal diagnoses			
Mental conditions	-0.00022***	-0.00028; -0.00017	-0.2
Circulatory conditions	0.00051***	0.00048; 0.00054	0.5
Digestive conditions	0.0010***	0.00096; 0.0011	0.9
Endocrine conditions	-0.00013***	-0.00016; -0.00011	-0.1
Musculoskeletal	0.0000029	-0.0000064; 0.000012	0.003
Respiratory	-0.000054***	-0.000080; -0.000028	-0.05
Injuries	0.0052***	0.0051; 0.0053	4.7
Cancer	0.000084***	0.000082; 0.000086	0.1
Number of morbidities			
0-1	-0.0021***	-0.0022; -0.0021	-1.9
2-5	0.0025***	0.0024; 0.0026	2.3
6 or more	0.0067***	0.0065; 0.0068	6.1
Private funding	0.0032***	0.0029; 0.0035	2.9

Unplanned admission	0.055***	0.055; 0.056	50.0
Transferred from secondary hospitals	-0.00073***	-0.00081; -0.00065	-0.7
Had surgical procedures in hospital	-0.0010***	-0.0012; -0.00092	-0.9
2. Specific effect component			
Sex	-0.00043	-0.0015; 0.00059	-0.4
Indigenous	0.00059***	0.00026; 0.00091	0.5
Age groups			
18-44 years	-0.0031***	-0.0037; -0.0025	-2.8
45-64 years	-0.00023	-0.00075; 0.00029	-0.2
65-74 years	0.00050*	0.00011; 0.00089	0.5
75 + years	0.0021***	0.0017; 0.0025	1.9
SEIFA			
Least disadvantage	0.00080	-0.00050; 0.0021	0.7
Less disadvantage	0.00054	-0.00037; 0.0014	0.5
Moderate disadvantage	0.00060	-0.00033; 0.0015	0.5
High disadvantage	0.00044	-0.00046; 0.0013	0.4
Highest disadvantage	0.00055	-0.00018; 0.0013	0.5
Unknown	-0.000070	-0.00017; 0.000031	-0.1
ARIA			
Major cities	0.0060*	0.00086; 0.011	5.5
Inner regional areas	0.00014	-0.00029; 0.00056	0.1
Outer regional areas	-0.00013	-0.00038; 0.00011	-0.1
Remote	-0.00050***	-0.00065; -0.00035	-0.5
Very Remote	-0.00032***	-0.00044; -0.00021	-0.3
Unknown	0.000092**	0.000037; 0.00015	0.1
Major principal diagnoses			
Mental conditions	-0.00062***	-0.00077; -0.00048	-0.6
Circulatory conditions	-0.0011***	-0.0014; -0.00087	-1.0
Digestive conditions	-0.0011***	-0.0014; -0.00087	-1.0
Endocrine conditions	0.000037	-0.00012; 0.00019	-0.1
Musculoskeletal	-0.0015***	-0.0018; -0.0012	-1.4
Respiratory	-0.00093***	-0.0011; -0.00076	-0.8
Injuries	0.00015	-0.000048; 0.00034	0.1
Cancer	-0.0022***	-0.0024; -0.0020	-2.0
Number of morbidities			
0-1	0.0019***	0.0015; 0.0024	1.7
2-5	0.0035***	0.0024; 0.0045	3.2
6 or more	-0.00089***	-0.0010; -0.00078	-0.8
Private funding	-0.00037***	-0.00057; -0.00017	-0.3
Unplanned admission	-0.0054***	-0.0064; -0.0044	-4.9
Transferred from secondary hospitals	-0.00089***	-0.0010; -0.00075	-0.8
Had surgical procedures in hospital	-0.00021**	-0.00035; -0.000062	-0.2
Constant	0.046***	0.041; 0.051	41.8

*Note: *** if p-value<0.001; ** if p-value<0.01; * if p-value<0.05*

Table 1B. Decomposition of the difference in the use of CT for unplanned admissions between two periods

	Number of CT per admission	95% CI	
The use of CT			
The past period	0.301	0.298; 0.304	
The recent period	0.418	0.414; 0.420	
Difference	0.117	0.112; 0.120	
Decomposition of the difference	Coefficient	95% CI	Percentage
Endowment component	0.020***	0.019; 0.021	17.1
Effect component	0.096***	0.092; 0.10	82.1
Specific endowment			
Sex	0.00096***	(0.00087; 0.0011)	0.8
Indigenous	-0.0024***	(-0.0026; -0.0021)	-2.0
Age groups			
18-44 years	0.0017***	(0.0016; 0.0019)	1.4
45-64 years	0.0011***	(0.00099; 0.0012)	0.9
65-74 years	-0.00011***	(-0.00012; -0.000092)	-0.1
75 + years	0.0000087***	(0.0000039; 0.000013)	0.01
SEIFA			
Least disadvantage	0.00023	(-0.000026; 0.00048)	0.2
Less disadvantage	0.000092	(-0.0000057; 0.00019)	0.1
Moderate disadvantage	0.00018	(-0.00021; 0.00057)	0.2
High disadvantage	-0.000023	(-0.000097; 0.000050)	-0.02
Highest disadvantage	-0.00036	(-0.0011; 0.00040)	-0.3
Unknown	-0.00021	(-0.00053; 0.00011)	-0.2
ARIA			
Major cities	-0.00043	(-0.0012; 0.00037)	-0.4
Inner regional areas	-0.00073	(-0.0019; 0.00040)	-0.6
Outer regional areas	-0.000031**	(-0.000053; -0.0000085)	-0.03
Remote	0.00000088	(-0.0000017; 0.0000035)	0.001
Very Remote	0.00014***	(0.000071; 0.00021)	0.1
Unknown	-0.00068	(-0.0013; -0.000048)	-0.6
Major principal diagnoses			
Mental conditions	0.00076***	(0.00065; 0.00087)	0.6
Circulatory conditions	-0.0039***	(-0.0043; -0.0036)	-3.3
Digestive conditions	0.00063***	(0.00058; 0.00069)	0.5
Endocrine conditions	0.00088***	(0.00073; 0.0010)	0.7
Musculoskeletal	-0.00062***	(-0.00077; -0.00047)	-0.5
Respiratory	0.0014***	(0.0011; 0.0016)	1.2
Injuries	0.0034***	(0.0032; 0.0035)	2.8
Cancer	-0.0042***	(-0.0044; -0.0040)	-3.5
Number of morbidities			
0-1	0.0020***	(0.0019; 0.0021)	1.7
2-5	0.0018***	(0.0017; 0.0019)	1.5

6 or more	0.010***	(0.010; 0.011)	8.3
Private funding	0.0094***	(0.0084; 0.010)	7.8
Transferred from secondary hospitals	0.00049***	(0.00044; 0.00054)	0.4
Admission with surgical procedures	-0.0019***	(-0.0022; -0.0017)	-1.6
Specific effect component			
Sex	0.0035	(-0.00021; 0.0072)	2.9
Indigenous	0.00050	(-0.00051; 0.0015)	0.4
Age groups			
18-44 years	-0.013***	(-0.015; -0.010)	-10.8
45-64 years	-0.0011	(-0.0027; 0.00042)	-0.9
65-74 years	0.0015**	(0.00046; 0.0026)	1.3
75 + years	0.0083***	(0.0066; 0.0100)	6.9
SEIFA			
Least disadvantage	0.0024	(-0.0023; 0.0071)	2
Less disadvantage	0.0023	(-0.00092; 0.0055)	1.9
Moderate disadvantage	0.0018	(-0.0015; 0.0051)	1.5
High disadvantage	0.0015	(-0.0017; 0.0047)	1.3
Highest disadvantage	0.0020	(-0.00063; 0.0046)	1.7
Unknown	-0.00034	(-0.00086; 0.00017)	-0.3
ARIA			
Major cities	0.0024	(-0.016; 0.020)	2
Inner regional areas	0.00030	(-0.0013; 0.0019)	0.3
Outer regional areas	0.000092	(-0.00081; 0.00100)	0.1
Remote	-0.0016***	(-0.0021; -0.0010)	-1.3
Very Remote	-0.00099***	(-0.0014; -0.00056)	-0.8
Unknown	0.00058**	(0.00019; 0.00097)	0.5
Major principal diagnoses			
Mental conditions	-0.0031***	(-0.0043; -0.0019)	-2.6
Circulatory conditions	-0.0045***	(-0.0061; -0.0029)	-3.8
Digestive conditions	-0.0034***	(-0.0047; -0.0022)	-2.8
Endocrine conditions	0.0010***	(0.00033; 0.0017)	0.8
Musculoskeletal	-0.0019***	(-0.0026; -0.0012)	-1.6
Respiratory	-0.0032***	(-0.0045; -0.0020)	-2.7
Injuries	0.0037***	(0.0021; 0.0053)	3.1
Cancer	-0.0044***	(-0.0050; -0.0038)	-3.7
Number of morbidities			
0-1	0.0079***	(0.0064; 0.0093)	6.6
2-5	0.0024	(-0.00097; 0.0057)	2
6 or more	-0.0060***	(-0.0068; -0.0052)	-5
Private funding sources	-0.00020	(-0.00099; 0.00058)	-0.2
Transferred from secondary hospitals	-0.0090	(-0.010; -0.0078)	-7.5
Admission with surgical procedures	-0.0015**	(-0.0024; -0.00050)	-1.3
Constant	0.11***	(0.091; 0.12)	91.7

*Note: *** if p-value<0.001; ** if p-value<0.01; * if p-value<0.05*

The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found		RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	1.1 Abstract, data sources. 1.2 Abstract, data sources 1.3 Abstract, data sources.
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported			Introduction, lines 30-65
Objectives	3	State specific objectives, including any prespecified hypotheses			Introduction, lines 68-70
Methods					
Study Design	4	Present key elements of study design early in the paper			Methods- line 72-73 and Study population (line 85-93)
Setting	5	Describe the setting, locations, and relevant dates, including			Methods, data sources and study population

		periods of recruitment, exposure, follow-up, and data collection			
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 *(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		RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	6.1 Methods, study population and design. 6.2 Methods, data sources. 6.3 Methods, data source, reference 28 and 29
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.		RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	Methods, outcome measures, independent measures
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement).			Methods, data sources, outcome measures, and independent measures

		Describe comparability of assessment methods if there is more than one group			
Bias	9	Describe any efforts to address potential sources of bias			Methods, statistical methods line 128-146
Study size	10	Explain how the study size was arrived at			Methods and Results (149-152)
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why			Methods, outcome measure, and independent measures
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (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 (e) Describe any sensitivity analyses			Methods, statistical methods
Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the	12.1 Methods 12.2 Methods, data sources

				database population used to create the study population. RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	12.3 Methods, data sources (76-87)
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram		RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	13.1 Method, study population and Results (lines 149-152)
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) *Cohort study* - summarise follow-up time (*e.g.*, average and total amount)			Results, lines 153-163 and Table 1

Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time *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			Results, Table 1
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (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			Results, (a) Figure 1, 2, and 3 and Appendix, lines 165-234 b) Categorisation provide in the methods (line 105-124) c) NA
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses			Methods lines 128-146
Discussion					
Key results	18	Summarise key results with reference to study objectives			Discussion, lines 236-251
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		RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over	Discussion, lines 310-320

				time, as they pertain to the study being reported.	
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence			Discussion and Conclusion section (lines 310-334).
Generalisability	21	Discuss the generalisability (external validity) of the study results			Australian context clear in manuscript with discussion of relevant literature
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			Role of the funding source, lines 341-344
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	22.1 Supplementary data provided to justify results and interpretation. Line 345-350: The data that support the findings of this study are available from the relevant data custodians of the study datasets. Restrictions by the data custodians mean that the data are not publicly available or able to be provided by the authors. Researchers

					wishing to access the datasets used in this study should refer to the WA data linkage application process (https://www.datalinkage-wa.org.au/access-and-application).

*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.

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Factors driving computed tomography utilisation in tertiary hospitals: a decomposition analysis using linked administrative data in Western Australia

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Factors driving computed tomography utilisation in tertiary hospitals: a decomposition analysis using linked administrative data in Western Australia

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Abstract

Objectives: While computed tomography (CT) scanning plays a significant role in health care, its increasing use has raised concerns about inappropriate use. This study investigated factors driving the changing use of CT among people admitted to tertiary hospitals in Western Australia (WA).

Design and setting: A repeated cross-sectional study of CT use in WA in 2003-2005 and 2013-2015 using linked administrative heath data at the individual patient level.

Participants: A total of 2,375,787 tertiary hospital admissions of people aged 18 years or older.

Main outcome measure: Rate of CT scanning per 1000 hospital admissions.

Methods: A multivariable decomposition model was used to quantify the contribution of changes in patient characteristics and changes in the probability of having a CT over the study period.

Results: The rate of CT scanning increased by 112 CT scans per 1000 admissions over the study period. Changes in the distribution of the observed patient characteristics were accounted for 62.7% of the growth in CT use. However, among unplanned admissions, changes in the distribution of patient characteristics only explained 17% of the growth in CT use, the remainder being explained by changes in the probability of having a CT scan. Whilst the relative probability of having a CT scan generally increased over time across most observed characteristics, it reduced in young adults (-2.8%), people living in the rural/remote areas (-0.8%) and people transferred from secondary hospitals (-0.8%).

Conclusions: Our study highlights potential improvements in practice towards reducing medical radiation exposure in certain high risk population. Since changes in the relative probability of having a CT scan (representing changes in scope) rather than changes in the distribution of the patient characteristics (representing changes in need) explained a major proportion of the growth in CT use, this warrants more in-depth investigations in clinical practices to better inform health policies promoting appropriate use of diagnostic imaging tests.

Strengths and limitations of this study

- This study utilised a large linked administrative dataset over a period of 13 years, allowing the measurement of the contributions of changes in demographic and clinical characteristics to the changing use of CT.
- With a rich source of individual level data, this study identified a wide range of demographic and clinical factors driving the use of CT in tertiary hospitals.
- Since the decomposition analysis methods only quantified the contribution of observed factors, contribution of any unobserved factors to the change of CT use was summed in the constant coefficient.
- Our study was limited to assessing the factors driving the use of CT scanning in tertiary (teaching) hospitals, therefore, caution is needed when generalising the results to other settings.

Introduction

Computed tomography (CT) is one of the most important technical developments in medicine and is now an essential part of clinical practice (1, 2). In Australia, CT accounted for 13% of diagnostic imaging tests with an average of 134 scans per 1000 people in 2017/18 (3, 4). It is estimated that diagnostic imaging tests increased the annual effective ionising radiation dose on the Australian population by 50% (5). In acknowledgement of the relatively high radiation burden of diagnostic imaging, Australia introduced Diagnostic reference levels (DRL) in 2011 providing a benchmark to facilitate monitoring and comparison of radiation dose between facilities (6).

Despite the advanced technology leading to significant contribution in healthcare, its increasing use has raised a concern about inappropriate use. Approximately one third of diagnostic imaging tests are estimated to be unnecessary or inappropriate, with the potential to do more harm than good and represent a waste of health care resources (7, 8). In the case of CT the potential harm includes exposure to ionising radiation and the associated risk of cancer to population. A previous study found a high rate of inappropriate CT among older patients and those with multi-morbidity (9).

In response to concerns of inappropriate utilisation of the advanced diagnostic technique, since early 2000, the Royal Australian and New Zealand College of Radiologists (RANZCR) have provided the standards of practice for clinical radiology (10). In Western Australia (WA), Diagnostic Imaging Pathways has been deployed to promote appropriate use of imaging (11, 12). Most recently, in 2015 NPS MedicineWise launched the Australian “Choosing Wisely” campaigns promoting discussion on reducing low value care (13), changing health care provider behaviour and increasing patient knowledge. The overall intention is to improve patient safety and efficiency in health service utilisation (13).

While substantial effort is under way to promote appropriate use of imaging tests, current data reporting variation in potentially avoidable diagnostic imaging tests, particularly for CT over the last decade are limited (9, 14, 15). Recent studies mainly focus on examining the prevalence of low value

care (16), the early trend of procedure uptake in hospital settings (17) and selected spinal imaging (18) following Choosing Wisely campaigns. Therefore, better understanding of changes in the use of CT scanning over the past decade and demographic and clinical factors driving the change in the use of CT are necessary to support monitoring the use of CT scanning and to guide future research and public health interventions. The aim of this study is to use decomposition analysis to examine factors driving changes in CT use between two periods of time in tertiary hospitals in WA: recent (2013 to 2015) and past (2003 to 2005).

Methods

We conducted an observational repeated cross-sectional study of CT use in WA in 2003-2005 and 2013-2015 using linked administrative heath data at the individual patient level. Reporting follows the Reporting of studies Conducted using Observational Routinely-collected health Data (RECORD) guidelines (19).

Data sources

The data sources included three datasets:

(i) WA Hospital Morbidity Data system (January 2003- May 2016) providing information on diagnosis, date of admission and discharge from all hospitals in WA, and basic socio-demographic and clinical characteristics.

(ii) WA Emergency Department (ED) presentation data (January 2003- December 2016) providing details of presentation time and date, presentation type, triage code, major diagnostic group and basic socio-demographic characteristics.

(iii) WA Picture archiving and communication system (PACS) data (January 2003 to May 2016) providing documentation on all computed tomography (CT) scans conducted in tertiary including date of the scan, and the CT protocols used. All the datasets were linked using probabilistic matching algorithms with a level of data accuracy up to 99.9% (20, 21).

Details of data linkage process is presented in the website of Western Australia Data Linkage (https://www.datalinkage-wa.org.au/dlb-services/linkage/).

Study population

The study population consisted of all hospital admissions in all four tertiary (teaching) hospitals located centrally in Perth, which accounted for nearly 50% of admissions in public hospitals, in WA between 2003 and 2015 inclusive, for people aged 18 years and older. Non-tertiary admissions (i.e. admission from secondary (district general) hospitals) were excluded as CT scans performed in the hospitals are not consistently included in the PACS dataset. The study population was then constructed into two study periods; past period (2003-2005) and recent period (2013-2015). To avoid over-counting hospital admissions, for example where a patient was transferred between hospitals, consecutive tertiary hospital admission records for an individual were aggregated into a single hospital admission where admission or discharge dates were nested or overlapping, or where an admission date was within one day of the discharge date. A tertiary hospital admission was counted from the first date of admission in a tertiary hospital–or where applicable– the date of a prior associated tertiary ED presentation so long as it resulted in an admission, to the last discharge date in tertiary hospitals.

Patient and Public Involvement

This study used linked administrative health data of all tertiary hospital admissions of people aged 18 years or older. The patients were not directly involved in the design or conduct of this study. Our consumer representative (Mr John Stubbs) was involved in the design of the grant application used to fund this research and is a member of the research team providing ongoing input to analysis of the data, interpretation of the results and development of publications. The Western Australian Data Linkage Branch and the data custodians of the WA Emergency Department Data Collection and the Picture Archiving Communications System data provided data for this project.

Outcome measures

The outcome measure of this study was the number of CT scans performed within a tertiary hospital admission. The number of CT scans was counted from the first day admitted to a tertiary hospital/presentation to a tertiary ED until the last date of discharge for that admission. To avoid over-counting the use of CT, multiple CT records with the same day and same anatomic areas were collapsed into one CT event (22).

Independent measures

This study measured basic demographic and socioeconomic characteristics including age (18-44, 45-64, 65-74, and 75+ years), sex, indigenous status, residential remoteness classified according to Accessibility Remoteness of Australia index (ARIA) (23) (major cities, inner regional areas, outer regional areas, remote and very remote), and quintiles of the Census-specific Socio-economic Indexes for Areas (SEIFA) index of relative socioeconomic disadvantage (24) (least disadvantage, less disadvantage, moderate disadvantage, high disadvantage, and highest disadvantage).

Clinical characteristics included major clinical diagnostic groups and the number of morbidities. Major clinical diagnostic groups included mental and behavioural disorders, circulatory system, digestive system, endocrine, nutritional and metabolic diseases, musculoskeletal system, respiratory system, injuries, and neoplasms. The conditions were identified in the principal diagnostic field of the hospital morbidity data record using ICD-AM-10 (the International Statistical Classification of Diseases and Related Health Problems, 10th Revision, Australian Modification). Multimorbidity was ascertained using the Multipurpose Australian Comorbidity Scoring system (25) using ICD-AM-10 across all diagnostic fields and was classified into 0-1, 2-5 and 6+ comorbidities. In addition, an admission was classified as having had a surgical procedure where the principal procedure field included one of the 20 most common surgical procedure as per ACHI codes (the Australian classification of health intervention) (26). Other independent measures included funding source (public or private), admission type (elective or unplanned admission) and admission with/without a transfer from secondary hospitals.

Statistical analysis

Descriptive analysis was conducted to examine the distribution of socio-demographic and clinical characteristics of the study population over two study periods; past period (2003-2005) and recent period (2013-2015) as well as the whole study population (2003-2015). Multivariable decomposition for nonlinear response models, an extension of Oaxaca-Blinder decomposition analysis (27), was conducted to decompose the differential rate of CT use between the two study periods into the endowment (distribution of observed patient characteristics) and effect (relative probability of having CT scan) components:

(1) The Endowment component quantifies the amount of the difference in the rate of CT use is explained by the changes in the distribution of observed socio-demographic and clinical characteristics between the two study periods.

(2) The Effect component describes how much of the difference in the rate of CT scanning is explained by a change in the relative probability of having CT across observed characteristics.

We conducted decomposition analyses for all tertiary admissions and for unplanned tertiary admissions separately using STATA SE 14 (27).

Results

Characteristics of tertiary admissions with CT scan by study periods

Of a total of 2,375,787 tertiary hospital admissions over the 12 year period (2003-2015), 303,439 admissions (12.8%) had at least one CT scan. The proportion of admissions incorporating CT increased from 8.9% in the past period (2003-2005) to 16.6% in the recent period (2013-2015) (Table 1). Overall, there was a small change in the distribution of both demographic and clinical characteristics among admissions that included CT between the two study periods. For example, the proportion of the patients who had a CT scan and were in the older ager group (75+ years) increased from 30.3% to 32.7% and people living in major cities with CT increased from 82.5% to 88.3%

between the past and recent period. Similarly within clinical characteristics, multi-morbidity (6+ morbidities) accounted for 27.8% of admissions with CT in the past period compared to 28.8% in the recent period. Among major diagnostic groups in the past period, injuries, circulatory system, cancer and digestive system accounted for 15.5%, 15.2%, 11.7% and 10.9% of admissions with CT, compared to 18.8%, 13.1%, 7.9% and 11.2% in recent period. For other characteristics, admission with CT in the recent period had a higher proportion of unplanned admission (90.1% vs. 86.8%) and private funding sources (21.0% vs. 7.7%) compared with the past period.

Decomposition results for the use of CT over the two periods

The results of the decomposition analysis of the difference in average number of CT scans between the two periods for all tertiary admissions and unplanned at the aggregated level are presented in Figure 1 (detail in Appendix- Table 1A-B). The difference in the rate of CT scans between two periods was 112 scans per 1000 admissions (95%CI, 110; 114 per 1000 admissions, p-value <0.001) for all tertiary admission and 117 scans per 1000 admissions (95%CI, 112; 120 per 1000 admissions, p-value <0.001) for unplanned tertiary admissions. While the change in the number of CT scans per admission across the two analyses were not substantially different, a marked difference in the results of the decomposition analysis was observed. Figure 1 shows that 62.7% of the difference in CT use for all tertiary admission was explained by variation in the distribution of all observed characteristics. The rest of the difference in CT usage was attributable to variation in the relative probability of having CT in observed characteristics and unobserved factors (captured in constant coefficient).

In contrast, when the analysis was restricted to unplanned admissions, the variation in the distribution of the observed characteristics explained only 17% of the difference in CT use between two periods while 82.7% was due to variation in the relative probability of having CT across observed and unobserved factors.

Details of decomposition analysis for all tertiary admissions

Figure 2 presents decomposition analysis in details of all observed demographic and clinical characteristics. Overall, changes in the distribution of the demographic characteristics including sex, indigenous status, age, SEIFA and ARIA explained only -0.8% of the change in CT use. Change in the distribution of the clinical characteristics including major principal diagnoses and groups of morbidities accounted for 12.4% of the change in CT use. Half of this change (6.1%) was attributable to multi-morbidity (6 or more morbidities) and 4.7% was due to injuries.

Over the study period changes in the relative probability of having a CT scan over the observed patient characteristics resulted in a 6.8% increase in the rate of CT scanning, while changes in the distribution of the characteristics of the observed patient characteristics reduced the rate of CT scanning by 2.6%. Interestingly, the relative probability of having a CT scan for those with young age was significantly lower than in the past period contributing 2.8% reduction in the number of CT scan between the two periods. In addition, the relative probability of having CT was higher for those identified as living in major cities in the recent period compared to the past period, and lower for people from remote/very remote areas in the recent period compared to the past period. The contribution of each component to the difference in the number of CT's per admission between the two periods was 5.5% (p-value=0.02) and -0.8% (p-values<0.001), respectively.

For clinical characteristics, the results indicated a lower relative probability of having a scan during a tertiary admission in the recent period compared with the past period for all the diagnostic groups, with the exception of those admitted for injuries and endocrine disorders. The increase in patients with multi-morbidities (2-5 comorbidities) contributed 3.2% to the difference between the two periods.

For other factors, the relative probability of having a CT scan following transfer from a secondary hospital in the recent period was significantly lower than in the past period, contributing 0.8% reduction to the rate of CT scan between the two periods. A lower relative probability of having a CT scan in the recent period compared with the past period for unplanned admission contributed -4.9%

to the difference in CT use between the two periods. Unobserved factors captured in the constant coefficient contributed to 41.8% of the variation in CT usage between the two periods.

Details of decomposition analysis for unplanned tertiary admissions

Similar to all tertiary admissions, the results for unplanned admission (Figure 3) indicated that a substantial proportion of variation in CT use between the two study periods (10.0%) was attributable to changes in the distribution of the observed clinical characteristics including multimorbidity and major diagnostic groups. However, changes in the distribution of the observed demographic characteristics such as age, sex and accessibility between two periods only explained a total of -0.5% the change in CT use.

For the specific effect component, a similar finding was also observed in unplanned admissions. Specifically, a lower relative probability of having a CT scan for those in the youngest age group (18-44 years) was observed in the recent period compared with the past. Likewise, a lower relative probability of having CT scan in the recent period versus the past period was observed among those admitted for condition such as circulatory, cancer, and respiratory; this accounted for -3.8%, -3.7%, and -2.7% of the difference in CT use. The relative probability of having a CT scan after transfer from a secondary hospital in the recent period was lower than in the past, contributing -7.5% to the change in the number of CT scans between the two periods.

Discussion

This is the first study to examine the contribution of demographic and clinical characteristics to changes in the rate of CT scanning in tertiary hospitals using multivariable decomposition analysis of linked health administrative data over an extended period of time. We found that nearly two thirds of the increase in the use of CT was attributable to changes in the distribution of observed characteristics, with changes in proportion of unplanned admissions accounting for the largest component. However when the analysis was restricted to unplanned admissions, changes in distribution of the observed characteristics only explained about a fifth of the difference in CT usage

and the rest was explained by the effect component. In both decomposition analyses, clinical characteristics (12.4% in all admissions and 10% in unplanned admissions) including major diagnostic groups and comorbidities rather than demographic characteristics contributed substantially to explain the variation in CT use between the two periods. Interestingly, our study observed a lower relative probability of having a CT scan in the recent period (2013-2015) compared with the past period (2003-2005) in two subgroups: young adults, which may reflect a movement towards minimising medical radiation exposure in the high risk population, and admissions transferred from secondary hospitals, reflecting either a reduction in inappropriate repeat imaging tests or greater access to CT in non-tertiary hospitals.

A recent study examined factors driving the increasing use of CT scan in Australia with a focus on the use of CT outside of the public hospital setting (28), which accounted for 73% of adult CT scans (29). Although the study also used the decomposition analysis approach, the only endowment component captured in this study was changes in the population age structure; the rest of the difference in CT use was captured in the number of CT scans per capita. The study found that a change in the number of CT scans per capita, interpreted as a "scope shift", rather than changes in the population age structure accounted for a major component in the change of CT use outside hospital settings over the period 1993 to 2013 (28). The previous study used changes in age structure as a marker of changes in need (e.g. an ageing population), which had been postulated as the reason for increasing CT scanning rates. The finding that changes in the age structure was responsible for only a small proportion of the rate of CT use suggested that "scope shift" (i.e. changes in the practice of CT) was driving the rate of use. Our findings again confirmed that the impact of changing in age structure (i.e. increasing proportion of older people) was not a major driver of the use of CT scanning. In addition, by using multivariable decomposition analysis, our study provides a more comprehensive picture of the contribution of various demographic, clinical and other observed factors driving the change in CT use in the hospital setting. This is because our analysis was able to differentiate the influence of changes in the distribution (endowment component) from changes in the relative probability of

having CT (effect component) across a large range of observed factors. Our study adds to the literature by showing that it is the change in distribution of comorbidities and clinical conditions which are often highly prevalent in the older population rather than the age of the population itself that contributed the largest component to the growth of CT use. This indicates the need of strengthen public health interventions to promote healthy ageing to reduce the burden on health care systems.

Our study found that while many observed factors drive the increase of CT use, the change in the relative probability of having CT scan in the young age group and in those with admissions transferred from secondary hospitals (once the variation in the distribution of these factors was accounted for) reduced the use of CT in the recent period compared with the past period. These finding are encouraging as they confirm a reduction in two groups where there has been concern regarding inappropriate imaging. The results coincide with the goals of education campaigns to raise provider awareness of the risk of ionising radiation, especially among children and young adults (30-32). Since children and young adults are more sensitive and have more years to develop radiation-induced cancer (30, 31), radiologists have become more cautious and may have taken care to minimise unnecessary CT scanning.

Despite challenges due to the vast geographical spread of Australia, over the last 15 years diagnostic imaging services have become more accessible to patients in both major cities and rural areas within a timely and a reasonable distance from their home (31). A report in 2012 shows that more than 90% of Australians can get access to a comprehensive diagnostic imaging facility within a distance of 100km from their residential areas (31) and up to 80% of patients have access to a CT machine within 10 km (31). Between 2003 and 2018, Australia increased the rate of CT equipment per head of population from 40.6 to 67 per million (33, 34). The government also provided a diagnostic imaging bulk billing incentive from November 2009 that increased the accessibility to the service through improving patient affordability. In addition, the government endorsed the diagnostic

imaging review reform package in 2011 and implemented it between 2011 and 2016, funded through the Medicare Benefits Schedule. One of the package objectives was to ensure accessibility to quality diagnostic imaging services for people in rural and remote areas. In addition, the package also aimed to promote for effective communication between practitioners and imaging service to ensure appropriate imaging (31). The increasing availability and accessibility of diagnostic imaging, in particular to CT scanners, raised concerns of potential overuse of CT scans increasing radiation exposure to patients and contributing additional costs to the health care system (15). However, we found that the relative probability of having CT scan in tertiary hospitals for people living in remote and very remote areas in the recent period was less than in the past period. Although the magnitude of the variation was small, it accounts for significantly lower use of CT scan in tertiary hospitals. Likewise, the rate of CT scan among admissions transferred from the secondary hospital in the recent period was also less than in the past period. This would be consistent with government efforts to ensure accessibility of diagnostic imaging service in rural and remote areas as well as improved information transfer between hospitals. Previous studies have highlighted the important role of image sharing technology in improving provider access and avoiding duplication of investigations (35-37). However, a recent study found that repeat CT scanning is relatively common for patients already imaged prior to transfer to a tertiary hospital, although there was a valid clinical reason for repeat scanning in the majority of cases (15). Despite signs of improvement in our study, further detailed exploration is required to establish the proportion of avoidable repeat scans and therefore the potential benefit in terms of reduced radiation exposure and costs.

This study has a number of limitations, largely due to the nature of linked administrative data. This study only decomposed the difference in CT use between the two study periods based on the available observed characteristics available in the administrative data. Thus, the contribution of unobserved factors was not addressed in this study, although they are captured in the constant value. This study only captured the use of CT in tertiary hospitals because we did not have comprehensive data on CT use in non-tertiary settings, limiting our ability to determine whether the

lower relative probability of having CT in the recent period in some subgroups was due to changes in practice or increasing accessibility of CT in other health care settings. While the linked administrative data can comprehensively capture use of health services over time without loss to follow up, information about clinical information is limited to relatively high-level diagnostic codes recorded in the HMDS. Therefore, our study cannot provide information about the proportion of scans that were justified.

In conclusion, the use of CT in tertiary hospitals increased between the two study periods in keeping with international trends. This is primarily due to changes in the distribution of unplanned admissions and the clinical characteristics of presenting patients rather than changing demographic characteristics. Among unplanned admissions only, changes in the relative probability of scanning were the major drivers of CT use, with the largest component of this relating to unobserved factors. In both results, clinical characteristics appear to be substantial component driving the growth of CT usage in the tertiary hospital setting while the role of demographic characteristics was minimal. Our study also highlights a potential improvement in practice towards reducing medial radiation exposure through a decrease CTs in subpopulations such as young adults and in those admitted via transfer admission from other hospitals. While the finding is limited to tertiary settings, the method used in our study can be applied in a broader context to characterise major factors driving the use of CT scanning as well as the use of diagnostic imaging tests. Our study may assist to identify areas worthy of more in-depth investigations to better inform health policy makers and interventions promoting appropriate use of diagnostic imaging tests.

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Competing interests

The authors have no competing interest to declare. The institutions of RM, NH, DY, MB and DM received grant funding from the National Medical Research Council of Australia for investigator-initiated research. The funding agreement ensured author independence in designing the study, interpreting the data, writing and publishing the report.

Authors' contributions

RM, MB, JD, DM, PO, JSl, SM, NTH conceived the idea and study design for the manuscript. NTH, RM, SM conducted data analyses and drafted the manuscript. RM, SM, NTH, MB contributed to statistical expertise. RM, MB, JD, DM, PO, JSl, SM, NTH contributed in analysis, interpreting the results, drafting and revising critically for important intellectual content of the manuscript. RM, MB, JD, DM, PO, JSl secured funding for the study. All authors read and approved the final version of the manuscript for publication. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

Ethics approval and consent to participate

Human research ethics approval was obtained from Curtin University Human Research Ethics Committee (SMEC-80-10) and the WA Department of Health Human Research Ethics Committee (2011/97) which exempted the study from requiring individual consent.

Patient consent

Not applicable

Data sharing statement

Data access is limited to only authors who require it for data analysis - the remaining authors do not have access to the data but did have full access to the results of the data analysis. The data that support the findings of this study are available from the relevant data custodians of the study datasets. Restrictions by the data custodians mean that the data are not publicly available or able to be provided by the authors. Researchers wishing to access the datasets used in this study should

refer to the WA data linkage application process (https://www.datalinkage-wa.org.au/access-and-application).

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List of tables

Figures

Table 1. Characteristics of the study population by study period and CT scan status

	Study period								All years 2003-2015 (2,375,787)			
	The past period (2003-2005) (N=519,286)				The recent period (2013-2015) (N=572,642)							
	Without CT scan (N= 473,120)		With CT scan (N= 46,166)		Without CT scan (N= 477,462)		With CT scan (N= 95,180)		Without CT scan (N= 2,072,348)		With CT scan (N= 303,439)	
	N	%	N	%	N	%	N	%	N	%	N	%
Female	237,021	50.1	21,232	46.0	248,412	52.0	43,865	46.1	1,057,280	51.0	137,988	45.5
Age groups												
18-44years	134,467	28.4	10,954	23.7	145,181	30.4	20,075	21.1	621,452	30.0	67,456	22.2
45-64 years	144,820	30.6	12,797	27.7	150,139	31.4	27,225	28.6	651,941	31.5	87,319	28.8
65-74 years	91,075	19.2	8,447	18.3	83,797	17.6	16,798	17.6	368,070	17.8	53,332	17.6
75+ years	102,758	21.7	13,968	30.3	98,345	20.6	31,082	32.7	430,885	20.8	95,332	31.4
Indigenous status	31,708	6.7	2,111	4.6	32,061	6.7	4,540	4.8	137,806	6.6	14,156	4.7
SEIFA												
Least disadvantage	129,988	27.5	12,522	27.1	130,427	27.3	27,885	29.3	595,921	28.8	90,660	29.9
Less disadvantage	89,310	18.9	8,495	18.4	87,703	18.4	17,850	18.8	364,787	17.6	53,241	17.5
Moderate disadvantage	91,594	19.4	9,112	19.7	99,533	20.8	19,549	20.5	449,532	21.7	65,203	21.5
High disadvantage	89,421	18.9	8,923	19.3	95,607	20.0	18,104	19.0	388,311	18.7	57,090	18.8
Highest disadvantage	70,595	14.9	6,900	14.9	61,291	12.8	11,344	11.9	262,172	12.7	35,691	11.8
unknown	2,212	0.5	214	0.5	2,901	0.6	448	0.5	11,625	0.6	1,554	0.5
ARIA												
Major cities	411,062	86.9	38,086	82.5	416,708	87.3	84,046	88.3	1,807,380	87.2	261,292	86.1
Inner regional areas	29,622	6.3	3,663	7.9	19,675	4.1	3,508	3.7	108,562	5.2	15,908	5.2
Outer regional areas	16,251	3.4	2,155	4.7	19,417	4.1	3,814	4.0	75,935	3.7	13,210	4.4
Remote	8,968	1.9	1,283	2.8	10,654	2.2	1,901	2.0	44,727	2.2	7,336	2.4
Very Remote	6,205	1.3	894	1.9	8,167	1.7	1,458	1.5	28,389	1.4	4,731	1.6
Unknown	1,012	0.2	85	0.2	2,841	0.6	453	0.5	7,355	0.4	962	0.3
Number of morbidity (MACSS) (Median – IQR)	2	2-3	4	2-6	2	2-3	4	2-6	2	2-3	3	2-6
Major clinical conditions												

	Study period								All years 2003-2015 (2,375,787)			
	The past period (2003-2005) (N=519,286)				The recent period (2013-2015) (N=572,642)							
	Without CT scan (N= 473,120)		With CT scan (N= 46,166)		Without CT scan (N= 477,462)		With CT scan (N= 95,180)		Without CT scan (N= 2,072,348)		With CT scan (N= 303,439)	
	N	%	N	%	N	%	N	%	N	%	N	%
Mental and behaviour disorders	11,065	2.3	2,015	4.4	15,514	3.2	3,296	3.5	61,756	3.0	11,109	3.7
Circulatory system	35,636	7.5	7,038	15.2	38,534	8.1	12,434	13.1	162,138	7.8	41,737	13.8
Digestive system	31,437	6.6	5,026	10.9	38,055	8.0	10,678	11.2	150,492	7.3	32,897	10.8
Endocrine	9,160	1.9	823	1.8	11,074	2.3	1,381	1.5	46,268	2.2	5,165	1.7
Musculoskeletal system	21,153	4.5	1,532	3.3	21,477	4.5	2,819	3.0	93,520	4.5	9,231	3.0
Respiratory system	15,013	3.2	2,918	6.3	17,001	3.6	5,241	5.5	68,859	3.3	17,149	5.7
Injury	23,483	5.0	7,165	15.5	31,608	6.6	17,913	18.8	126,703	6.1	53,420	17.6
Cancer	21,608	4.6	5,389	11.7	22,465	4.7	7,520	7.9	96,232	4.6	28,783	9.5
Funding sources												
Public	447,927	94.7	42,612	92.3	416,248	87.2	75,202	79.0	1,894,581	91.4	258,126	85.1
Private	25,193	5.3	3,554	7.7	61,214	12.8	19,978	21.0	177,767	8.6	45,313	14.9
Unplanned admissions												
No	316,762	67.0	6,089	13.2	259,764	54.4	9,387	9.9	1,245,273	60.1	34,058	11.2
Yes	156,358	33.0	40,077	86.8	217,698	45.6	85,793	90.1	827,075	39.9	269,381	88.8
Transferred from secondary hospitals												
No	459,539	97.1	41,742	90.4	455,496	95.4	88,480	93.0	1,990,570	96.1	277,994	91.6
Yes	13,581	2.9	4,424	9.6	21,966	4.6	6,700	7.0	81,778	3.9	25,445	8.4
Surgical procedure												
No	457,900	96.8	42,803	92.7	449,708	94.2	87,721	92.2	1,975,259	95.3	280,008	92.3
Yes	15,220	3.2	3,363	7.3	27,754	5.8	7,459	7.8	97,089	4.7	23,431	7.7
Morbidity group												
0-1	103,369	21.85	6,165	13.35	116,826	24.47	13,361	14.04	514,216	24.81	46,686	15.4
2-5	349,557	73.88	27,175	58.86	329,844	69.08	54,377	57.13	1,452,109	70.07	175,377	57.8
6+	20,194	4.27	12,826	27.78	30,792	6.45	27,442	28.83	106,023	5.12	81,376	26.82

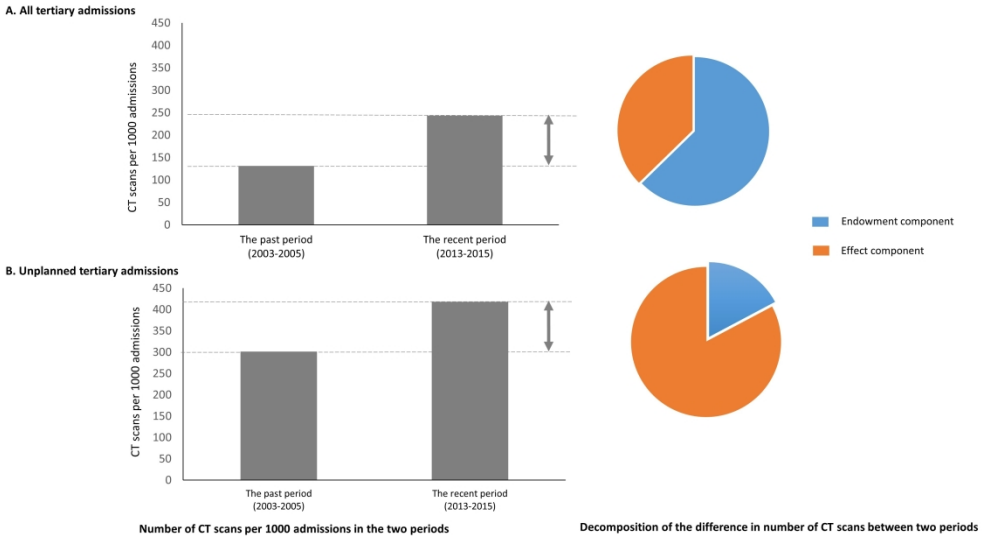

Figure 1. Decomposition analysis of the difference in average number of CT scans between the two periods

338x190mm (300 x 300 DPI)

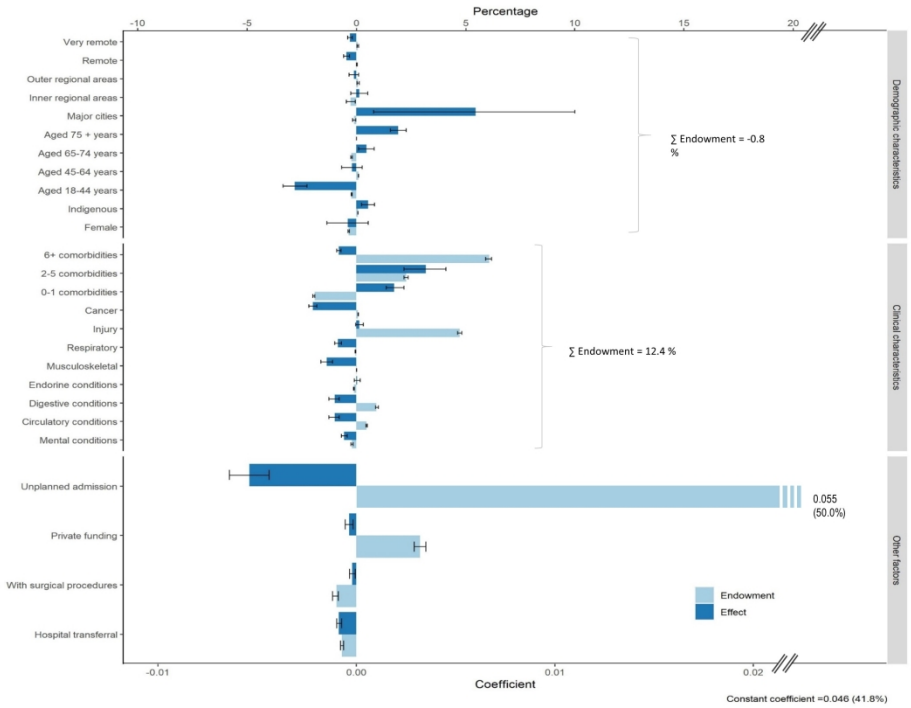

Figure 2. Details of decomposition analysis of the difference in average number of CT scans between the two periods for all tertiary admissions

254x190mm (300 x 300 DPI)

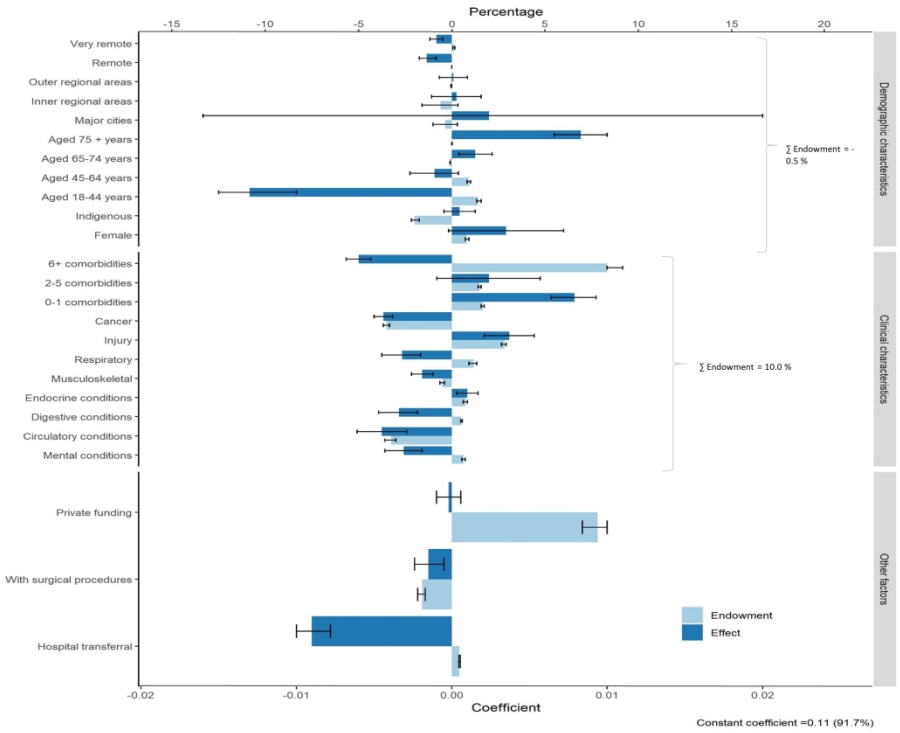

Figure 3. Details of decomposition analysis of the difference in average number of CT scans between the two periods for unplanned tertiary admissions

254x190mm (300 x 300 DPI)

Table 1A. Decomposition of the difference in the use of CT of all tertiary admissions between two periods

	Number of CT per admission	95% CI	
The use of CT			
The past period	0.131	0.129; 0.132	
The recent period	0.243	0.241; 0.245	
Difference	0.112	0.110; 0.114	
Decomposition output	Coefficient	95% CI	Percentage
Endowment component	0.069***	0.068; 0.070	62.7
Effect component	0.043***	0.041; 0.045	37.3
1. Specific endowment component			
Sex	-0.00039***	-0.00043; -0.00036	-0.4
Indigenous	0.000074***	0.000066; 0.000081	0.1
Age groups			
18-44 years	-0.00025***	-0.00027; -0.00023	-0.2
45-64 years	0.00010***	0.000089; 0.00011	0.1
65-74 years	-0.00025***	-0.00029; -0.00021	-0.2
75 + years	-0.0000039**	-0.0000066; -0.0000012	-0.004
SEIFA			
Least disadvantage	0.0000081	-0.0000085; 0.000025	0.01
Less disadvantage	-0.000020	-0.000053; 0.000013	-0.02
Moderate disadvantage	0.000056	-0.000060; 0.00017	0.1
High disadvantage	0.000061	-0.000015; 0.00014	0.1
Highest disadvantage	-0.00010	-0.00029; 0.000086	-0.1
Unknown	-0.000028	-0.000075; 0.000018	-0.2
ARIA			
Major cities	-0.00012**	-0.00020; -0.000034	-0.1
Inner regional areas	-0.00029*	-0.00052; -0.000055	-0.3
Outer regional areas	0.000076**	0.000027; 0.00013	0.1
Remote	0.000014	-0.0000095; 0.000037	0.01
Very Remote	0.000065**	0.000028; 0.00010	0.1
Unknown	-0.00015*	-0.00030; -0.0000086	-0.1
Major principal diagnoses			
Mental conditions	-0.00022***	-0.00028; -0.00017	-0.2
Circulatory conditions	0.00051***	0.00048; 0.00054	0.5
Digestive conditions	0.0010***	0.00096; 0.0011	0.9
Endocrine conditions	-0.00013***	-0.00016; -0.00011	-0.1
Musculoskeletal	0.0000029	-0.0000064; 0.000012	0.003
Respiratory	-0.000054***	-0.000080; -0.000028	-0.05
Injuries	0.0052***	0.0051; 0.0053	4.7
Cancer	0.000084***	0.000082; 0.000086	0.1
Number of morbidities			
0-1	-0.0021***	-0.0022; -0.0021	-1.9
2-5	0.0025***	0.0024; 0.0026	2.3
6 or more	0.0067***	0.0065; 0.0068	6.1
Private funding	0.0032***	0.0029; 0.0035	2.9

Unplanned admission	0.055***	0.055; 0.056	50.0
Transferred from secondary hospitals	-0.00073***	-0.00081; -0.00065	-0.7
Had surgical procedures in hospital	-0.0010***	-0.0012; -0.00092	-0.9
2. Specific effect component			
Sex	-0.00043	-0.0015; 0.00059	-0.4
Indigenous	0.00059***	0.00026; 0.00091	0.5
Age groups			
18-44 years	-0.0031***	-0.0037; -0.0025	-2.8
45-64 years	-0.00023	-0.00075; 0.00029	-0.2
65-74 years	0.00050*	0.00011; 0.00089	0.5
75 + years	0.0021***	0.0017; 0.0025	1.9
SEIFA			
Least disadvantage	0.00080	-0.00050; 0.0021	0.7
Less disadvantage	0.00054	-0.00037; 0.0014	0.5
Moderate disadvantage	0.00060	-0.00033; 0.0015	0.5
High disadvantage	0.00044	-0.00046; 0.0013	0.4
Highest disadvantage	0.00055	-0.00018; 0.0013	0.5
Unknown	-0.000070	-0.00017; 0.000031	-0.1
ARIA			
Major cities	0.0060*	0.00086; 0.011	5.5
Inner regional areas	0.00014	-0.00029; 0.00056	0.1
Outer regional areas	-0.00013	-0.00038; 0.00011	-0.1
Remote	-0.00050***	-0.00065; -0.00035	-0.5
Very Remote	-0.00032***	-0.00044; -0.00021	-0.3
Unknown	0.000092**	0.000037; 0.00015	0.1
Major principal diagnoses			
Mental conditions	-0.00062***	-0.00077; -0.00048	-0.6
Circulatory conditions	-0.0011***	-0.0014; -0.00087	-1.0
Digestive conditions	-0.0011***	-0.0014; -0.00087	-1.0
Endocrine conditions	0.000037	-0.00012; 0.00019	-0.1
Musculoskeletal	-0.0015***	-0.0018; -0.0012	-1.4
Respiratory	-0.00093***	-0.0011; -0.00076	-0.8
Injuries	0.00015	-0.000048; 0.00034	0.1
Cancer	-0.0022***	-0.0024; -0.0020	-2.0
Number of morbidities			
0-1	0.0019***	0.0015; 0.0024	1.7
2-5	0.0035***	0.0024; 0.0045	3.2
6 or more	-0.00089***	-0.0010; -0.00078	-0.8
Private funding	-0.00037***	-0.00057; -0.00017	-0.3
Unplanned admission	-0.0054***	-0.0064; -0.0044	-4.9
Transferred from secondary hospitals	-0.00089***	-0.0010; -0.00075	-0.8
Had surgical procedures in hospital	-0.00021**	-0.00035; -0.000062	-0.2
Constant	0.046***	0.041; 0.051	41.8

*Note: *** if p-value<0.001; ** if p-value<0.01; * if p-value<0.05*

Table 1B. Decomposition of the difference in the use of CT for unplanned admissions between two periods

	Number of CT per admission	95% CI	
The use of CT			
The past period	0.301	0.298; 0.304	
The recent period	0.418	0.414; 0.420	
Difference	0.117	0.112; 0.120	
Decomposition of the difference	Coefficient	95% CI	Percentage
Endowment component	0.020***	0.019; 0.021	17.1
Effect component	0.096***	0.092; 0.10	82.1
Specific endowment			
Sex	0.00096***	(0.00087; 0.0011)	0.8
Indigenous	-0.0024***	(-0.0026; -0.0021)	-2.0
Age groups			
18-44 years	0.0017***	(0.0016; 0.0019)	1.4
45-64 years	0.0011***	(0.00099; 0.0012)	0.9
65-74 years	-0.00011***	(-0.00012; -0.000092)	-0.1
75 + years	0.0000087***	(0.0000039; 0.000013)	0.01
SEIFA			
Least disadvantage	0.00023	(-0.000026; 0.00048)	0.2
Less disadvantage	0.000092	(-0.0000057; 0.00019)	0.1
Moderate disadvantage	0.00018	(-0.00021; 0.00057)	0.2
High disadvantage	-0.000023	(-0.000097; 0.000050)	-0.02
Highest disadvantage	-0.00036	(-0.0011; 0.00040)	-0.3
Unknown	-0.00021	(-0.00053; 0.00011)	-0.2
ARIA			
Major cities	-0.00043	(-0.0012; 0.00037)	-0.4
Inner regional areas	-0.00073	(-0.0019; 0.00040)	-0.6
Outer regional areas	-0.000031**	(-0.000053; -0.0000085)	-0.03
Remote	0.00000088	(-0.0000017; 0.0000035)	0.001
Very Remote	0.00014***	(0.000071; 0.00021)	0.1
Unknown	-0.00068	(-0.0013; -0.000048)	-0.6
Major principal diagnoses			
Mental conditions	0.00076***	(0.00065; 0.00087)	0.6
Circulatory conditions	-0.0039***	(-0.0043; -0.0036)	-3.3
Digestive conditions	0.00063***	(0.00058; 0.00069)	0.5
Endocrine conditions	0.00088***	(0.00073; 0.0010)	0.7
Musculoskeletal	-0.00062***	(-0.00077; -0.00047)	-0.5
Respiratory	0.0014***	(0.0011; 0.0016)	1.2
Injuries	0.0034***	(0.0032; 0.0035)	2.8
Cancer	-0.0042***	(-0.0044; -0.0040)	-3.5
Number of morbidities			
0-1	0.0020***	(0.0019; 0.0021)	1.7
2-5	0.0018***	(0.0017; 0.0019)	1.5

6 or more	0.010***	(0.010; 0.011)	8.3
Private funding	0.0094***	(0.0084; 0.010)	7.8
Transferred from secondary hospitals	0.00049***	(0.00044; 0.00054)	0.4
Admission with surgical procedures	-0.0019***	(-0.0022; -0.0017)	-1.6
Specific effect component			
Sex	0.0035	(-0.00021; 0.0072)	2.9
Indigenous	0.00050	(-0.00051; 0.0015)	0.4
Age groups			
18-44 years	-0.013***	(-0.015; -0.010)	-10.8
45-64 years	-0.0011	(-0.0027; 0.00042)	-0.9
65-74 years	0.0015**	(0.00046; 0.0026)	1.3
75 + years	0.0083***	(0.0066; 0.0100)	6.9
SEIFA			
Least disadvantage	0.0024	(-0.0023; 0.0071)	2
Less disadvantage	0.0023	(-0.00092; 0.0055)	1.9
Moderate disadvantage	0.0018	(-0.0015; 0.0051)	1.5
High disadvantage	0.0015	(-0.0017; 0.0047)	1.3
Highest disadvantage	0.0020	(-0.00063; 0.0046)	1.7
Unknown	-0.00034	(-0.00086; 0.00017)	-0.3
ARIA			
Major cities	0.0024	(-0.016; 0.020)	2
Inner regional areas	0.00030	(-0.0013; 0.0019)	0.3
Outer regional areas	0.000092	(-0.00081; 0.00100)	0.1
Remote	-0.0016***	(-0.0021; -0.0010)	-1.3
Very Remote	-0.00099***	(-0.0014; -0.00056)	-0.8
Unknown	0.00058**	(0.00019; 0.00097)	0.5
Major principal diagnoses			
Mental conditions	-0.0031***	(-0.0043; -0.0019)	-2.6
Circulatory conditions	-0.0045***	(-0.0061; -0.0029)	-3.8
Digestive conditions	-0.0034***	(-0.0047; -0.0022)	-2.8
Endocrine conditions	0.0010***	(0.00033; 0.0017)	0.8
Musculoskeletal	-0.0019***	(-0.0026; -0.0012)	-1.6
Respiratory	-0.0032***	(-0.0045; -0.0020)	-2.7
Injuries	0.0037***	(0.0021; 0.0053)	3.1
Cancer	-0.0044***	(-0.0050; -0.0038)	-3.7
Number of morbidities			
0-1	0.0079***	(0.0064; 0.0093)	6.6
2-5	0.0024	(-0.00097; 0.0057)	2
6 or more	-0.0060***	(-0.0068; -0.0052)	-5
Private funding sources	-0.00020	(-0.00099; 0.00058)	-0.2
Transferred from secondary hospitals	-0.0090	(-0.010; -0.0078)	-7.5
Admission with surgical procedures	-0.0015**	(-0.0024; -0.00050)	-1.3
Constant	0.11***	(0.091; 0.12)	91.7

*Note: *** if p-value<0.001; ** if p-value<0.01; * if p-value<0.05*

The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found		RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	1.1 Abstract, data sources. 1.2 Abstract, data sources 1.3 Abstract, data sources.
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported			Introduction, lines 71-91
Objectives	3	State specific objectives, including any prespecified hypotheses			Introduction, lines 92-101
Methods					
Study Design	4	Present key elements of study design early in the paper			Methods- line 102-106 and Study population (line 121-134)
Setting	5	Describe the setting, locations, and relevant dates, including			Methods, data sources and study population

		periods of recruitment, exposure, follow-up, and data collection			
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 *(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		RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	6.1 Methods, study population and design. 6.2 Methods, data sources. 6.3 Methods, data source, reference 20 and 21
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.		RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	Methods, outcome measures, independent measures
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement).			Methods, data sources, outcome measures, and independent measures

		Describe comparability of assessment methods if there is more than one group			
Bias	9	Describe any efforts to address potential sources of bias			Methods, statistical methods line 171-184
Study size	10	Explain how the study size was arrived at			Methods and Results (187-190)
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why			Methods, outcome measure, and independent measures
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (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 (e) Describe any sensitivity analyses			Methods, statistical methods
Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the	12.1 Methods 12.2 Methods, data sources

				database population used to create the study population. RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	12.3 Methods, data sources
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram		RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	13.1 Method, study population and Results (190-200)
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) *Cohort study* - summarise follow-up time (*e.g.*, average and total amount)			Results, lines 190-200 and Table 1

Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time *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			Results, Table 1
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (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			Results, (a) Figure 1, 2, and 3 and Appendix b) Categorisation provide in the methods c) NA
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses			Methods lines 183-184
Discussion					
Key results	18	Summarise key results with reference to study objectives			Discussion, lines 262-277
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		RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over	Discussion, lines 340-351

				time, as they pertain to the study being reported.	
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence			Discussion and Conclusion section (lines 352-365).
Generalisability	21	Discuss the generalisability (external validity) of the study results			Australian context clear in manuscript with discussion of relevant literature
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			Role of the funding source, lines 367-369
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	22.1 Supplementary data provided to justify results and interpretation. Line 389-396: The data that support the findings of this study are available from the relevant data custodians of the study datasets. Restrictions by the data custodians mean that the data are not publicly available or able to be provided by the authors. Researchers

					wishing to access the datasets used in this study should refer to the WA data linkage application process (https://www.datalinkage-wa.org.au/access-and-application).

*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.