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Trend in CT utilisation and its impact on length of stay, readmission and hospital mortality in Western Australia tertiary hospitals: an analysis of linked administrative data 2003–2015

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ABSTRACT

Objective High use of CT scanning has raised concern due to the potential ionising radiation exposure. This study examined trends of CT during admission to tertiary hospitals and its associations with length of stay (LOS), readmission and mortality.

Design Retrospective observational study from 2003 to 2015.

Setting West Australian linked administrative records at individual level.

Participants 2 375 787 episodes of tertiary hospital admission in adults aged 18+ years.

Main outcome measures LOS, 30-day readmissions and mortality stratified by CT use status (any, multiple (CTs to multiple areas during episode), and repeat (repeated CT to the same area)).

Methods Multivariable regression models were used to calculate adjusted rate of CT use status. The significance of changes since 2003 in the outcomes (LOS, 30-day readmission and mortality) was compared among patients with specific CT imaging status relative to those without.

Results Between 2003 and 2015, while the rate of CT increased 3.4% annually, the rate of repeat CTs significantly decreased −1.8% annually and multiple CT showed no change. Compared with 2003 while LOS had a greater decrease in those with any CT, 30-day readmissions had a greater increase among those with any CT, while the probability of mortality remained unchanged between the any CT/no CT groups. A similar result was observed in patients with multiple and repeat CT scanning, except for a significant increase in mortality in the recent years in the repeat CT group.

Conclusion The observed pattern of increase in CT utilisation is likely to be activity-based funding policy-driven based on the discordance between LOS and readmissions. Meanwhile, the repeat CT reduction aligns with a more selective strategy of use based on clinical severity. Future research should incorporate in-hospital and out-of-hospital CT to better understand overall CT trends and potential shifts between settings over time.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ The scope of the study was limited to CT use in tertiary hospitals and not generalisable to other settings.

⇒ This study does not account for reasons for requesting a CT scan or whether a repeat CT improved clinical decision-making or health outcomes.

⇒ The study is not generalisable to CT scanning in children.

⇒ The cohort includes all admissions to all tertiary hospitals in Western Australia which removes bias associated with sampling or reliance on self-reported data.

BACKGROUND

CT provides important information to guide clinical management.[1] There has been an increase in CT use in Australia over recent years,[2–4] which has raised concerns due to the potential for malignancy due to ionising radiation, potential harms of contrast agent[5 6] and incidental findings,[7] increasing health system costs and questions about the appropriateness of the examinations performed.[8 9] A study in the USA estimated that the annual individual effective radiation dose from diagnostic and interventional medical procedures in 2016 was 2.3 mSv, of which CT accounted for approximately 63%.[10] The Australian Radiation Protection and Nuclear Safety Agency estimated that in 2009 CT may have contributed to 1.2 mSv per person per annum, equal to half of natural background radiation in Australia (2.2–2.4 mSv per annum).[8 11] The effective dose for an individual patient having a CT can range from 3.6 times the annual background for a non-contrast chest CT to 7 times the annual background for cardiac

CT,[8] making CT a significant risk factor for cancer. It is recommended that medical imaging is only used when the potential clinical benefit outweighs potential risks and so that the lowest practical radiation dose is delivered to answer the clinical question.[12 13] Evidence shows that build-up or cumulative radiation exposure posits cancer risk,[14] suggesting that repeat CT scans within a short window of time such as a hospital stay introduces often unjustified risk for patients. Moreover, repeat CT scans within a hospitalisation are more likely to be unwarranted compared with non-repeat ones.[15] Evidence has demonstrated that short-term repeat CTs led to changes in diagnosis in under one-third of cases, indicating that repeat CT is not good practice.[16] Reducing the rate of repeat CT has since attracted attention from healthcare policy makers aiming to improve care quality, reduce waste and cost. A more targeted practice of limiting repeat CT scans to patients with severe health conditions found empirical support as more advisable than routine repeat scanning,[17] with clinical follow-up to be used where possible instead.[18–20]

There is a lack of evidence regarding trends in utilisation of overall CT, multiple and repeat CT during hospitalisation, as well as how changes in CT utilisation affects the length of stay (LOS), readmission and mortality. This basic information is integral to developing policy in order to rationalise CT use and reduce unintentional harms and the opportunity costs of CT, where not clinically indicated. The well-established linked data infrastructure of Western Australia (WA), that is, the ability to link CT utilisation data to hospital admissions and emergency department (ED) presentations using probabilistic linkage via the WA data linkage system,[21] affords the opportunity to undertake individual level analyses of the use of CT, multiple and repeat CT within hospitalisations across an entire population. This study aimed to:
1. Quantify the rate of any CT, multiple CTs (2+CTs) and repeat scanning (2+CTs in the same anatomical areas).
2. Characterise changing patterns of CT use over time and the associated changes in mortality, readmission and LOS stratified by CT scan status (no CT, any CT, multiple and repeated CT).

METHODS
We conducted a retrospective observational cohort study of CT scanning use in adults admitted to tertiary (teaching) hospitals in WA between January 2003 and December 2015 using individual level linked administrative data. Reporting follows the Reporting of studies Conducted using Observational Routinely-collected health Data guidelines.[22]

Data sources
Data were extracted from:
1. The WA hospital morbidity data collection (HMDC), which contains information related to inpatient care in all hospitals (public and private) in WA from January 2003 to May 2016. The data included diagnoses and procedure codes, dates of admission and discharge, and basic patient demographic characteristics.
2. The WA emergency department data collection (EDDC), which includes data of all patients presenting to all publicly funded WA EDs between January 2003 and December 2016. The data included presentation date and time, presentation type (emergency and elective), triage code, major diagnostic group, and demographic characteristics.
3. The WA picture archiving and communication system, with CT utilisation data including the date of the scan, the type of CT examination undertaken (eg, non-contrast head CT, etc) and the source of referral for the CT for the study population.
4. WA death registrations records from 2003 to 2015, containing information on all deaths in WA including date and cause of death.

Study population
The study population was adults aged 18+ years with an admission to a WA tertiary hospital. The unit of observation in this study was an episode of inpatient hospitalisation. The period of hospitalisation began on the earliest of either the admission date recorded in the HMDC, or if the individual was admitted via ED, the date of presentation to a tertiary ED, and ended on the date discharged from the tertiary hospital. Admissions to hospital within 1 day of a discharge (or nested within another hospitalisation) were classified as a single episode of contiguous hospitalisation.

CT scan use status
The number of CTs was the number of scans performed during each patient's episode of hospitalisation, where more than one scan within the same day recorded in the same anatomical area was counted as a single CT event.[23] As shown in online supplemental appendix 1 episodes of hospitalisation were classified as either having no CT or any CT (at least one CT). Episodes with one or more CTs were further classified into: yes/no multiple CTs (2+CTs regardless of anatomical areas) or yes/no repeat CTs (2+CTs in the same anatomical area on different days) (figure 1). We reported the four anatomical areas (overall, anatomical areas used for classification of repeat CT were head, face, soft-tissue neck, chest, spine, abdomen/pelvis and extremity) which had the highest frequency of repeat CT.

Outcome measures
Length of stay
Sourced from the HMDC and ED data, LOS captured number of days from the admission date to tertiary hospital or presenting to tertiary ED (where the patient was admitted via ED) to the date of the final discharge. Hospitalisations with the same day admission and discharge were counted as 1 day LOS.
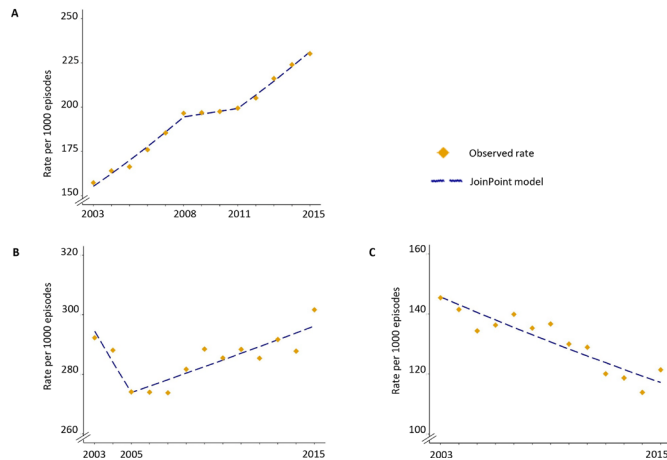
Figure 1 JoinPoint regression the trend in (A) any CT, (B) multiple CT and (C) repeat CT. (A) Per 1000 tertiary episodes of hospitalisations, (B) and (C) per 1000 tertiary episodes of hospitalisations with at least one CT.

Number of 30-day readmissions after discharge

For each hospitalisation, the number of 30-day readmissions after discharge was calculated from the HMDC data including readmissions to either tertiary or secondary (district general) hospitals. Where patients had multiple hospitalisations, the number of readmissions was calculated for each tertiary hospitalisation. Therefore, a tertiary hospitalisation could be an index event and also be counted in the 30-day readmission if its admission was within 30 days of a previous discharge.

Mortality

Thirty-day and ninety-day mortality (the latter from admission or discharge, the former from discharge only) was identified using WA death registration records.[24] For those with multiple tertiary hospitalisations within 30 (or 90) days, the mortality was assigned to the last hospitalisation; prior hospitalisations did not contribute to this outcome even if death occurred within 30/90 days.

Covariates

Basic demographic characteristics taken from HMDC, EDDC and mortality data included sex; age in years and Indigenous status (adjustment covariate only), accessibility to services was measured using the accessibility/remoteness of index of Australia (ARIA).[25] Socioeconomic status was classified using the socioeconomic indexes for areas (SEIFA) based on the index of relative socioeconomic disadvantage for census closest to the date of discharge categorised as quintiles.[26] Admission type was categorised as either elective or emergency as recorded in the HMDC. Where episodes incorporated multiple admissions, this was classified according to the coding of the first admission. The top five (based on frequency of CT) specific principal diagnostic groups were identified using the International Classification of Diseases, 10th revision, Australian modification (ICD-10-AM) for each anatomical area of CT. In addition, all admissions were classified based on major diagnosis chapters identified using the ICD-10-AM in the principal diagnostic field.

Analysis

Descriptive analyses were used to examine changes in the distribution of the characteristics of the study population in the first (2003) and final (2015) year of the study period according to the use of CT (any, multiple and repeat CT). Sankey diagrams[27] were used to identify the top five principal diagnoses associated with single use and repeat CT in 2003 and 2015 for the four selected anatomical areas (head, spine, chest, abdomen/pelvis). Sankey diagrams were generated using the networkD3 package in R.[27] Separate multivariable Poisson regression models were used to calculate the adjusted rate of any CT, multiple CTs and repeat CT over the study period and to identify factors associated with each classification of CT use. The adjusted rate of any, multiple, and repeat CT were further examined using a JoinPoint regression model (V.4.8.0.1)[28 29] to identify any significant changes in the trend reported as the estimated annual percentage rate change (APC) for identified periods and the average APC (AAPC) over the study period for overall and across age group and sex. JoinPoint regression was also conducted for the trend in repeat CT in the four selected anatomical areas.

Multivariable negative binomial models accounting for over-dispersion and within-subject correlation were used to examine the trend in LOS (days) and number of 30-day readmissions after discharge stratified by CT scan status (any, multiple and repeat CTs) used over the study period. Multivariable logistic regressions accounting for within-subject correlation were used to examine the trend in the probability of hospital 30-day mortality after discharge, 90-day mortality after discharge and 90-day mortality after admission. Postestimation predictive margins with contrasts were used to compare the difference in the outcomes between with and without CT status (any, multiple and repeat CT) observed in each year vs the difference observed in the baseline year in 2003. The method first measured the outcomes (LOS, 30-day readmission and probability of mortality) in each year adjusting for any variation in observed demographic and clinical characteristics over the 13 years for those with and without a particular CT scan status (panel A in figures 2–4). It then took the difference in the outcomes between those with and without a particular CT scan status in each follow-up year to compare with the difference observed in the reference year (panel B in figures 2–4). Details of steps to calculate postestimation predictive margins with contrasts is presented in online supplemental appendix 2.[30] This was undertaken to demonstrate whether there was a significant change in the incremental impact of CT use on the outcomes of interest over the study period. Analyses were undertaken using Stata SE V.15.[31]

Tertiary Length of stay
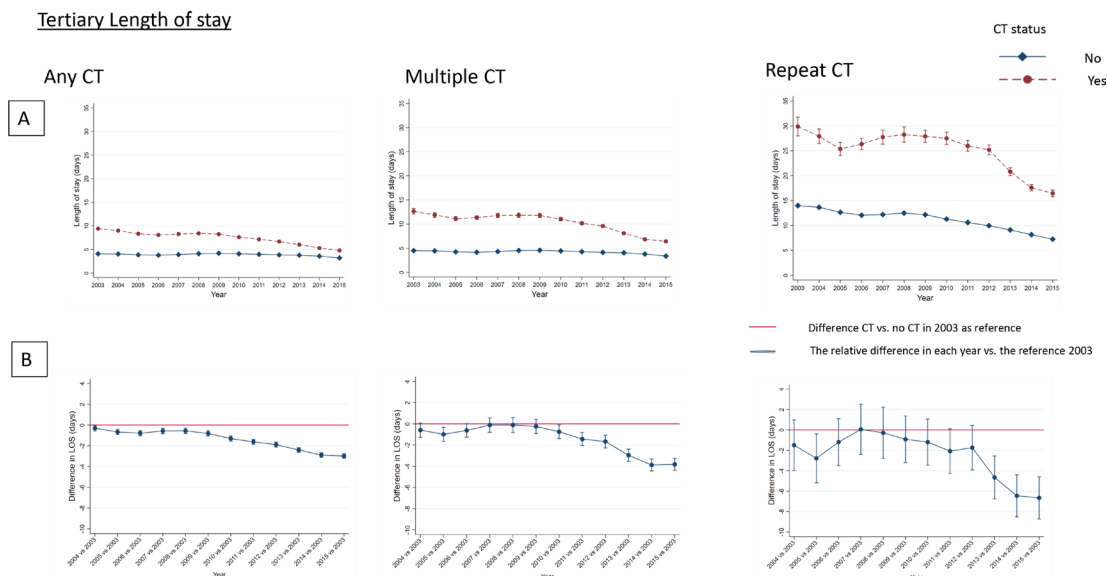
Figure 2 Trends in length of stay (days) for hospitalisations with and without CT. (A) The adjusted rate for tertiary length of stay between hospital admissions with and without CT for any, multiple and repeat CT. (B) The rate difference in tertiary length of stay between hospital admissions with and without CT for any, multiple and repeat CT relative to the rate difference in 2003 for each group.

RESULTS

Characteristics of the study population

A total of 2 375 787 episodes were included. Table 1 presents characteristics of the study population at two-time points (2003 and 2015) according to CT status. While the distributions of basic demographic characteristics were similar between the two-time points, admissions with high number of comorbidities (6+), unplanned admissions, surgical procedures and diagnosis with injury/poison and circulatory system disorders was higher in 2015 than in 2003 (table 1). The percentage of hospitalisations with at least one CT increased from 8.5% in 2003 to 17.5%

in 2015, whereas the percentage of these incorporating multiple CTs remained unchanged (~27%) and repeat CT reduced from 12.3% to 10.3% (see table 1). This pattern of change was observed across sex, age groups, SEIFA and ARIA. While median LOS for all admissions significantly increased from 1 (IQR 1–4) to 2 (IQR 1–4) days between the two-time points, it reduced nearly by half for admissions with at least one CT, multiple and repeat CT (see table 1).

Changes in the top five principal diagnoses and the overall number of discrete diagnoses associated with CT use were also explored across four anatomical areas of CT

30-day readmissions
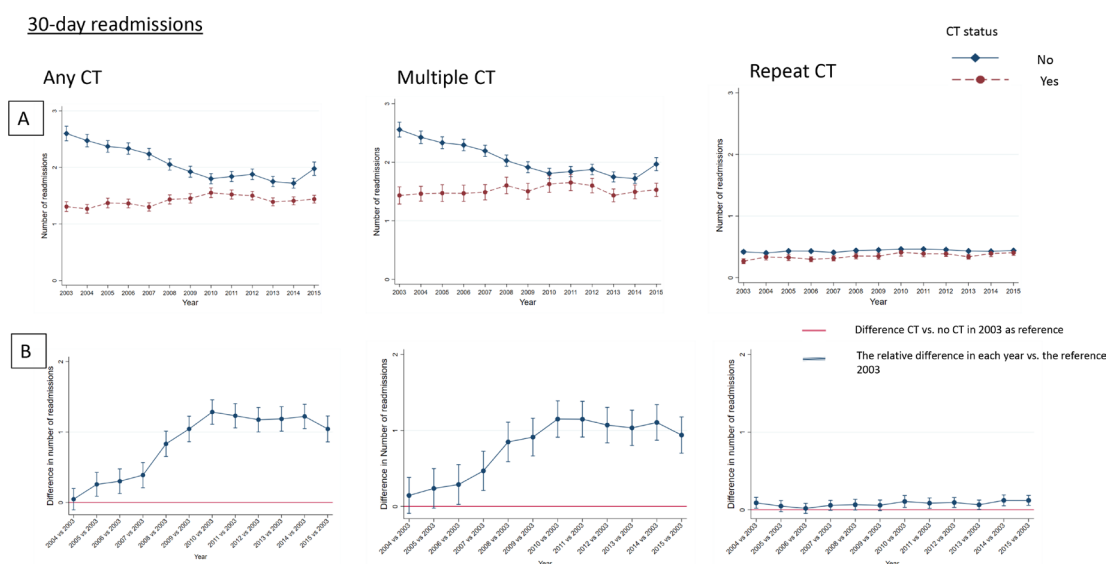
Figure 3 Trends in the rate of 30-day readmissions for hospitalisations with and without CT. (A) The adjusted rate for 30-day readmissions with and without CT for any, multiple and repeat CT. (B) The rate difference for 30-day readmission between those with and without CT for any, multiple and repeat CT relative to the rate difference in 2003 for each group.
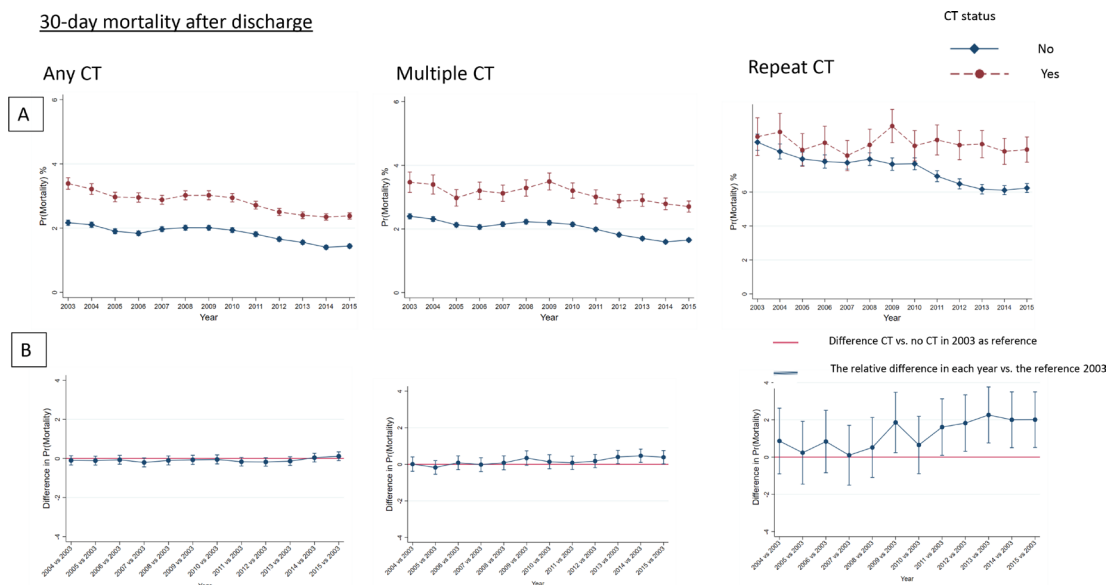
Figure 4 Trends in the rate of 30-day mortality after discharge for hospitalisations with and without CT. (A) The adjusted probability of 30-day mortality after discharge for hospitalisations with and without CT for any, multiple and repeat CT. (B) The rate difference probability of 30-day mortality after discharge between hospitalisations with and without CT for any, multiple and repeat CT relative to the difference in 2003 for each group.

for 2003 and 2015: repeat CT was highest in head (13.4%), followed by spine (9.2%), abdomen/pelvis (8.9%) and chest (6.0%) (online supplemental appendix 3). While the top five diagnoses for admissions with a single vs repeat CTs in these anatomical areas were quite similar between time points, the overall number of discrete diagnoses were much higher in 2015 (online supplemental appendix 3).

Factors associated with the CT use
After adjusting for all observed demographic, socioeconomic, clinical characteristics and year of observation, older age groups had a significantly higher rate of CT but a significantly lower rates of multiple and repeat CT compared with youngest age groups. People living further from major cities had a significantly higher rate of any, multiple and repeated CT, while those living in higher disadvantaged socioeconomic areas had a significantly lower rate of any and repeat CT. Compared with elective, emergency admissions had a five times higher rate of having any CT but only a 16% higher rate of repeat CT (table 2). After adjusting for changes in observed sociodemographic and clinical characteristics the rate of hospitalisations with CT increased significantly over the study period, whereas the rate of multiple CT showed no significant difference and the rate of repeat CT significantly reduced (table 2).

Trends in the CT use
JoinPoint analysis indicated a linear annual reduction (AAPC) of –1.8% (95% CI –2.3% to –1.3%) in the rate of repeat CT over the study period, an annual non-linear increase (AAPC) of 3.8% (95% CI 2.5 to 4.3) for any CT and no change for multiple CTs (figure 1). The result was

consistent across sex and age groups (details in online supplemental appendix 4). The pattern of change in the rate of repeat CT varied across different anatomical areas (online supplemental appendix 5).

Change in differences in the outcomes relative to the baseline difference in 2003 stratified by CT use status
Length of stay
While LOS was significantly higher among hospital admissions with any CT, multiple or repeat CT compared with those without CT (figure 2A), the difference in LOS between hospital admissions with and without CT in the recent years from 2009 was significantly lower compared with the baseline year in 2003 (figure 2B).

Readmissions
In contrast, while number of 30-day readmissions from discharge was consistently lower among hospitalisation with any CT compared with those without CT, relative to the difference observed in 2003, the 30-day readmission rate among those with CT increased, approaching the group without CT (figure 3). Similar results were observed among hospitalisations with multiple and repeated CT as shown in figure 3. However, the significant difference in the baseline in repeat CT was observed from 2010 onwards.

Mortality
Hospital 30-day mortality after discharge was significantly higher among those with any CT, multiple CT and repeat CT over the study period, except for repeated CT for a few years at the beginning of the study period (figure 4A). Relative to the difference observed in 2003, there was no significant change in the difference in probability of the

Table 1 Characteristics of the study population in 2003 and 2015 by CT status

	2003								2015							
	Total		At least one CT scan		Multiple scanning (2+CT scans)		Repeat CT scanning		Total		At least one CT scan		Multiple scanning (2+CT scans)		Repeat CT scanning	
Characteristics	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Overall	165 598	100	14 118	8.5	3 799	26.9	1 739	12.3	189 170	100	33 178	17.5	9 171	27.6	3 427	10.3
Sex																
Male	82 056	49.6	7 502	9.1	2 143	28.6	964	12.8	91 770	48.5	17 910	19.5	5 377	30.0	2 082	11.6
Female	83 542	50.4	6 616	7.9	1 656	25.0	775	11.7	97 400	51.5	15 268	15.7	3 794	24.8	1 345	8.8
Age groups																
18–44	47 389	28.6	3 422	7.2	899	26.27	435	12.7	54 198	28.7	6 760	12.5	1 844	27.3	705	10.4
45–64	49 946	30.2	3 830	7.7	1 097	28.64	498	13.0	58 436	30.9	9 409	16.1	2 679	28.5	1 032	10.9
65+	68 263	41.2	6 866	10.1	1 803	26.26	806	11.7	76 536	40.5	17 009	22.2	4 648	27.3	1 690	9.9
SEIFA																
Least disadvantage	51 357	31.0	4 161	8.1	1 051	25.26	523	12.6	45 951	24.3	8 973	19.5	2 326	25.9	849	9.5
Less disadvantage	32 570	19.7	2 725	8.4	748	27.45	338	12.4	38 804	20.5	6 617	17.0	1 784	26.9	655	9.9
Moderate disadvantage	17 322	10.5	1 616	9.3	437	27.04	187	11.6	36 354	19.2	6 455	17.7	1 714	26.5	625	9.7
Highly/highest disadvantage	63 501	38.3	5 523	8.7	1 530	27.70	676	12.2	66 754	35.3	10 974	16.4	3 290	29.9	1 279	11.6
Unknown	848	0.5	93	10.9	33	35.48	15	16.1	1 307	0.7	159	12.2	57	35.8	19	11.9
ARIA																
Major cities	143 290	86.5	11 570	8.1	2 914	25.19	1 343	11.6	165 076	87.3	29 395	17.8	7 841	26.7	2 836	9.6
Inner regional areas	10 279	6.2	1 138	11.1	380	33.39	181	15.9	7 497	4.0	1 193	15.9	430	36.0	196	16.4
Outer regional areas	5 993	3.6	679	11.3	237	34.90	102	15.0	7 921	4.2	1 304	16.5	471	36.1	208	15.9
Remote and very remote areas	5 641	3.4	693	12.3	259	37.37	109	15.7	7 290	3.9	1 107	15.2	371	33.5	168	15.2
Admission type																
Elective	101 471	61.3	1 988	1.9	731	36.77	204	10.3	82 446	43.6	3 316	4.0	826	24.9	344	10.4
Emergency	64 127	38.7	12 130	18.9	3 068	25.29	1 535	12.6	106 724	56.4	29 862	27.9	8 345	27.9	3 083	10.3
Comorbidities																
0–1	35 602	21.5	1 985	5.6	387	19.50	85	4.3	40 839	21.6	4 470	10.9	646	14.5	133	2.9
2–5	120 272	72.6	8 393	6.9	1 885	22.46	744	8.8	128 109	67.7	18 893	14.7	4 409	23.3	1 235	6.5
6+	9 724	5.9	3 740	38.5	1 527	40.83	910	24.3	20 222	10.7	9 815	48.5	4 116	41.9	2 059	20.9
Involving surgical procedures																
No	159 530	96.3	13 095	8.2	3 469	26.49	1 555	11.9	177 170	93.7	30 627	17.3	8 268	27.0	2 991	9.8
Yes	6 068	3.7	1 023	16.9	330	32.26	184	17.9	12 000	6.3	2 551	21.3	903	35.4	436	17.1
Diagnosis chapter with a high frequent use of CT																

Continued

Table 1 Continued

Characteristics	2003								2015							
	Total		At least one CT scan		Multiple scanning (2+CT scans)		Repeat CT scanning		Total		At least one CT scan		Multiple scanning (2+CT scans)		Repeat CT scanning	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Others	84 013	50.7	1 206	1.4	300	24.88	83	6.9	73 298	38.7	2 479	3.4	649	26.2	145	5.8
Infectious	1 744	1.1	352	20.2	98	27.84	51	14.5	3 632	1.9	1 105	30.4	318	28.8	112	10.1
Neoplasm	12 168	7.3	1 883	15.5	914	48.54	285	15.1	14 235	7.5	2 974	20.9	1 164	39.1	411	13.8
Mental	4 283	2.6	708	16.5	56	7.91	28	3.9	5 763	3.0	1 174	20.4	216	18.4	56	4.8
Nervous system	2 688	1.6	793	29.5	103	12.99	71	8.9	4 928	2.6	1 622	32.9	344	21.2	138	8.5
Ear and mastoid	478	0.3	91	19.0	8	8.79	NP		757	0.4	332	43.8	44	13.3	7	2.1
Circulatory system	13 875	8.4	2 191	15.8	683	31.17	460	20.9	17 207	9.1	4 406	25.6	1 460	33.1	773	17.5
Respiratory	5 838	3.5	861	14.7	211	24.51	69	8.0	7 959	4.2	2 007	25.2	347	17.3	108	5.4
Digestive	11 617	7.0	1 487	12.8	309	20.78	183	12.3	15 473	8.2	3 867	24.9	773	19.9	422	10.9
Genitourinary	6 323	3.8	754	11.9	70	9.28	28	3.7	8 443	4.5	1 939	22.9	210	10.8	82	4.2
Congenital	345	0.2	39	11.3	15	38.46	NP		405	0.2	64	15.8	18	28.1	14	21.9
Symptom/signs	8 277	5.0	1 235	14.9	176	14.25	36	2.9	14 055	7.4	3 862	27.5	567	14.7	117	3.0
Injury/poison	13 949	8.4	2 518	18.1	856	34.00	433	17.2	23 015	12.2	7 347	31.9	3 061	41.7	1 042	14.2
Length of stay (median, IQR)	1	1–4	9	4–19	15	7–33	24	13–47	2	1–4	4	2–9	8	3–17	14	7–28

Any CT scanning: an episode of admission with any CT scanning; multiple CT scans: an episode of admission with two or more CT scans; repeat CT scanning: an episode of admission with two or more CT scans in the same anatomical area.
Others include disease of blood and blood forming organs; disease of the eyes and adnexa; disease of the skin and subcutaneous tissue; disease of the musculoskeletal system and connective tissue; and pregnancy and childbirth.
ARIA, accessibility and remoteness index of Australia; NP, not provided; SEIFA, socioeconomic indexes for areas.

Table 2 Factors associated with any, multiple or repeat CT in tertiary hospitals

	Any CT scanning		Multiple CT scans		Repeat CT scanning	
	IRR	95% CI	IRR	95% CI	IRR	95% CI
Year						
2003	1	(1 to 1)	1	(1 to 1)	1	(1 to 1)
2004	1.04***	(1.02 to 1.07)	0.99	(0.94 to 1.03)	0.97	(0.91 to 1.04)
2005	1.06***	(1.03 to 1.08)	0.94**	(0.90 to 0.98)	0.92*	(0.87 to 0.99)
2006	1.12***	(1.09 to 1.14)	0.94**	(0.90 to 0.98)	0.94*	(0.88 to 1.00)
2007	1.18***	(1.15 to 1.20)	0.94**	(0.90 to 0.98)	0.96	(0.90 to 1.02)
2008	1.25***	(1.22 to 1.28)	0.96	(0.92 to 1.00)	0.93*	(0.87 to 0.99)
2009	1.25***	(1.22 to 1.28)	0.99	(0.95 to 1.03)	0.94	(0.88 to 1.00)
2010	1.26***	(1.23 to 1.28)	0.98	(0.94 to 1.02)	0.89***	(0.84 to 0.95)
2011	1.27***	(1.24 to 1.29)	0.99	(0.95 to 1.03)	0.89***	(0.83 to 0.94)
2012	1.30***	(1.28 to 1.33)	0.98	(0.94 to 1.02)	0.83***	(0.78 to 0.88)
2013	1.37***	(1.35 to 1.40)	1.00	(0.96 to 1.04)	0.82***	(0.77 to 0.87)
2014	1.42***	(1.40 to 1.45)	0.98	(0.95 to 1.02)	0.78***	(0.74 to 0.83)
2015	1.46***	(1.43 to 1.49)	1.03	(0.99 to 1.07)	0.83***	(0.79 to 0.88)
Sex						
Male	1	(1 to 1)	1	(1 to 1)	1	(1 to 1)
Female	0.90***	(0.89 to 0.90)	0.87***	(0.86 to 0.88)	0.85***	(0.83 to 0.87)
Age group						
18–44 years	1	(1 to 1)	1	(1 to 1)	1	(1 to 1)
45–64 years	1.25***	(1.24 to 1.27)	0.96***	(0.94 to 0.98)	0.85***	(0.82 to 0.88)
65+ years	1.30***	(1.29 to 1.31)	0.81***	(0.79 to 0.82)	0.59***	(0.57 to 0.61)
ARIA						
Major cities	1	(1 to 1)	1	(1 to 1)	1	(1 to 1)
Inner regional areas	1.05***	(1.03 to 1.06)	1.13***	(1.10 to 1.17)	1.24***	(1.19 to 1.30)
Outer regional areas	1.12***	(1.10 to 1.14)	1.14***	(1.11 to 1.18)	1.16***	(1.10 to 1.21)
Remote and very remote areas	1.21***	(1.18 to 1.23)	1.14***	(1.10 to 1.18)	1.19***	(1.13 to 1.26)
Unknown	0.66***	(0.60 to 0.73)	1.02	(0.86 to 1.21)	0.71*	(0.53 to 0.94)
SEIFA						
Least disadvantage	1	(1 to 1)	1	(1 to 1)	1	(1 to 1)
Less disadvantage	0.99*	(0.98 to 1.00)	1.00	(0.98 to 1.02)	0.97	(0.94 to 1.01)
Moderate disadvantage	0.99*	(0.98 to 1.00)	1.00	(0.98 to 1.02)	0.96*	(0.93 to 1.00)
Highly/highest disadvantage	0.99**	(0.98 to 1.00)	1.01	(0.99 to 1.03)	0.97*	(0.94 to 1.00)
Unknown	1.01	(0.94 to 1.09)	1.06	(0.93 to 1.20)	1.11	(0.92 to 1.34)
Number of morbidity						
0–1	1	(1 to 1)	1	(1 to 1)	1	(1 to 1)
2–5	1.42***	(1.41 to 1.44)	1.61***	(1.57 to 1.66)	2.68***	(2.53 to 2.84)
6+	2.90***	(2.87 to 2.94)	2.96***	(2.88 to 3.05)	8.51***	(8.03 to 9.03)
Admission type						
Elective	1	(1 to 1)	1	(1 to 1)	1	(1 to 1)
Emergency	5.35***	(5.28 to 5.41)	1.20***	(1.17 to 1.23)	1.16***	(1.11 to 1.20)
Involving surgical procedure						
No	1	(1 to 1)	1	(1 to 1)	1	(1 to 1)
Yes	0.85***	(0.83 to 0.86)	1.02*	(1.00 to 1.05)	1.13***	(1.09 to 1.17)
Diagnosis chapter with a high frequent use of CT						

Continued

Table 2 Continued

	Any CT scanning		Multiple CT scans		Repeat CT scanning	
	IRR	95% CI	IRR	95% CI	IRR	95% CI
Others†	1	(1 to 1)	1	(1 to 1)	1	(1 to 1)
Infectious	3.09***	(3.02 to 3.17)	1.01	(0.96 to 1.06)	1.40***	(1.29 to 1.52)
Neoplasm	5.63***	(5.54 to 5.73)	1.84***	(1.79 to 1.90)	2.27***	(2.14 to 2.40)
Mental	2.37***	(2.31 to 2.42)	0.56***	(0.53 to 0.59)	0.73***	(0.66 to 0.81)
Nervous system	6.11***	(5.98 to 6.24)	0.79***	(0.75 to 0.83)	1.57***	(1.46 to 1.69)
Ear and mastoid	7.05***	(6.77 to 7.34)	0.62***	(0.55 to 0.70)	0.86	(0.69 to 1.08)
Circulatory system	3.16***	(3.10 to 3.21)	1.25***	(1.22 to 1.29)	2.96***	(2.80 to 3.12)
Respiratory	2.55***	(2.50 to 2.60)	0.86***	(0.82 to 0.89)	1.07	(0.99 to 1.15)
Digestive	3.47***	(3.41 to 3.53)	0.85***	(0.82 to 0.88)	1.81***	(1.71 to 1.92)
Genitourinary	3.69***	(3.62 to 3.76)	0.45***	(0.42 to 0.47)	0.83***	(0.76 to 0.91)
Congenital	6.40***	(5.95 to 6.89)	1.31***	(1.14 to 1.52)	3.73***	(3.14 to 4.43)
Symptom/signs	3.84***	(3.78 to 3.91)	0.58***	(0.55 to 0.60)	0.66***	(0.61 to 0.71)
Injury/poison	3.69***	(3.63 to 3.74)	1.60***	(1.56 to 1.65)	2.46***	(2.33 to 2.60)

Any CT scanning: an episode of admission with any CT scanning; multiple CT scans: an episode of admission with two or more CT scans; repeat CT scanning: an episode of admission with two or more CT scans in the same anatomical areas.
*P value <0.05; **p value <0.01, ***p value <0.001. All models were adjusted with Indigenous status, but the data are not shown.
†Others include disease of blood and blood forming organs; disease of the eyes and adnexa; disease of the skin and subcutaneous tissue; disease of the musculoskeletal system and connective tissue; and pregnancy and childbirth.
ARIA, accessibility and remoteness index of Australia; IRR, Incidence Rate Ratio; SEIFA, socioeconomic indexes for areas.

30-day mortality after discharge over the study period in both any CT and multiple CT, but there was for repeat CT from 2010 onward (figure 4B). For repeat CT, the difference in 30-day mortality after discharge increased compared with the baseline. A similar result was observed with hospital 90-day mortality after discharge (online supplemental appendix 6) and hospital 90-day mortality after admission (online supplemental appendix 7).

DISCUSSION

Results indicated that among episodes of hospitalisation with CT, a quarter involved multiple CTs and about 10% had repeated CTs of the same anatomical area. Interestingly, after accounting for all observed patient factors the use of CT while admitted to tertiary hospitals increased by nearly 50% over the study period. In contrast, the rate of multiple CTs remained unchanged and repeat CT reduced by approximately 18%. We found that during a single tertiary hospitalisation there was an increased probability of receiving a CT scan, and this was associated with a reduced LOS but an increased readmission rate, and no change in mortality. In contrast, the probability of receiving multiple CTs was unchanged and repeat CTs decreased compared to 2003.

Although many studies have raised concerns about CT use and its clinical role, related published literature regarding multiple and repeat CT, especially the prevalence of repeat CT, is relatively sparse. Our observed rate of repeat CT across major anatomical areas during hospitalisation was 10% with a median LOS of 14 days. The highest rate was in head CT (13.4%), spine CT (9.2%), abdomen/pelvis CT (8.9%) and chest CT (6.0%). In the USA, Lee et al[16] found that the repeated CT rate in the abdomen within 1 month of an initial CT conducted during an ED presentation was 10% which was slightly higher than our finding. Another study in a US tertiary hospital indicated that abdomen repeat imaging was performed in 43.2% of patients within 90 days of an index scan.[32] Literature suggests that only a third or less of repeat CT in patients with abdominal pain yielded new or worse findings.[16 33] Similarly in most patients with mild traumatic brain injury, routine repeated head CT has no clinical benefit.[17 34] Although the rate of repeat CT in our study was lower compared with US literature, the window of measurement was much shorter (14 days median LOS) and limited to a single hospitalisation.

However, our study added to the literature information on how changes in use of repeat CT impacts on hospital LOS, 30-day readmission and mortality. We used these outcomes as indicators of impact on quality of care associated with practice change.[24] The practice of CT both associated with reduced LOS and increased readmission compared with the baseline are likely to be policy-driven, whereas multiple and repeat CTs were associated with a significant increase in mortality after 2010 onwards, indicating difference in severity between the groups. Existing evidence shows a positive association between mortality and a higher-level severity,[35–37] therefore we used mortality to distinguish more severe cases. We found that the change in use of repeat and multiple

CT was associated with an increase in mortality rate in recent years, while no change in mortality was observed for CT scans overall. These findings suggest that repeat CT became more selectively used for higher levels of clinical severity. Taken that the targeted use of repeat CTs was already advocated in earlier literature,[17–19] our findings may be the result of improvements in practice.

The reduction in the rate of repeat CT during tertiary hospitalisation is likely multi-factorial. Specifically, reductions in CT use for monitoring patients' progress during hospitalisation could be driven by (i) a greater awareness and concern about the radiation dose involved[14 38] or (ii) an increased understanding about the limited value of CT in some clinical settings.[17] While the former is not supported by Australian evidence indicating generally poor knowledge of patient radiation dose associated with diagnostic imaging demonstrated by doctors[39 40] and a need for additional education,[40] the latter is more likely according to our findings. Specifically, we found that the change in multiple and repeat CT was associated with a higher rate of mortality in recent years compared with the baseline year, suggesting more multiple and repeated CT were administered to higher risk groups. Furthermore, this result may indicate a growing understanding of limited clinical contribution from repeat CT within a hospitalisation for those outside of the severe level.[17–19]

Another explanation for the reduction in repeat CT might be a shift of repeated CT to the out-of-hospital setting. This argument aligns with an association of the LOS reduction and any CT in the present study, where a consistent shorter LOS across all groups (any, multi and repeat) supports a change on a system/strategic level. In Australia, there are divided responsibilities for funding that involve all levels of government including federal, state and territory, and local as well as private and non-government sectors.[41] Hospital 'cost-shifting' between sectors (from the internal hospital budget) (state governments) to the Medicare budget (federal government) has been discussed in the literature.[42] This explanation aligns with our finding that people living in remote/rural areas (with less access to out-of-hospital CT) had significantly higher rates of repeat CT compared with their major city (greater access to services) counterparts after adjusting for all observed factors. CT is less available in rural/remote areas,[43] limiting ability to shift diagnostic imaging to outside hospital settings for these patients. In addition, because of limited access to diagnostic imaging in these areas, repeat CT before discharge may help to increase physicians' certainty about patients' clinical status. However, this intolerance of uncertainty and risk aversion may also lead to over testing, especially if the consequences of missing a diagnosis are severe.[44] This raises another issue about inequality of access to high quality of care for rural and remote populations. As our study was limited to tertiary hospitals, further research with complete capture of CT use across healthcare settings would provide a more comprehensive evaluation to confirm whether there is an actual reduction in the use of repeat CT or cost-shifting via substitution of out-of-hospital imaging.

Finally, the findings revealed that readmissions were increased across all CT groups compared with 2003. The pattern of consistent increase of readmissions and decrease in LOS across any, multiple and repeat CT also implies system changes, which could potentially be explained through changes in the Australian health system change, for example, the National Health Reform and Activity Based Funding Model (ABFM).[45] Financial reasons based on clinical activities within a hospitalisation could be linked to an earlier patient discharge (shorter LOS) to distribute activities across different hospitalisations for the same patient. In a systematic review and meta-analysis, Palmer et al[46] found that ABFM can cause an increase in readmission and a decrease in LOS, both of which were found in the present study.

In contrast, the observed increase in the rate of any CT could be explained by an increase in the use of CT for the initial diagnosis, especially in emergency admissions. This was supported by our finding that the use of CT in emergency admissions was five times higher than in elective admissions but only minor differences (16%) in repeat CT was observed between these admission types. This could be either due to changes in practice (ie, propensity to use CT) or changes in the clinical profile of the patients being hospitalised. Given that we adjusted for important clinical factors and patients' characteristics, the observed increase in rate of CT is unlikely to be due to changes in patient profile. The changes in practice driving the growth of any CT are supported by our finding of expansion in the use of CT in terms of a broader range of clinical conditions in 2015 compared with 2003, which also aligns with evidence that changes in practice instigated CT use to grow in Australia,[47] and advancements in technology, CT accuracy and skill level of the tertiary hospital staff could also promote its wider use.[48]

Our study has several limitations, which warrant further investigation. It was limited to CT use in tertiary hospitals and therefore, the generalisability of our finding to other settings is unclear. Tertiary hospitals often care for patients with higher acuity who may require more frequent monitoring of their disease progress, thus, the prevalence of repeat CT may be higher compared with other settings. In addition, this study used administrative data collected largely for re-imbursement and casemix/benchmarking purposes. Therefore, we could not account for reasons for requesting a CT scan over and above the principal diagnosis, nor could we evaluate whether a repeat CT improved clinical decision making or health outcomes. Given that our data did not contain other imaging modalities such as MRI, it was not possible to examine of the use of other modalities as a substitute of CT. Interpretations of our findings are limited and should be treated with caution, since we were not able to determine if CT was replaced/substituted by other imaging modalities and whether the use of CT was a function of availability of the alternative modalities. Our study was also limited to adults

aged 18+ years and therefore is not generalisable to CT scanning in children. Finally, using linked administrative data, we could not capture all factors which may confound the findings over the 13 years study period. However, impact of this limitation can be mitigated by using post-estimation predictive margins with contrasts method. The method took the difference between those with and without a particular CT scan status in comparison with the difference observed in the reference year, therefore, the without CT scan status could act as the control group to minimise the impact of the unobserved confounders. A major strength of our study is the comprehensiveness of the capture of the cohort. All admissions to all tertiary hospitals in WA were included which removes bias associated with sampling or reliance on self-reported data. The availability of a wide-range of sociodemographic and clinical characteristics (including our ability to capture comorbidity) in the data allowed evaluation of CT use considering a wide range of covariates.

CONCLUSION

About one in ten admissions with CT scanning had a repeat CT. While CT during tertiary hospitalisations increased by nearly 50%, the rate of repeat CT decreased, and multiple CT remained unchanged. The repeat CT reduction is in line with international efforts to reduce unnecessary testing, an increased awareness of radiation dose concerns and more selective strategy of use based on severity. The latter is more likely to be the driver of the change, since the reduction was only observed in repeat CT in head and chest while repeat CT in other areas remained unchanged. We found patterns of change in CT utilisation are likely to be activity-based funding policy-driven, though in our study we could not rule out cost shifting as the explanation for the observed reduction in repeat scanning during an observed hospitalisation. In addition, further research with complete linkage across healthcare settings to fully capture the CT use is warranted to provide a comprehensive evaluation in the use of repeat CT and changes over time. Data covering all healthcare settings would build on the current work by confirming, for example, whether changes observed over time reflect cost shifting as hypothesised, or whether differences in trends in rural populations reflect differing service availability, highlighting areas where policy and service changes could lead to more optimal use of CT.

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Author note The study reporting follows the Reporting of studies Conducted using Observational Routinely-collected health Data (RECORD) guidelines.

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