Manuscript title:

Radiation dosimetry assessment of routine CT scanning protocols used in Western Australia

Short Title: Radiation dosimetry of CT protocols in Western Australia

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Abstract

Technical data on local CT practice in Western Australia were collected for five major CT providers using a self-completed questionnaire. The CTDIvol DLP and effective dose for each protocol were obtained and providers were ranked according to radiation burden for each clinical scenario. The mean, median, 75th percentile and standard deviation were calculated for both effective dose and DLP for each scenario and these values compared with published data. CT utilisation data were used to estimate the attributable radiation dose to the WA population and the potential change in population annual effective dose according to protocol used was estimated. We found wide variations in technique and radiation dose exist across providers for similar examinations producing a higher radiation burden than reported internationally. As expected the CT protocol used dramatically affects the radiation dose received and this has a significant effect on annual population doses. The study highlights the need for recognition and understanding of both the degree of variation in radiation dose across providers and the relatively high radiation burden afforded by protocols in use in Western Australia so necessary dialogue can be launched for practitioner consensus of appropriate diagnostic reference levels in CT scanning.

1. Introduction

One of the most potent factors driving innovations in medicine has been technological advances in diagnostic imaging [1]. Despite the benefits that these innovations have brought, concerns have been expressed about the escalating cost of unrestrained use of medical imaging. Introduction of helical (spiral) Computed Tomography (CT) scanning resulted in large increases in examinations performed and average 'scanned patient volume' per examination[2]. In the United States it was estimated that the number of CT examinations performed over the last decade increased by between two-fold and seven-fold[2, 3].

During its infancy while CT was recognised as a relatively high radiation dose procedure there was appreciable clinical justification for using it. Initially no other modality could compete with CT on the diagnostic accuracy of brain scans; and when CT of the rest of the body first began, its use was largely limited to cancer patients where radiation dose presented lesser risks[4]. However, the circumstances of CT use are now very different[5]. Today CT is used extensively in benign disease and young patients, for whom radiation protection considerations hold greater weight[4]. Some countries have attempted to reduce the population radiation dose from medical imaging procedures through guidelines, advising on clinical indications for utilisation and / or reference levels for the radiation dose received from each type of examination[6,7]. To date while Australia has developed some clinical guidelines it has not implemented diagnostic reference levels despite the potential for dose reductions of up to 30%[8].

The only study, apart from that performed by UNSCEAR (which included limited Australian data)[9], to assess CT utilisation and dosimetry in Australia was a survey in 1996 of all CT facilities conducted by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), formerly the Australian Radiation Laboratory[10]. This study found Australia had the second highest provision of CT scanners per capita with triple the number of CT scanners per capita compared with the UK or New Zealand and a slightly higher provision than the US. Australia recorded just over 60 examinations per 1,000 people, a level of utilisation three times that of the UK and New Zealand rates and similar to the US. Of most concern was the mean dose per examination from CT in Australia was between 50% and 69% higher than observed in any other country (6.6mSv compared with 4.4mSv in Japan and New Zealand and 3.9mSv in the UK). The authors attributed the larger dose per examination to a higher average number of scans (slices) per examination in Australia. The high dose per examination combined with the large number of examinations performed equated to a mean effective dose per capita in Australia five times greater than in New Zealand and seven times the UK[10]. In 2011 an OECD report[11] again documented that Australia had the second highest provision of CT scanners per capita; however, utilisation was below the OECD average at 94 per 1,000 population (OECD average 132 per 1,000) ranking well below the US (228 per 1,000) but still above the UK (73 per 1,000). It should be noted that these figures exclude examinations undertaken on in-patients in Australian public hospitals and therefore are not comprehensive.

Practice guidelines are limited and not universally agreed upon in Australia, not only in regard to the indication of use for specific diagnostic radiology procedures, but also on how to conduct a particular procedure to provide sufficient diagnostic quality with the least radiation burden. Currently, for any single clinical indication, a multitude of different protocols are used without consensus. An important reason for this situation is a lack of recent relevant local evidence as the substrate from which consensus can be achieved.

The purpose of this study was to (i) determine the range of radiation dose attributable to differences in CT protocols reported by a sample of providers in Western Australia (WA) for a range of CT scans undertaken commonly on adults; ii) determine how the radiation burden of these protocols compares with similar published surveys and national diagnostic reference levels; and (iii) determine the effect on the annual population cumulative effective radiation dose between 2005 and 2010 produced by differences in reported CT scanning protocols used in WA.

2. Methods

2.1. Data collection

Technical data on local CT practice in Western Australia were collected for five major CT providers by means of a questionnaire that was self-completed and followed up by interviewing the respondents to clarify and validate the information provided. The questionnaire was that used by the national survey of doses from CT in the UK in 2003[12] and was amended only in terms of the clinical scenarios examined (addition of chest for pulmonary embolus) and was limited to examinations performed on adults. The questionnaire sought scanning data in relation to standard protocols for seven common CT examinations shown below performed on standard (average-sized) patients to represent "usual practice".

1. Routine Head for trauma or stroke
2. Chest for lung cancer (known or suspected metastases)
3. Chest for pulmonary embolism
4. High resolution Chest for diffuse lung disease
5. Abdomen for liver metastases (upper abdomen for abscess)
6. Abdomen / Pelvis (unspecified clinical indication)
7. Chest/Abdomen /Pelvis for lymphoma staging

The seven clinical scenarios were chosen after liaison with clinicians to provide an overview of protocols (i) used frequently in the clinical setting for adult patients, (ii) provide a range of scenarios covering a range of anatomic locations involving radiosensitive organs and (iii) facilitate comparison with published protocols and diagnostic reference levels. Specific clinical indications were included

for all types of CT examination since these could influence the scanning technique used. This approach was intended to make the data from different CT centres more comparable.

Protocol information (excluding the scout view) consisting of separate scanning sequences where appropriate, each representing a single helical exposure or a series of similar axial exposures using identical scan conditions was collected for each provider. Only those sequences performed routinely for most patients were included in the data analysis. The data collected included various technical parameters such as kilovoltage (kV), milliamperage (mA), tube rotation times, collimation widths, pitch, scanning method, typical anatomical reference start-stop positions of the scan. Respondents were asked to report the average volume weighted CT dose index (CTDIvol) and dose–length product (DLP) based on up to ten standard (average-sized) adult patients undergoing each protocol.

The providers surveyed included one tertiary metropolitan public hospital, two private metropolitan hospitals, one secondary public hospital whose radiology services were provided onsite by a private radiology group, and one rural hospital whose radiology services were provided onsite by a private radiology group.

2.2. Radiation dosimetry

Dosimetry involved reporting of values of CTDIvol, DLP and calculation of effective dose for each sequence accomplished on the basis of the scan settings provided in the questionnaires and the representative scanner-specific dosimetrics published by ImPACT as part of its CT patient dosimetry calculator[13] based on International Commission on Radiological Protection (ICRP) 103[14] tissue weighting factors. Either average tube current (with automatic modulation) or current-time products (without automatic modulation) were used as reported by each site. DLPs for each sequence were reported in the questionnaire. Effective doses were derived by obtaining scan length by dividing DLP by CTDIvol, then using this and other reported parameters in the ImPACT dose calculator. It was found that ImPACT frequently gave somewhat different values of CTDIvol to those reported so the effective dose given by ImPACT was corrected by the ratio of reported CTDIvol and that given by ImPACT. Protocol (cumulative) values of DLP and effective dose were also calculated on the basis of summation over all routine sequences reported for each standard protocol. Incomplete or inconsistent data provided in questionnaires were discussed at a follow up interview with providers.

Providers were ranked according to the protocol effective dose for each clinical scenario and the lowest, median and highest dose values for each protocol were identified together with the maximum / minimum ratio for each scenario. In addition the mean, median, 75th percentile and standard deviation was calculated for both effective dose and DLP for each scenario. These values were compared with published data for both DLP and effective dose.

2.3. CT Scans and WA Adult Population

The numbers of CT scans performed in Western Australia on adults by gender and age were identified using (i) Hospital Morbidity data (HMDS) for hospitalised patients (2005-2010) and (ii) Medicare Benefits Schedule data (MBS) for out-of-hospital procedures (1999-2010). Published MBS data were also used to determine the total number of medical imaging and CT scanning investigations performed in each Australian State. When the CT examination was not used exclusively for the clinical scenario detailed in the survey the allocation of number of CT scans attributed to that scenario was obtained using a combination of the HMDS code (providing the examination performed) and diagnosis code. Since diagnosis codes were only available in the in-patient setting the relative frequencies observed for each examination / diagnosis combination were then used to estimate the number of CT scans performed for each clinical scenario in the out-of-hospital setting.

2.4. Cumulative Population Dose

The lowest, median and highest doses for each protocol were multiplied by the number of CT scans estimated to have been performed in each clinical scenario in the study in Western Australia and used to calculate the best, median and worst case cumulative annual population effective dose from 2005 to 2010. The annual number of CT scans and effective dose attributed to each clinical scenario was then ranked in order of contribution to the annual total (1 being the greatest contributor and 7 being the lowest contributor).

3. Results

Table 1 shows a summary of the sequence related scanning parameters and dosimetry for the seven CT scanning clinical procedures evaluated. The scanning parameters and radiation dosimetry varied greatly across providers for the same clinical scenario.

3.1. Examination technique CT scanning procedures: number of sequences

Only two clinical settings (chest for lung cancer and abdomen/pelvis for abscess) provided concordance between all providers routinely undertaking the same number of sequences (one). The greatest discordance was observed in abdomen CT for liver metastases where three providers reported one sequence, one provider reported two sequences and one provider (D) reported four sequences routinely performed.

Table 1 Scanning parameters and radiation dose for seven commonly performed CT scanning clinical procedures across the five clinical sites in Western Australia

Scan type / clinical scenario	Provider code	Sector	Seq[a]	Detectors	Scan Type	kV	mA	Pitch	CTDIvol[b]	DLP[c]	Effective Dose[d]
Routine Head for Trauma or Stroke	A	Public	1	64 Slice	Helical	120	338	0.423	86.70	1256	3.30
	B	Private	1	64 Slice	Helical	140	120	0.328	70.40	1021	2.40
	C	Private	1	64 Slice	Helical	135	220	0.328	129.20	1873	4.30
	D	Private	1	Dual Slice	Axial	135	150	1.000	99.40	1441	3.40
	E	Private	1	16 Slice	Axial	140	140	1.000	69.60	1009	2.40
			2	16 Slice	Axial	120	110	1.000	37.60	545	1.30
			3	16 Slice	Axial	120	80	1.000	27.30	397	0.93
Chest for Lung Cancer	A	Public	1	64 Slice	Helical	120	402	1.078	26.60	1131	20.0
	B	Private	1	64 Slice	Helical	120	300	0.828	17.20	474	8.5
	C	Private	1	64 Slice	Helical	120	300	0.828	17.20	732	13.0
	D	Private	1	Dual Slice	Helical	120	350	1.500	34.00	934	16.0
	E	Private	1	16 Slice	Helical	120	440	0.750	28.50	1212	22.0
Chest for Pulmonary Emboli	A	Public	1	64 Slice	Helical	120	498	0.673	35.20	968	17.0
	B	Private	1	64 Slice	Helical	120	300	0.828	13.80	379	6.8
	C	Private	1	64 Slice	Helical	120	300	0.828	17.20	474	8.5
	D	Private	1	Dual Slice	Axial	120	100	1.000	29.90	823	14.0
			2	Dual Slice	Axial	120	350	1.000	27.90	768	13.0
	E	Private	1	16 Slice	Helical	120	440	1.500	17.80	490	8.9
Chest for Diffuse Lung Disease	A	Public	1	64 Slice	Helical	140	369	0.516	38.10	1048	19.0
	B	Private	1	64 Slice	Helical	120	235	0.828	13.50	371	6.6
			2	64 Slice	Helical	120	80	1.484	2.60	71	1.3
	C	Private	1	64 Slice	Helical	120	300	0.828	17.20	474	8.5
			2	64 Slice	Axial	120	292	1.000	16.80	461	8.2
	D	Private	1	Dual Slice	Axial	140	160	1.000	23.60	649	11.0
	E	Private	1	16 Slice	Axial	120	440	1.000	26.70	735	13.0
Abdomen for Liver Metastases	A	Public	1	64 Slice	Helical	120	309	0.891	24.70	1138	19.5
	B	Private	1	64 Slice	Helical	120	300	0.828	17.20	793	14.0
			2	64 Slice	Helical	120	650	0.828	37.30	1717	30.0
	C	Private	1	64 Slice	Helical	120	302	0.828	17.30	798	14.0
	D	Private	1	Dual Slice	Helical	120	250	1.500	17.90	429	7.0
			2	Dual Slice	Helical	120	350	1.500	25.00	600	9.7
			3	Dual Slice	Helical	120	350	1.500	25.00	1150	19.5
			4	Dual Slice	Helical	120	350	1.500	25.00	600	9.7
	E	Private	1	16 Slice	Helical	120	435	0.750	28.20	1297	23.0
Abdomen and Pelvis for abscess	A	Public	1	64 Slice	Helical	120	333	0.891	26.70	1226	21.5
	B	Private	1	64 Slice	Helical	120	300	0.828	17.20	793	14.0
	C	Private	1	64 Slice	Helical	120	302	0.828	17.30	798	14.0
	D	Private	1	Dual Slice	Helical	120	350	1.500	25.00	1150	19.5
	E	Private	1	16 Slice	Helical	120	435	0.750	28.20	1297	23.0
Chest, Abdomen and Pelvis for Lymphoma Staging	A	Public	1	64 Slice	Helical	120	431	1.078	24.80	1720	29.50
	B	Private	1	64 Slice	Helical	120	600	0.828	34.50	2395	41.50
			2	64 Slice	Helical	120	660	0.828	37.90	2635	45.50
	C	Private	1	64 Slice	Helical	120	300	0.828	17.20	474	8.50
			2	64 Slice	Helical	120	300	0.828	17.20	793	14.00
	D	Private	1	Dual Slice	Helical	120	300	1.500	21.40	589	10.00
			2	Dual Slice	Helical	120	300	1.500	21.40	986	17.00
	E	Private	1	16 Slice	Helical	120	430	0.750	27.90	1936	34.00

[a]Seq = sequence number (numbers over 1 indicate multiple scanning acquisitions within the same protocol).
[b]CTDIvol = Volumetric CT Dose Index, measured in mGy.
[c]DLP = Dose Length Product, measured in mGy.cm.
[d]Effective Dose = mSv calculated using ImPACT for each sequence.

3.2. Examination technique CT scanning procedures: kV, mA and pitch

Two scenarios presented some variation between providers for kV. With respect to routine Head CT providers reported a range of kV settings ranging from 120 (three providers to 140 (two providers). Notably provider E reported using 140kV for the first sequence and 120kV for the remaining two sequences. Similarly for Chest for diffuse lung disease; while the most common setting was 120kV, two providers reported using 140kV.

With respect to mA it was noted there was not always correlation between high kV and low mA which would be expected. While pitch for all sequences is reported in the table, only pitch values for helical scans were evaluated for concordance. Pitch was quite variable in all clinical scenarios except Head CT which reported the smallest differences in pitch ranging from 0.33 to 0.42.

3.3. Radiation dosimetry: protocols

The cumulative radiation dosimetry in terms of DLP and effective dose calculated for each protocol is shown in table 2. This table also shows their ranking with respect to radiation burden, absolute and relative differences compared with the protocol generating the median radiation dose across providers in each scenario and the maximum/minimum ratio. The public provider ranked either highest or second highest in radiation burden in four of the seven clinical scenarios under examination and did not rank as lowest in any clinical scenario. When the ranking was averaged across all procedures the several private providers had a lower average rank than the public provider indicating that generally the public provider used protocols which gave higher radiation dose than the private providers.

When evaluating differences between the maximum and minimum doses reported the largest ratios were observed in chest CT for pulmonary embolism and CT Chest/Abdo/Pelvis examinations where the max/min ratios were 4.0 and 3.9 respectively. This equated to an absolute difference of 18mSv for chest CT for pulmonary embolism and 58mSv for CT Chest/Abdo/Pelvis. The smallest maximum to minimum ratio was observed for CT of the abdomen/pelvis (1.6) and CT head (1.9) equating to absolute differences of 3.5mSv and 1.2mSv respectively.

Table 2 Variation in radiation dose for seven commonly performed CT scanning protocols across five clinical sites in Western Australia

Scan type / clinical scenario	Provider code	Sector	Protocol[a] DLP (mGy cm)	Protocol[b] Effective Dose (mSv)	Ranking[c]	Difference from Median protocol		Max/min ratio[d]
						Effective dose (mSv)	Relative difference (Percent)	
Head for Trauma or Stroke	A	Public	1256	3.30	2	-0.1	-2.9	1.9
	B	Private	1021	2.40	1	-1.0	-29.4	
	C	Private	1873	4.30	4	+0.9	+26.5	
	D	***Private***	***1441***	***3.40***	***3***	***0.0***	***0.0***	
	E	Private	1951	4.63	5	+1.2	+36.2	
Chest for Lung Cancer	A	Public	1131	20.00	4	+4.0	+25.0	2.6
	B	Private	474	8.50	1	-7.5	-46.9	
	C	Private	732	13.00	2	-3.0	-18.8	
	D	***Private***	***934***	***16.00***	***3***	***0.0***	***0.00***	
	E	Private	1212	22.00	5	+6.0	+37.5	
Chest for Pulmonary Emboli	A	Public	968	17.00	4	+8.1	+91.0	4.0
	B	Private	379	6.80	1	-2.1	-23.6	
	C	Private	474	8.50	2	-0.4	-4.5	
	D	Private	1591	27.00	5	+18.1	+203.4	
	E	***Private***	***490***	***8.90***	***3***	***0.0***	***0.00***	
Chest for Diffuse Lung Disease	A	Public	1048	19.00	5	+6.0	+46.2	2.4
	B	Private	442	7.90	1	-5.1	-39.2	
	C	Private	935	16.70	4	+3.7	+28.5	
	D	Private	649	11.00	2	-2.0	-15.4	
	E	***Private***	***735***	***13.00***	***3***	***0.0***	***0.00***	
Abdomen for Liver Metastases	A	Public	1138	19.50	2	-3.5	-15.2	3.3
	B	Private	2510	44.00	4	+21.0	+91.3	
	C	Private	798	14.00	1	-9.0	-39.1	
	D	Private	2779	45.75	5	+22.8	+98.9	
	E	***Private***	***1297***	***23.00***	***3***	***0.00***	***0.0***	
Abdomen and Pelvis for Abscess	A	Public	1226	21.50	4	+2.00	+10.3	1.6
	B	Private	793	14.00	1	-5.5	-28.2	
	C	Private	798	14.00	1	-5.5	-28.2	
	D	***Private***	***1150***	***19.50***	***3***	***0.0***	***0.0***	
	E	Private	1297	23.00	5	+3.5	+18.0	
Chest, Abdomen and Pelvis for Lymphoma Staging	***A***	***Public***	***1720***	***29.50***	***3***	***0.0***	***0.0***	3.9
	B	Private	5030	87.00	5	+57.5	+194.9	
	C	Private	1267	22.50	1	-7.0	-23.7	
	D	Private	1575	27.00	2	-2.5	-8.5	
	E	Private	1936	34.00	4	+4.5	+15.3	

[a]Protocol DLP = Sum of DLP values in protocol where multiple sequences included.
[b]Protocol Effective Dose = cumulative effective dose over all sequences in protocol (excludes scout view).
[c]Ranked according to total radiation burden (DLP or effective dose) per protocol lowest (1) to highest (5). Protocol affording the median radiation burden = 3 (bold italic).
[d]Max/min ratio based on protocol effective doses in clinical scenario across the five clinical sites.

3.4. Comparison of DLP and effective dose values with published data

Tables 3 and 4 show the mean, median, 75th percentile, standard deviation, minimum and maximum DLP (table 3) and effective dose (table 4) values reported in the current study for the entire protocol for each of the seven clinical scenarios considered. It also shows a range of mean values reported in the literature obtained by similar self-complete surveys and four examples of national diagnostic reference levels (DRL's) expressed in terms of DLP and effective dose. Our results indicate providers in Western Australia use higher dose (mean DLP and effective dose) protocols than those reported in the literature across all scenarios. The values reported for the 75th percentile from our study (ie the standard method used to generate a national DRL) show that if these results were used WA would have DRL's markedly higher than other countries. In the case of Abdominal CT the DRL would be almost three times greater than the upper range of the highest published DRL for that examination (DLP base DRL for Canada).

Table 3 Comparison of DLP values for CT protocols performed in Western Australia for seven common clinical scenarios with published literature and international diagnostic reference levels

Scan type/clinical scenario	This Study						Published data (mean values)[b]				National DRL's[c]			
	Mean	Median	75th percentile	Std. dev.	Min.	Max.	Sudan	Tanzania	Greece	Italy	EU (1999)	UK (2003)	British Colombia (2004)	Canada (2008)
Protocol DLP (mGy cm)[a]														
Head for Trauma or Stroke	1508.4	1441	1912	398.3	1021	1951	758	913	919	725	1050	760-930	1300	930-1300
Chest for Lung Cancer	896.6	934	1171.5	300.6	474	1212	327	783	429	473	650	760-940	600	580-650
Chest for Pulmonary Emboli	780.4	490	1279.5	507.8	379	1591	327	-	-	-	280	-	-	-
Chest for Diffuse Lung Disease	761.8	735	991.5	238.5	442	1048	327	-	-	-	900	-	-	-
Abdomen for Liver Metastases	1704.4	1297	2644.5	882.1	798	2779	437	982	493	517	780	470-460		470-920
Abdomen and Pelvis for Abscess	1052.8	1150	1261.5	240.6	793	1297	264	908	538	538	570	430-580	110	560-110
Chest, Abdomen and Pelvis for Lymphoma	2305.6	1720	3483	1542.3	1267	5030	-	-	-	-		-	-	-

[a]Protocol DLP = DLP value for the protocol (Sum of DLP values in protocol where multiple sequences included).
[b]Published data references: Sudan - Suliman (2011)[15]; Tanzania - Ngaile (2006)[16]; Greece - Papadimitriou (2003)[17], Italy - Origgi (2006)[18]. Dash (-) indicates no value reported.
[c]National DRL's (Diagnostic Reference Levels) references: EU - European Commission 16262 (1999)[19]; UK - Shrimpton (2003)[12]; British columbia - Aldrich (2006)[20]; Canada - Health Canada (2008)[21]. Dash (-) indicates no value reported.

Table 4 Comparison of Effective doses for CT protocols performed in Western Australia for seven common clinical scenarios with published literature and international diagnostic reference levels

	This Study						Published data (mean values)[b]				National DRL's[c]			
Scan type/clinical scenario	Mean	Median	75th percentile	Std. dev.	Min.	Max.	Sudan	Tanzania	Greece	Italy	EU (1999)	UK (2003)	British Colombia (2004)	Canada (2008)
Protocol Effective Dose (mSv)[a]														
Head for Trauma or Stroke	3.61	3.4	4.5	0.9	2.4	4.6	1.6	2.1	2.1	1.7	2.4	1.5	2.8	-
Chest for Lung Cancer	15.9	16	21	5.4	8.5	22.0	4.6	13	7.3	8	8.8	5.5	9	-
Chest for Pulmonary Emboli	13.64	8.9	22	8.5	6.8	27.0	-	-	-	-	-	-	-	-
Chest for Diffuse Lung Disease	13.52	13	17.9	4.4	7.9	19.0	-	-	-	-	-	-	-	-
Abdomen for Liver Metastases	29.25	23	44.9	14.6	14.0	45.8	6.6	15	7.4	7.8	9	5.3	10.2	-
Abdomen and Pelvis for Abscess	18.4	19.5	22.3	4.2	14.0	23.0	4	17	10.3	8.9	10.8	7.1	16.5	-
Chest, Abdomen and Pelvis for Lymphoma	40	29.5	60.5	26.6	22.5	87.0	-	-	-	-	-	-	-	-

[a]Protocol DLP = DLP value for the protocol (Sum of DLP values in protocol where multiple sequences included).
[b]Published data references: Sudan - Suliman (2011)[15]; Tanzania - Ngaile (2006)[16]; Greece - Papadimitriou (2003)[17], Italy - Origgi (2006)[18]. Dash (-) indicates no value reported.
[c]National DRL's (Diagnostic Reference Levels) references: EU - European Commission 16262 (1999)[19]; UK - Shrimpton (2003)[12]; British columbia - Aldrich (2006)[20]; Canada - Health Canada (2008)[21]. Dash (-) indicates no value reported

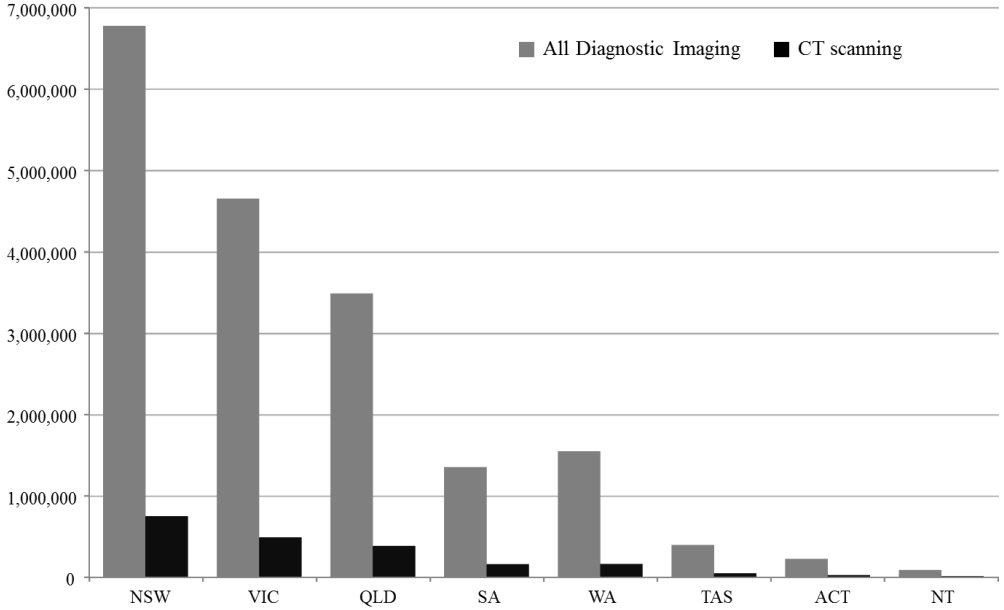
3.5. Demographic profile of CT scanning in Australia and Western Australia

Figure 1 shows information about the volume of medical imaging and CT examinations conducted in Australia by State, across time and gender, funded under the Medicare Benefit Schedule (MBS) which is largely serviced by privately owned providers in the out-of-hospital setting. In WA, like other Australian States, CT scanning accounts for approximately 10% of medical imaging examinations (panel A). While this proportion remained relatively stable (panel C) the total number of CT examinations has increased by approximately 52% over the past 12 years (panel B) compared with a 70% increase in medical imaging procedures as a whole. In this setting CT scanning is more often conducted on males than females (panel C).

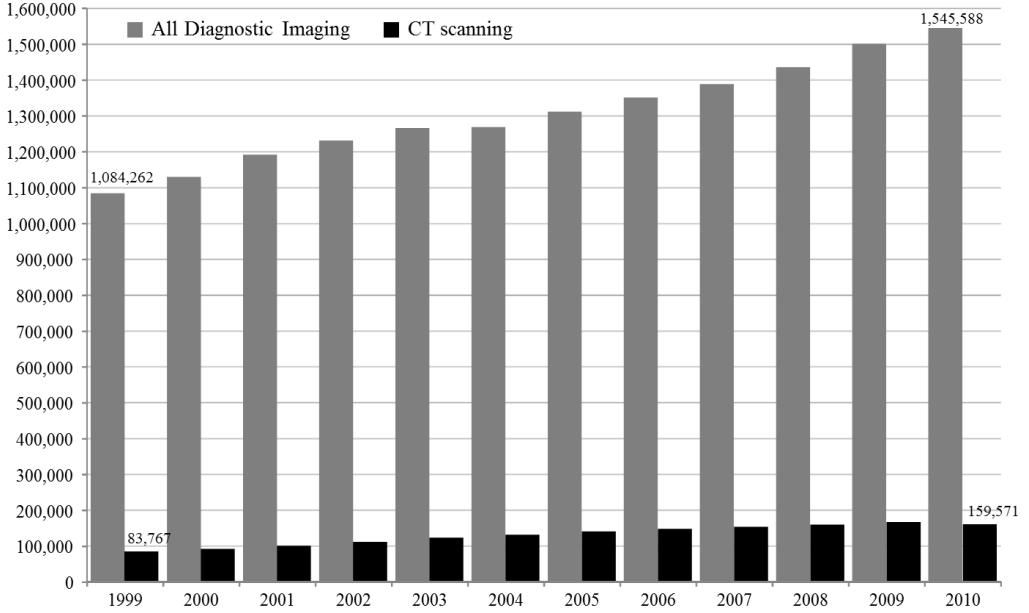
The trends are similar for hospitalised patients although, as shown in figure 2, the types of examinations conducted are different. In hospitalised patients (incorporating both private & public hospitals) the CT scanning scenarios included in our study accounted for the majority of CT performed (figure 2, panel A). Comparatively, in the MBS setting (largely out-of-hospital) CT scanning scenarios included in our study only accounted for approximately 50% of the CT scans undertaken. This demonstrates the significant difference in the clinical patient population of the two settings. The age profile of patients undergoing CT examinations performed under the MBS (panel B) and in-hospital (panel C) is also slightly different, with the MBS setting having a slightly younger profile.

Figure 1 Number and proportion of medical imaging and CT examinations conducted in Australia and Western Australia funded under the Medicare Benefits Scheme

A: Number of procedures in 2010 by Australian State/Territory



B: Number of procedures in Western Australia annually from 1999 to 2010



C: Proportion of medical imaging accounted for by CT scanning according to gender 1999 to 2010

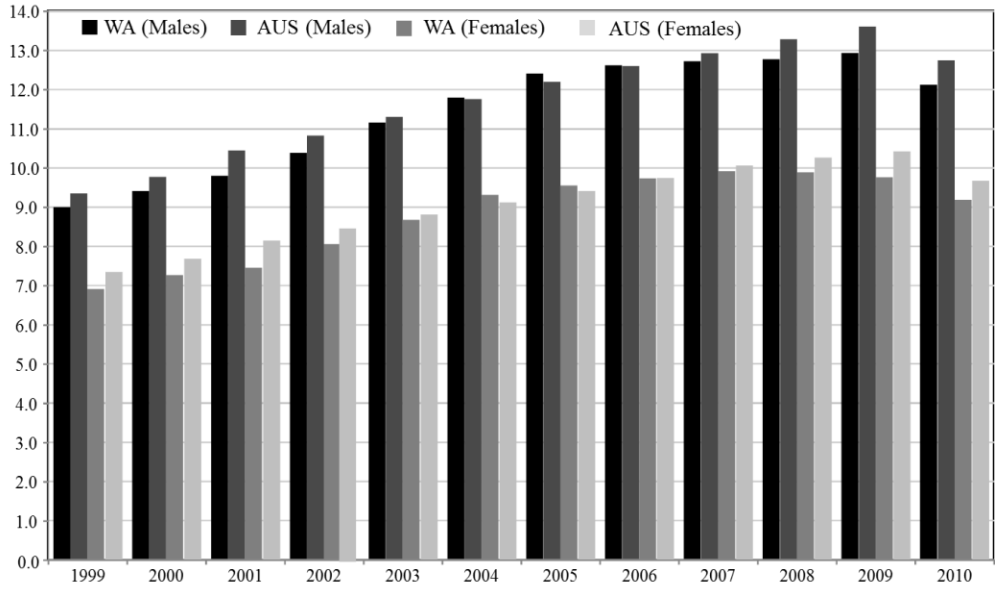
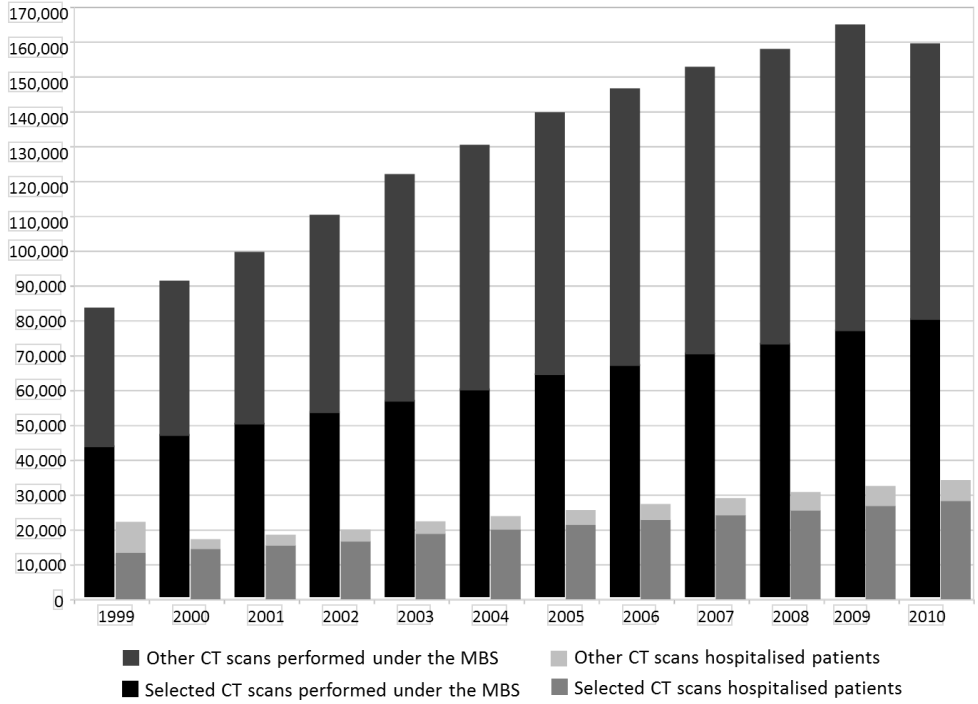
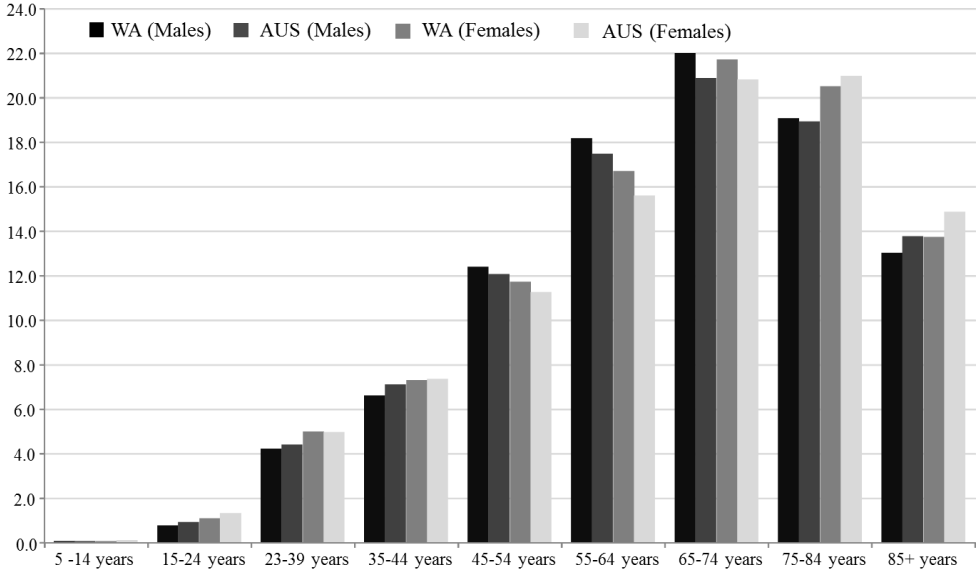


Figure 2 Number (A) and proportion (B+C) of CT scans (all and selected in the study) performed (under the MBS and in hospitalised patients) in Western Australia

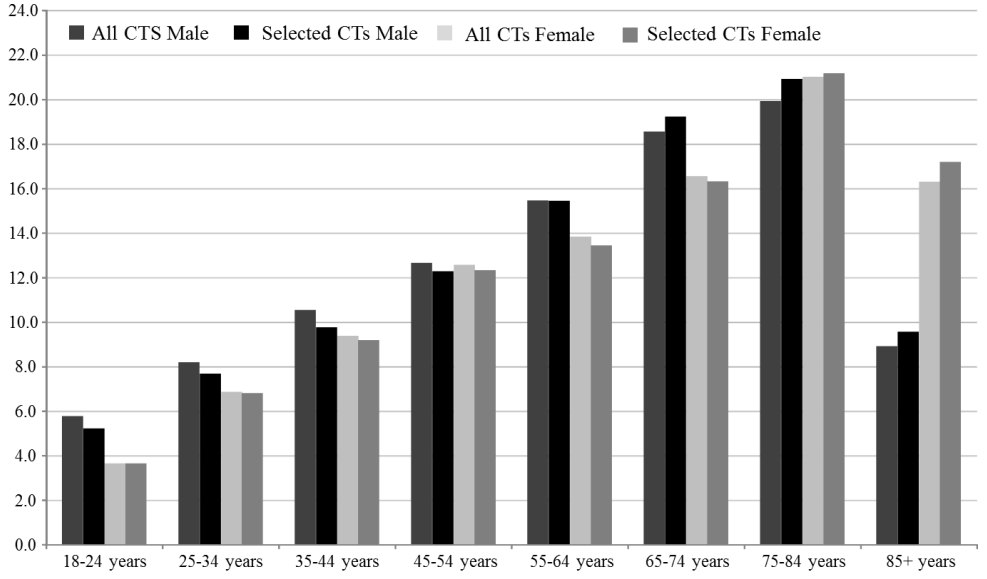
A: Number of CT scans performed (under the MBS and in hospitalised patients) in WA 1999-2010



B: Proportion of CT examinations performed under the MBS in 2010 by age & gender



C: Proportion of CT examinations performed in hospitalised patients in 2010 by age & gender



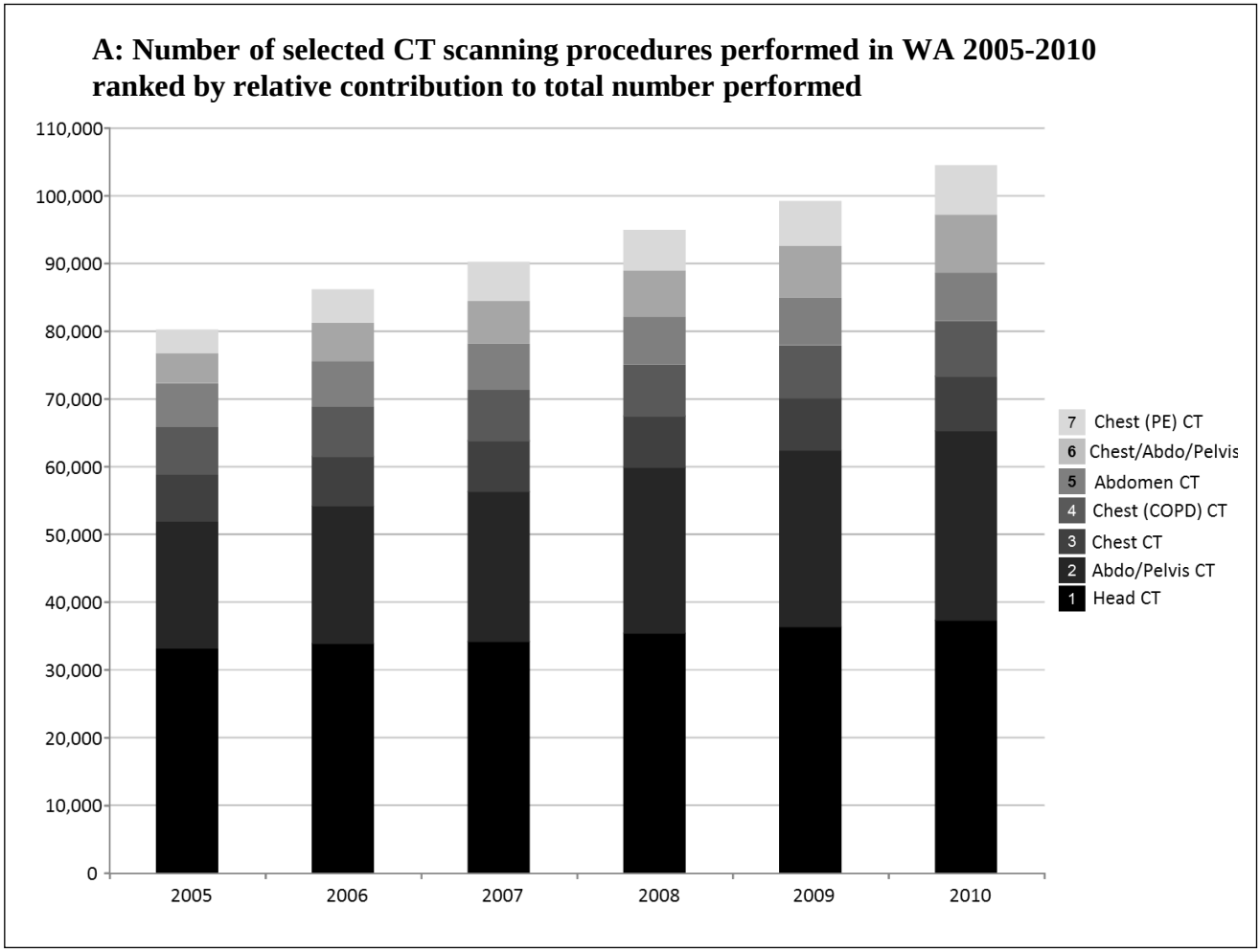
3.6. Ranking of clinical scenario by annual frequency and population effective dose

Figure 3 shows the clinical scenarios included in the study ranked by contribution to the total number of CT scans performed (panel A) and the population annual effective dose using the median dose protocol (panel B) in WA 2005 to 2010. Figure 3, panel B indicates that the total population annual effective dose received by the WA population rose from 1,006,581mSv in 2005 to 1,424,475mSv in 2010, an increase of 42%. The increase shown is solely attributable to the increase in volume of CT scanning performed since no adjustment to the protocol doses was made across years. The figure shows that while Head CT is the most frequently performed (panel A) it does not account for the highest burden in effective dose, only contributing 127,040mSv to the total in 2010. Abdo/Pelvis CT accounts for the highest radiation burden (552,726mSv in 2010), being a relatively high dose protocol and having the second rank with regards to frequency. Of note Chest/Abdo/Pelvis CT while being relatively uncommon (rank 6 in frequency) is ranked second in contribution to the total population annual effective dose contributing 291,551mSv in 2010 due to its high dose.

3.7. Potential change in population annual effective dose according to protocol used

Figure 4 indicates the increase and decrease in the annual effective population dose achievable by consistently using the highest or lowest dose protocols observed in our study. Using this method an additional 865,006mSv (60%) would have been added to the annual population effective dose if the highest dose protocol had been utilised across all clinical scenarios in 2010. In contrast, if the lowest dose protocol observed were consistently utilised, a reduction of 460,421mSv (32%) could have been achieved. Figure 4 also indicates the influence the changes in the annual number of CT scans have had on the potential for increased and decreased population effective dose. The potential increase in effective dose by moving to the highest dose protocol has risen by 32% (287,279mSv) since 2005 due to the increase in frequency of CT scanning in these clinical scenarios. Conversely the potential reduction in the population effective dose has risen from 330,120mSv in 2005 to 460,421mSv in 2010, affording an additional 28% (130,301mSv) potential reduction.

Figure 3 CT scanning procedures selected in the study performed in Western Australia 2005-2010 ranked according to (A) contribution to total annual number and (B) annual population effective dose (mSv)



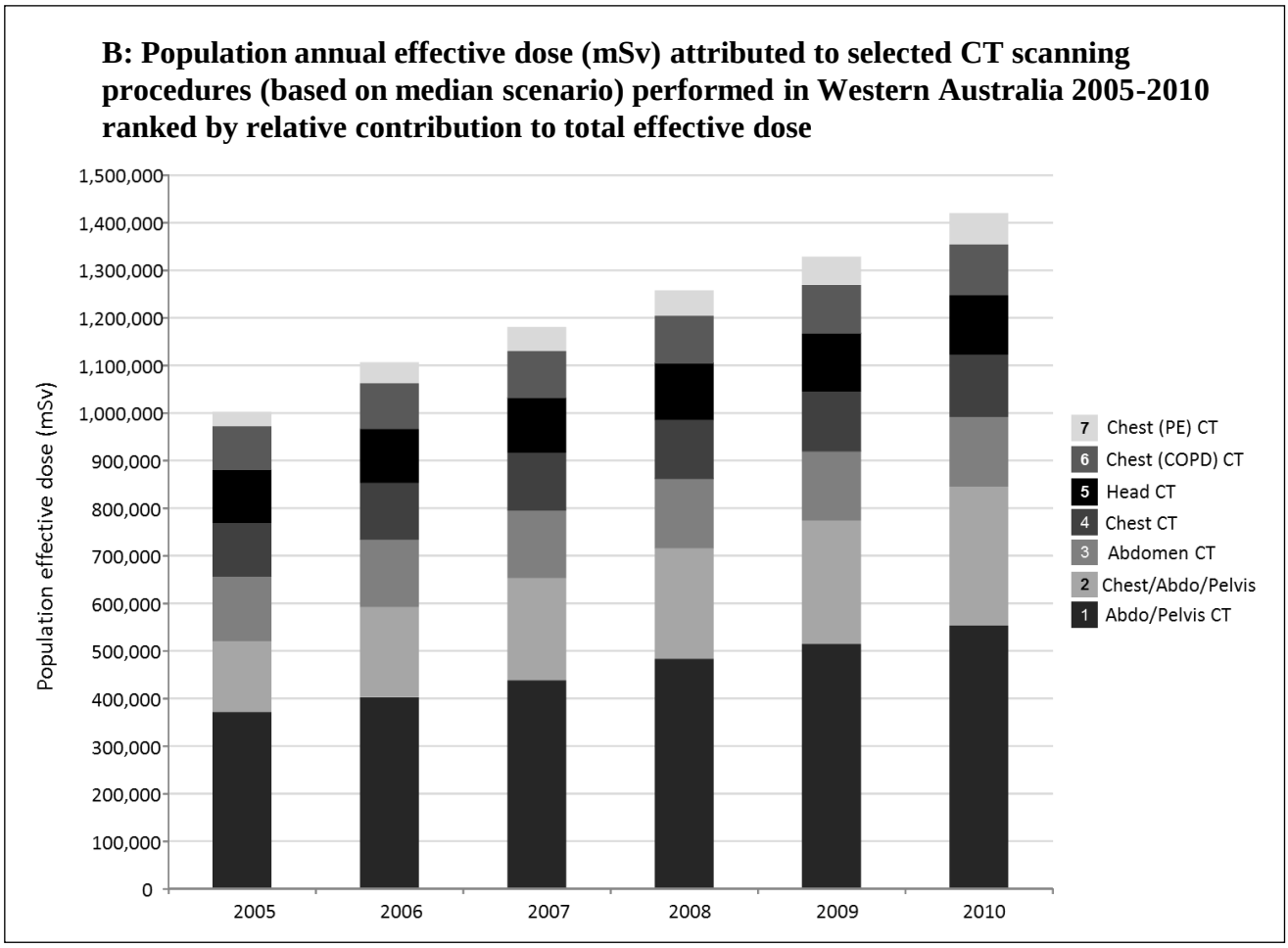
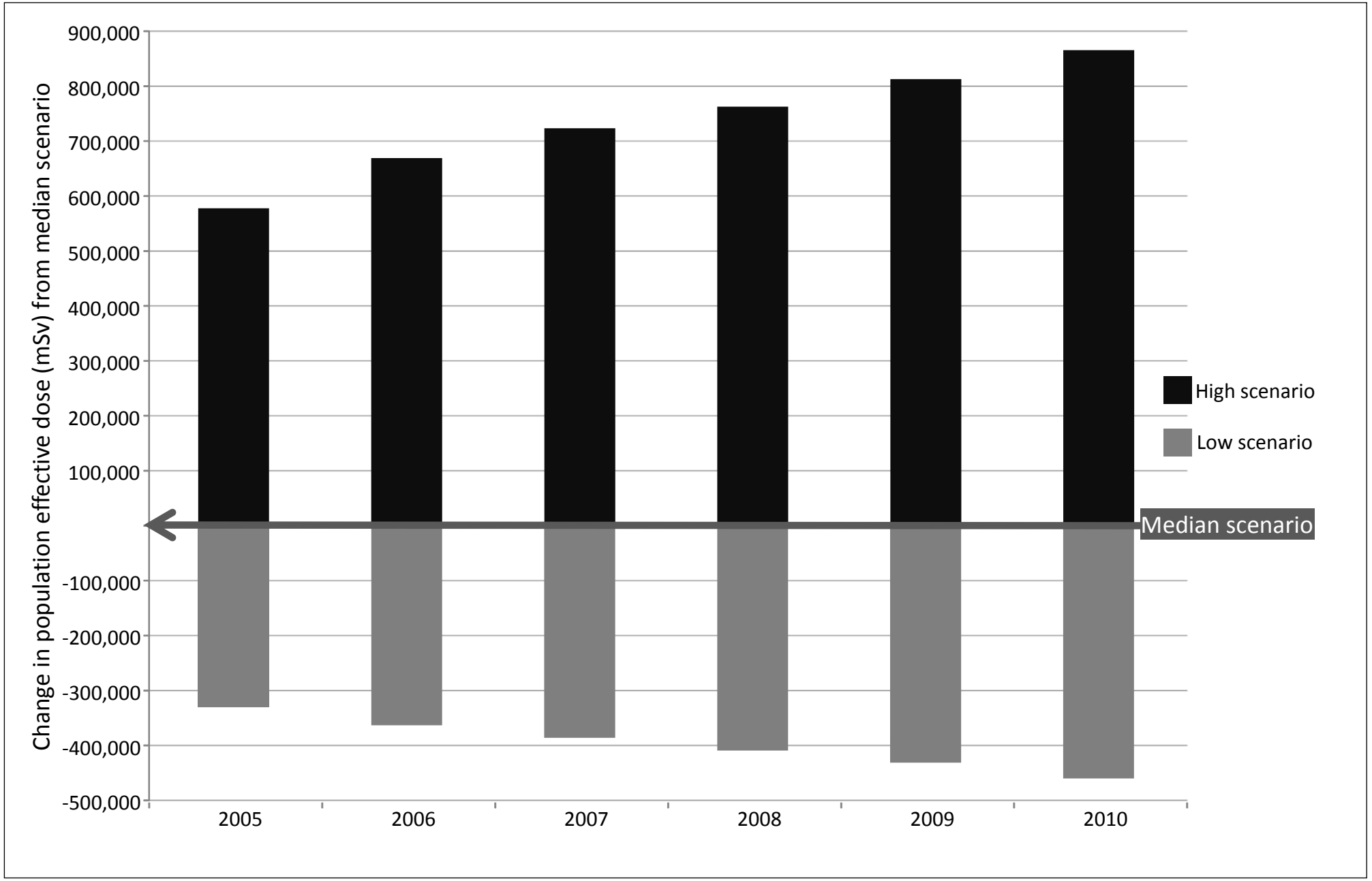


Figure 4 Potential change in Western Australian population annual effective dose (mSv) afforded by moving to low or high dose scenarios



4. Discussion

The current study has provided a snapshot of CT scanning practice in WA using previously validated and robust methods of data collection for dose assessment[22]. The results of this study are based on assessments for standard examinations which provide the basic framework for typical practice for any particular provider. The methods employed in data collection were previously validated by a study in the UK which showed doses to individual patients were similar on average to those for the corresponding standard protocol, and where there was significant variation it was largely due to additional sequences for further phases of contrast.[22] Thus our study is likely to under rather than overestimate the upper limit of patient radiation dose. One limitation of our study is that it included only a limited sample of CT providers in WA and therefore may not be representative of all providers.

This study demonstrates wide variations in technique and radiation dose across providers for similar examinations and the protocols reported by WA providers produce a higher radiation burden than reported in the international literature. Detailed information regarding patient numbers according to clinical scenario has allowed for the annual population cumulative effective doses to be calculated as well as the trends in the number of CT scans relative to the type of examination. As expected the CT protocol used can dramatically affect the radiation dose received during a single CT examination and this has a significant effect on annual population doses which may in turn lead to significant changes in the likelihood of adverse biologic changes due to exposure to medical radiation.

Medical applications of ionising radiation are accepted as essential tools for protecting and improving health[23]. However, they also represent a significant source of radiation exposure to the population. The average effective background dose received by the Australian population is approximately 1.5 mSv per year[24]. Medical radiation, primarily from diagnostic imaging, has been estimated in 1999 to add an additional 50% (0.8 mSv) to the average population exposure[24], with diagnostic imaging comprising 95% of man-made radiation exposure[9,25]. In our study we recorded 1,424,475mSv (based on the median dose protocols reported) for the seven clinical scenarios investigated in a population of 1,761,788 individuals aged 18+years[26] which equates to an average population exposure of 0.81mSv attributable to the WA adult population in 2010 from the clinical CT scenarios included in our study. It should be recognised that while the clinical scenarios included in our study represented the majority (approximately 85%) of the CT examinations performed in hospitalised patients they only account for approximately 50% of the CT examinations undertaken in the out-of-hospital setting. Thus the average population exposure attributable to CT scanning in WA is likely to be far greater than estimated here and hence the dose attributable to medical imaging as a whole much greater than that reported in the literature.

The world mean effective dose per examination and annual collective dose have increased in recent years[25]. However, rather than averaging over the whole population, it is more relevant to compare typical medical radiation doses with the background radiation. The UNSCEAR report[9] showed that in developed countries, CT accounts for a few per cent of procedures but delivers almost one half of the

radiation exposure from medical diagnosis. Hence CT represents the largest man-made source of exposure to ionising radiation with the average dose per examination six times higher than natural background[9]. Our data has a total dose of 1,420,000mSv in 105,000 procedures giving an average dose of 13.5mSv, which is almost 10 times the natural background in Australia.

It is accepted by all international regulatory bodies that there is no threshold for the induction of cancer by ionising radiation and therefore it can be expected that diagnostic imaging procedures will induce some cancers[27]. Co-efficients for lifetime attributable risks of radiation induced cancer for a generalised population are that for every 1Sv of radiation dose received by the average person the risk of death will increase by 5%[28,29]. Note that this is a very crude approximation that allows a potential for reduced risk at low dose by reducing the risk by a Dose and Dose Rate Effectiveness Factor (DDREF) of 50%. Since the magnitude of the difference in radiation dose between the lowest and highest protocol for some clinical scenarios in our study ranged from 50 to 60mSv, this would equate to a potential increase in the risk of death for an average person of 0.3%. Thus consensus between radiology providers on lowest clinically valid dosage protocols is crucial to reduce unnecessary exposure to radiation.

Recognition of the variation in radiation dose across providers and comparison with other published surveys and national diagnostic reference levels is also required since our study has shown the radiation burden afforded by protocols in use in WA is higher by international standards. This result is not surprising given the results of the previous dose survey undertaken in 1996[10] which also reported that Australian CT doses were higher by international standards. Our study confirms that this remains the case fourteen years later despite the publication of the earlier Australian study, increasing media attention regarding CT dosimetry and further development of dose reference levels internationally. Combined with the previous finding that Australia has a relatively high utilisation of CT scanning these data indicate an urgent need for dialogue in the Australian setting. While the establishment of WA specific dose reference levels (DRLs) is the goal, it should be recognised the accepted method of their calculation (ie 75th percentile of current doses) may not be appropriate without investigation of the context if the radiation dose appears higher than the norm internationally.

4.1. Conclusion

This study has provided a snapshot of CT scanning practice in Western Australia using previously validated robust methods of data collection for dose assessment. The study shows there are wide variations in technique and radiation dose across providers for similar examinations and that the protocols reported by Western Australian providers produce a higher radiation burden in an international context. The study highlights the need for recognition and understanding of both the degree of variation in radiation dose across providers and the relatively high radiation burden afforded

by protocols in use in Western Australia so necessary dialogue can be launched for practitioner consensus of appropriate diagnostic reference levels in CT scanning.

Acknowledgments

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