Australian Per Caput Doses from Diagnostic Imaging and Nuclear Medicine

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The Australian use of CT increased strongly from its introduction in 1976 until 2010 with an associated increase in per caput dose from the use of radiation in medicine. Per caput doses from medical uses of radiation are now comparable to the natural background as the largest source of radiation exposure to the Australian population. The frequency of diagnostic imaging of diagnostic imaging procedures together with estimates of doses per procedure are reviewed based on data from the Australian national health insurance scheme, estimates of procedures funded by other mechanisms and best estimates of doses per procedure. Estimates of doses per procedure are informed by data from a national survey of diagnostic reference levels commenced in 2011.

Key Words: Dose, Per Caput, Computed Tomography

Introduction

The total ionising radiation dose to the Australian population comes from two distinct sources, natural and man made. The dose from natural sources remains relatively constant at approximately 1.5 mSv per year[1], however, the dose from man made sources is subject to greater variation and needs to be re-evaluated more often. Man made sources of ionising radiation include industrial sources, consumer products, nuclear fallout, and most importantly medical sources, in particular medical imaging. A 2009 report by the NCRP showed that medical sources contributed 48% of the total ionising radiation dose to the US public[2] and this percentage is expected to be similar in Australia.

The ionising radiation dose to the Australian population as a result of medical imaging has been estimated twice in recent years. In 1999 it was estimated to be 0.8 mSv per year[1] and in 2004 it was estimated to be 1.3 mSv per year[3], showing an increase of 0.5 mSv in just five years. This increase is largely due to the growth of Computed Tomography (CT), which was first introduced in Australia in 1976 and, with its superior image quality, has been gaining popularity every since. Between 2000 and 2010 the number of CT procedures performed in Australia grew by an average of 7.2% per year, more than four times greater than the average population growth over the same time period of 1.6% per year. In addition to the popularity of CT procedures there are also the relatively large associated patient doses. While a standard chest x-ray will result in a patient dose of approximately 0.01 mSv, a standard chest CT will result in a patient dose of approximately 2.5 mSv[4].

Considering the last dose estimate for medical imaging was made in 2004 and the rapid growth of CT procedures, it is time this dose estimate was updated.

Methods

The ionising radiation dose to the Australian population as a result of medical imaging, both diagnostic imaging and nuclear medicine, was estimated for the year 2010. An individual estimate was made of the dose per caput from five different imaging modalities then these estimates were summed together to give a total dose for medical imaging. The five modalities were CT, Interventional procedures, Nuclear Medicine, General Radiography/Fluoroscopy and Mammography. The estimate for each modality was based on frequency data obtained from Medicare Australia[5] or BreastScreen Australia[6], with dose estimates obtained from the Dose Datamed study[4], an Australian and New Zealand Nuclear Medicine Survey[7] and Radiation Dose to Patients from Radiopharmaceuticals[8].

Frequency Data

For all modalities except mammography, frequency data was obtained from Medicare Australia[5], the Australian national health insurance scheme. Medicare Australia records statistics in terms of 'item numbers', with each 'item number' representing a specific procedure. The statistics for each 'item number' are broken down in terms of geographical state, age and gender of the patient.

For the mammography dose estimate frequency data from BreastScreen Australia[6] was used as these procedures are not captured by Medicare Australia. This data consisted of the total procedures recorded over a number of years only, no geographical state or age of patient information was obtained.

Data Gap

Medicare Australia does not capture all medical imaging procedures performed in Australia. Procedures that are not captured include public hospital patient radiology, military veterans, workplace accident referrals and transport accident referrals. A previous CT dose survey[3] conducted by the Australian Radiation Laboratory in the mid 90's collected data on the percentage of procedures performed at practices that were not captured by Medicare Australia. A result of 24% was obtained indicating that Medicare Australia data represented only 76% of actual procedures performed for Computed Tomography. To account for this, a factor of 1.32 was applied to the frequency data for the four modalities using Medicare Australia data.

Dose Estimates

Dose Datamed Study

The Dose Datamed Study[4] involved a survey of a wide range of common radiological procedures in ten European countries. From the results of the survey a list of the "Top 20" exams were outlined that were considered to make the largest contribution to population dose from medical imaging, see Table 1. For each of the "Top 20" exams, a low, average and high exposure group was defined with an effective dose specified for each exam and exposure group. The low/high exposure groups being the average effective dose from the two countries with the lowest/highest doses and the average exposure group being the average effective dose from all ten participating countries.

Table 1. Dose Datamed "Top 20" Exams and mean effective doses[4].(Colour added for this publication).

Exam type	Mean E per examination (mSv)		
	Higher exposure group	**Average exposure group**	**Lower exposure group**
1. Chest/Thorax	0.25	0.10	0.03
2. Cervical Spine	0.70	0.27	0.04
3. Thoracic Spine	2.00	1.00	0.40
4. Lumbar Spine	2.80	1.90	0.50
5. Mammography	0.40	0.33	0.25
6. Abdomen	1.80	1.50	0.50
7. Pelvis & Hip	1.35	0.90	0.45
8. Ba meal	15.00	7.70	2.60
9. Ba enema	12.50	8.60	6.40
10. Ba follow	24.50	10.00	4.40
11. IVU	3.50	4.00	2.60
12. Cardiac Angio.	11.25	9.10	5.30
All Angiography	**8.60**	**9.20**	**7.30**
13. CT head	2.40	2.00	1.60
14. CT neck	2.80	2.50	2.40
15. CT chest	8.20	8.00	6.60
16. CT spine	6.00	5.30	3.60
17. CT abdomen	13.50	12.00	10.20
18. CT pelvis	8.80	8.70	8.70
19. CT trunk	24.40	14.00	10.40
All CT	7.05	6.10	5.35
20. PTCA	17.00	14.00	13.151
All Interventional	**15.35**	**10.70**	**6.50**

Nuclear Medicine Survey

The Dose Datamed list of "Top 20" exams does not include any nuclear medicine procedures. This is because nuclear medicine procedures are much less common in European practice. Australian practice however, shares more similarity with US practice in that the frequency of nuclear medicine procedures is higher. The dose estimates for nuclear medicine were obtained from a joint Australian and New Zealand survey[7]and Radiation Dose to Patients from Radiopharmaceuticals[8].

Results

Computed Tomography

Seven of the "Top 20" exams related to CT, see Table 1. The frequency of each exam was calculated by grouping the 'item numbers' relevant to each exam and taking the sum of the procedures in each group for the calendar year 2010. The frequency of each exam type was multiplied by the dose per exam for each exposure level, see Table 2. The total dose from the seven exam types was then divided by the Australian population[9] in 2010 to obtain a dose per person value for each of the exposure groups, the highest being 1.11 mSv per person per year, these are also shown in Table 2.

Table 2. Frequency and dose data for CT exams.

Dose Datamed Category	Frequency	Dose per procedure (mSv)			Total dose (mSv)		
		Low	Average	High	Low	Average	High
CT Head	736637	1.6	2.0	2.4	1178618	1473273	1767928
CT Neck	136644	2.4	2.5	2.8	327945	341609	382603
CT Chest	346375	6.6	8.0	8.2	2286072	2770997	2840272
CT Spine	357543	3.6	5.3	6.0	1287155	1894979	2145259
CT Abdo	24886	10.2	12.0	13.5	253837	298632	335960
CT Pelvis	24998	8.7	8.7	8.8	217484	217484	219984
CT Trunk	701628	10.4	14.0	24.4	7296926	9822785	17119711
				Total Dose (mSv)	12848038	16819759	24811716
				Total Dose per person (mSv)	**0.58**	**0.76**	**1.11**

Interventional Procedures

Two of the 'Top 20" exams related to interventional procedures, Cardiac Angiography and Percutaneous Transluminal Coronary Angioplasty, (PTCA), see Table1. The total dose from these two procedures was calculated using the same method as described for CT and is shown in Table 3.The dose corresponding to the high exposure group was 0.12 mSv per person per year.

Table 3. Frequency and dose data for Interventional procedures.

Dose Datamed Category	Frequency	Dose per procedure (mSv)			Total dose (mSv)		
		Low	Average	High	Low	Average	High
Cardiac Angiography	204295	5.30	9.12	10.75	1082764	1863625	2196172
PTCA	31185	13.15	14.0	17.0	410083	436590	530145
				Total Dose (mSv)	1492847	2300215	2726317
				Total Dose per person (mSv)	**0.07**	**0.10**	**0.12**

Nuclear Medicine

From the Medicare Australia item numbers eighteen categories based on body region were identified for nuclear medicine procedures. The frequency for each category was calculated using the same method as for CT. A dose estimate was made for each individual item number by multiplying the Most Common Activity (MCA) as obtained from the Australia and New Zealand joint survey[7] by the effective dose as obtained from Radiation Dose to Patients from Radiopharmaceuticals[8] in mSv/MBq, see Equation 1.

$$Effective\ Dose = Most\ Common\ Activity\ (MBq) \times Absorbed\ Dose\ (mSv/MBq) \qquad \text{Equation 1.}$$

Table 4 shows the frequency and total dose per category as well as the total dose per person per year of 0.11 mSv. An effective dose per category could not be calculated due to their being a range of effective doses in each category.

Table 4. Frequency and total dose from nuclear medicine procedures.

Body region	Frequency	Total Dose (mSv)
Heart	125108	1073706
Lung	22367	48634
Liver and Spleen	1090	5200
Gallbladder	7599	25838
GIT	8885	20022
Kidney	14543	29780
Urogenital	317	1648
Brain (CSF)	5415	20651
Bone (whole body)	143678	655173
Whole Body	6395	131106
Bone Marrow	154	224
Bone (limited)	70713	322450
Limited	2710	42641
Thyroid	33505	87113
Parthyroid	5669	35828
Adrenal	710	1846
Other	585	1050
Bone (infection)	342	2188
Total Dose (mSv)		**22505099**
Total Dose per person (mSv)		**0.11**

General Radiography/Fluoroscopy

The remaining eleven of the 'Top 20" exams related to general radiography/fluoroscopy, see Table1. Mammography was included in this list but the Australian dose from mammography was calculated separately as its own modality. This was done because Medicare Australia captures only a small proportion of all breast screening procedures and also because the dose from mammography alone was sought. A number of high frequency 'item numbers' relating to imaging of the spine were not compatible with the three spine exam types specified in Table 1, so to insure these procedures were included in the calculation an addition exam type "Whole Spine" was added to this list. A dose estimate for the "Whole Spine" exam was conservatively estimated by summing the dose from the Cervical, Thoracic and Lumbar Spine exam types. The total dose for the eleven procedures was then calculated using the same method as described for CT and is shown in Table 5. The dose corresponding to the high exposure group was 0.30 mSv per person per year.

Table 5. Frequency and dose data for General Radiography/Fluoroscopy exams.

Dose Datamed Category	Frequency	Dose per procedure (mSv)			Total dose (mSv)		
		Low	Average	High	Low	Average	High
Chest	2402223	0.03	0.12	0.21	72067	285865	504467
C Spine	359363	0.05	0.27	0.70	16171	98226	251554
T Spine	94187	0.70	0.70	0.70	65931	65931	65931
L Spine	456472	0.50	1.86	2.90	228236	849038	1323768
Whole Spine	429807	1.25	2.81	4.30	535109	1206037	1848168
Abdo	271832	0.50	1.53	1.80	135916	415902	489297
Pelvis	559889	0.45	0.89	1.35	251950	498301	755850
Ba meal	77999	2.65	7.71	15.05	206697	601371	1173882
Ba enema	2219	6.45	8.60	12.35	14312	19083	27404
Ba follow	5067	4.40	10.48	28.90	22297	53096	146450
IVU	3172	2.55	4.03	3.50	8088	12783	11102
Total Dose (mSv)					1556774	4105632	6597873
Total Dose per person (mSv)					**0.07**	**0.18**	**0.30**

Mammography

Frequency data for mammography screening was obtained from BreastScreen Australia[6] in the form of total procedures for a series of financial years. From this data a frequency (total) for the calendar year of 2010 was estimated. The total dose for mammography was then calculated using the same method as described for CT and is shown in Table 6. The dose corresponding to the high exposure group was 0.03 mSv per person per year.

Table 6. Frequency and dose data for Mammography

Dose Datamed Category	Frequency	Dose per procedures (mSv)			Total dose (mSv)		
		Low	Average	High	Low	Average	High
Mammography	1471000	0.25	0.33	0.40	367750	485430	588400
Total Dose (mSv)					367750	485430	588400
Total Dose per person (mSv)					**0.02**	**0.02**	**0.03**

Total Dose Estimate

A summary of the dose estimates from each of the five modalities is shown in Table 7. The total dose per person per year varies from 0.9 mSv for the low exposure group to 1.7 mSv for the high exposure group.

Table 7. Summary of the dose per person for each exposure group and the collective total.

Modality	Dose (mSv)		
	Low	Average	High
Computed Tomography	0.58	0.76	1.11
Interventional Procedures	0.07	0.10	0.12
Nuclear Medicine		0.11	
General Radiography/Fluoroscopy	0.08	0.19	0.30
Mammography	0.02	0.02	0.03
Total Dose per person (mSv)	**0.9**	**1.2**	**1.7**

The exposure group that best represents Australian practice was chosen by comparing CT doses from the mid 90's survey[3] with those calculated using retrospective Medicare Australia frequency data and the CT doses from the "Top 20", see Figure 1.

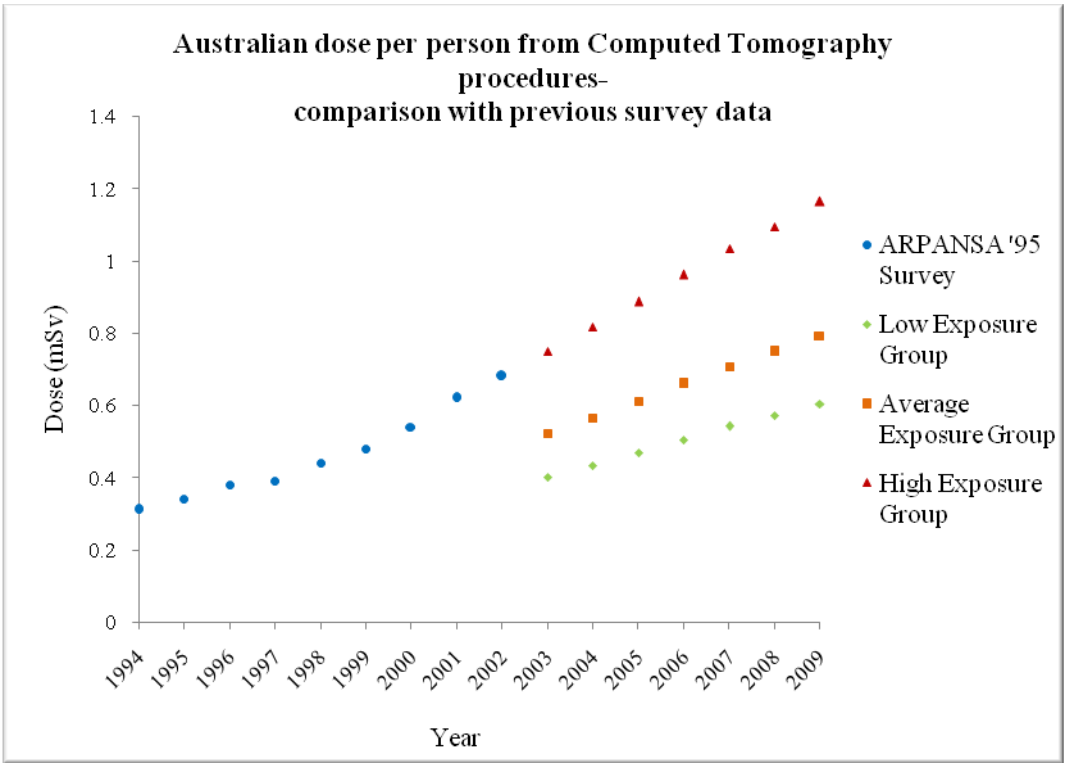

Figure 1. The Australian Computed Tomography dose per person, a comparison with previous survey data.

Figure 1 indicates that Australian CT doses are comparable with the "High Exposure Group" of the Dose Datamed study, and as such the dose to the Australian population from diagnostic imaging and nuclear medicine is estimated to be 1.7 mSv per person per year, see Table 7.

Discussion

There is uncertainty in both the frequency data and the dose estimates used. The uncertainty in the dose estimates used is thought to make the largest contribution to uncertainty in the overall dose but it is hard to quantify. The total dose of 1.7 mSv was chosen based on a comparison with dose estimates made nearly twenty years ago. While it is possible to observe trends in procedure frequency, significant changes in technology mean that trends in dose are not directly proportional to frequency and hence cannot be estimated based on frequency alone. An Australian National Diagnostic Reference Level Survey is currently underway which will provide up to date dose data for a number of common Computed Tomography procedures which may lead to a recalculation of the dose from CT alone. It is intended that the National Diagnostic Reference Level Survey will be expanded in the future to cover interventional fluoroscopy, nuclear medicine, mammography and general radiography, which should provide more relevant dose data for all modalities.

The uncertainty in the frequency data could be quantified by an uncertainty in the data gap between procedures captured by Medicare Australia and the total procedures that are actually performed. The estimate that 24% of procedures are not captured by Medicare Australia is currently the only one available in reference to the adult population. It is also acknowledged that 24% relates specifically to CT procedures and there is little justification, other than that it is the only percentage available, for its application to other modalities. That being said, it is consistent with the percentage reported in recent discussions with nuclear medicine practices. The decision to use 24% across all modalities calculated using frequency data obtained from Medicare Australia is considered to produce a conservative dose estimate.

Conclusion

The total ionising radiation dose to the Australian population as a result of diagnostic imaging and nuclear medicine was estimated to be 1.7 mSv per person per year, This is considered to be a conservative estimate in relation to uncertainty in the frequency estimate. The uncertainty in the dose estimates is considered to be large but unknown. The results of current and future surveys of Australian doses from medical imaging will help refine this value.

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