The Economics of Radiation Risk Reduction in Medical Imaging

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Background:

A foundation upon which Medical Physicists build a case for their position in health care involves the application of their knowledge and ability to optimizing the clinical benefits derived by patients in undergoing diagnosis and/or treatment involving ionizing radiation based imaging procedures. While it is well accepted that reducing the individual doses patients receive while undergoing imaging procedures translates to an overall reduction in their risk of developing cancer it is not understood how this saving translates to a societal benefit in terms of gains in loss of life expectancy. The basis of this analysis is the quality adjusted life year (QALY) which is a health economics measure of disease burden that considers the impact of interventions on both the quality and quantity of life gained or lost.

In this study we employ rudimentary cost-utility analysis to place a value estimate on the cost-per-QALY associated with efforts to reduce radiation exposures.

Methods:

Procedure Characteristics: This analysis is run as a simulation study using available data and current accepted understanding of clinical mechanism to theoretically assess the impact on the Australian population through interventions to reduce radiation exposure associated with a range of common ionizing radiation based imaging procedures.

To undertake this analysis, a model was constructed to simulate the annual workload from a range of 20 procedures. The procedures selected were those covered by the Dose Datamed 2 project (DDM2). In doing this key characteristics, necessary to establish a usable model, are available including:

- Procedure frequencies
- Population age and gender distributions
- Procedure radiation exposures (by country)

An underlying assumption in the use of this data is that clinical outcomes for the different procedures considered are similar and not dependent on level of exposure. Based on this assumption, comparison of procedure doses by nation can provide an indication of realistic potential dose reductions. For this simulation, current Australian radiation doses for each procedure type are assumed to be the DDM2 average.

Model Description: The Monte Carlo model constructed for this simulation is described in Simulation Cycle. Although the estimated annual workload across the 20 procedures was ~4.5M studies, the model was run across a total of 100M studies. Each run therefore simulates 20 years of operation and can therefore better account for some degree of variation in analysing rare endpoints. Runs were conducted at four radiation levels: DDM2 average (assumed current Australian practice), a 90% of DDM2 average, 25th percentile (Q1) DDM2 and minimum DDM2. The DDM2 dose distributions for each procedure are summarized in Figure 1.

While the main focus of this analysis is the impact of dose reduction strategies for the patient, a simulation study was also carried out to explore the impact reductions would have for clinical personnel involved in cardiac imaging procedures. This involved application of a conversion factor to the patient dose to provide an estimate of exposure to the cardiologist and nurse. This analysis was then run across a typical working life based on average clinician volumes.

Simulation Cycle: The simulation cycle for each pass of the model is as follows:

Step 1: Using estimated workload distributions, identify a Procedure Type for the simulated patient (SP) to undergo (see http://ddmed.eu/about_ddm2). (Figure 1)
Step 2: Use the procedure data distribution to set the Age and Gender of the SP.
Step 3: Using Australian date (see http://www.aihw.gov.au/deaths/life-expectancy/) calculate the Life Expectancy of the SP
Step 4: Based on Age and Gender assign Height & Weight for the SP. (see: body habitus data Adult :http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/4364.0.55.0012011-12 Child: http://www.cdc.gov/growthcharts/percentile_data_files.htm)
Step 5: Based on Height & Weight, derive a patient exposure size Correction Factor (CF).
Step 6: Based on Procedure Type estimate the baseline Effective Dose (E). (Figure 1)
Step 7: For relevant procedures, apply CF to E to adjust for patent size.
Step 8: Using the Age and Gender of the SP along with the size adjusted E (Step 6) derive an estimate of the incidence and death risk for Solid cancer and Leukaemia (BEIR VII).
Step 9: Simulate an imaging procedure and determine if a cancer was induced.
- If NO, then the life expectancy lost through the procedure is 0 so go back and simulate a new patient/procedure starting from Step 1
- If YES, then run the following cycle irrespective of type of cancer.

Step 10: Estimate the potential residual life expectancy at risk from exposure.
Step 11: Based on type of cancer, calculate latency period for cancer diagnosis.
Step 12: Determine whether cancer diagnosis results in a death:
- If YES, calculate Total Life Lost + 1 year (to account for loss of quality of life in period of illness leading to death).
- If NO, non-fatal cancer – QALY is 20% of potential life expectancy to account for Quality Loss during illness.
Step 13: Simulate a new patient/procedure starting from Step 1

Cost Impact: In this simulation it is assumed that dose reduction can be achieved without impacting procedure performance. As such, no impact on the benefit from under going the procedure is included as this is assumed to be a constant within each individual study. The outcome of the simulation is an estimate of the QALY change associate with each set of assumptions for each scenario. To convert this to an estimate of the relative financial impact of the different scenarios compared to baseline (mean exposure levels) a weighting factor of $66k/QALY was used (based in the approval threshold for drugs on the PBS, see: http://economicstudents.com/2015/03/a-life-how-much-is-it-worth/). .

Clinician Impact Analysis: Using data from Kim (Health Phys, 2008) and Bor (Med Phys, 2009) conversion factors linking patient dose to cardiologist (0.783 uSv/mSv), Scrub Nurse (0.261 uSv/mSv) and Scout Nurse (0.078 uSv/mSv) were derived. Current employment gender biases of 90% male for cardiologist and 90% female for nursing were assumed. Simulations were run across an estimated working life (duration and caseload) for each group.

Results:

A summary of the simulation results for the patient impact evaluation is provided in Table 1.

For cardiologists and nurses involved in cardiac procedures the savings are less significant with QALY gains of 0.006 and 0.004 respectively associated with reduction form the average to Q1 levels for individuals performing an average annual caseload across a working life.
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Table 1: Summary of results of the simulation runs.

Total = 4.37M Procedures/year	Baseline	Less 10%	Q1	Minimum
Potential				
Solid Deaths	152	137	106	33
Leukemia Deaths	33	30	26	8
Solid Incidents (inc Deaths)	244	220	172	55
Leukemia Incidents (inc Deaths)	37	34	29	9
Effective				
Effective Deaths (Solid)	95	84	65	20
Effective Deaths (Leukemia)	29	26	23	7
Annual Total				
Total Life Expectancy (M Years)	131	131	131	131
Adjusted Dose (mSv)	5682234	5111265	4117852	1368724
Loss of Life Expectancy (Years)	2301.84	2064.55	1589.43	481.03
Value				
QALY Gain	n/a	238.4	716.2	1835.7
Value ($66k/QALY) $M	n/a	$15.73	$47.27	$121.16

Discussion & Conclusion:

It is evident from the DDM2 report that substantial variation in radiation exposures exists. If it can be assumed that clinical efficacy is not correlated with exposure and that practices in countries assorted with high exposures deliver similar clinical outcomes to those at the low end of the spectrum then it would seem reasonable to assume that gains are achievable.

This analysis suggests that these efforts to reduce radiation exposures to patients undergoing imaging procedures could have a significant financial impact on the community with the value of life saved being placed at $50M/year if a shift was made from the estimated current average dose to a level consisted with the 1st quartile in the DDM2 report.

While this analysis has largely focused on the loss of effective life for those developing cancers as a result of their procedures, a limitation of this study is that it does not include consideration of any costs associated with the care and treatment of individuals developing cancer. For example, a 2005 report compiled by the AIHW using data from 2001 suggested that leukaemia was the most expensive cancer in Australia with lifetime treatment costs of $51k per patient (or $75k adjusted to current values). This simulation suggests that shifting from the average dose per study to the 1st quartile would reduce the leukaemia induction incidence from ~40 to ~30 cases which would equate to a saving of ~ $750k/year in treatment costs.

Another potential limitation of the study is that it assumes that all patients being exposed have a life expectancy consistent with the general population at the same age. This therefore ignores any potential impact of the clinical condition for which the patients is being imaged. As an example, patients undergoing a coronary angioplasty face a potential mortality risk of ~ 5% at 1 year and ~ 18% at 5 years (Spoon et al.; Cause of death after PCI, Circulation. 2014;129:1286-1294). While the premise of this analysis is that clinical outcomes will be similar for the different models, the reduced survival due to the clinical condition of the patients may impact the QALY loss due to cancer induction.

This analysis suggests that significant societal gain can be delivered through efforts to reduce the radiation risks associated with medical imaging procedures. Medical Physicists, Biomedical Engineers and Radiopharmaceutical Scientists are best placed to provide leadership in these efforts.
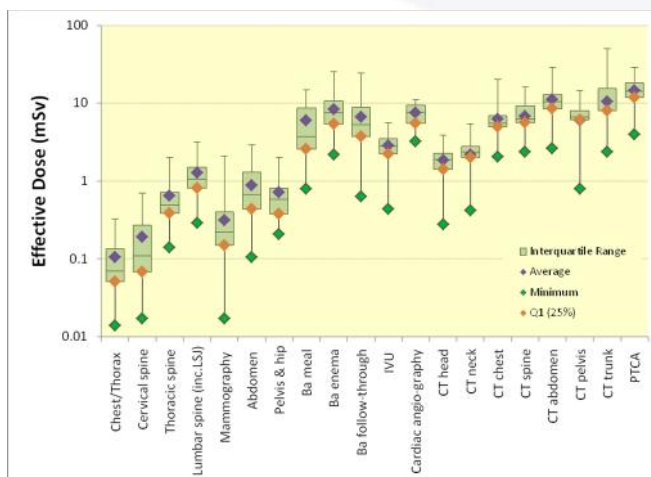

Figure 1: Radiation exposure distributions considered in the Monte Carlo model. Data is drawn from DDM2 (http://ddmed.eu/about_ddm2).