Cumulative radiation in critically ill patients: a retrospective audit of ionising radiation exposure in an intensive care unit

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Ionising radiation is continuous and ubiquitous, coming from both natural and artificial sources and can be expressed in millisieverts (mSv), which is the measurement of the biological effect of the absorbed radiation dose. At natural background levels, Australians are exposed to 1.5 mSv of radiation annually, while residents in the United States receive about 3.1 mSv.[1,2] This level increases with artificial exposures another 1.7 mSv for Australia and 3.1 mSv for the United States, totalling an average yearly exposure of 3.2 mSv and 6.2 mSv, respectively.[2,3] Most artificial exposures derive from medical sources. Ionising radiation is a crucial tool in medicine, aiding both diagnosis and therapy. Among hospitalised patients, diagnostic and interventional radiology is potentially most frequently used for patients admitted to intensive care units (ICUs).

Diagnostic radiation is used to aid ICU clinicians in both disease diagnosis and management. Previous studies attempting to calculate patients' cumulative effective dose (CED) over their stay in the ICU have been limited to exclusive populations within the ICU and, thus, overestimate cumulative exposure.[4-12] The real burden of radiological exposure in ICU patients remains unknown.

Conventional x-rays, computed tomography (CT), fluoroscopy and nuclear medicine are all forms of ionising radiation that clinicians use to enable quicker and more accurate patient diagnosis. Mettler and colleagues[13] collated the average effective doses of each radiological exam worldwide between 1980 and 2008. An anterior–posterior chest x-ray, the most common radiological procedure prescribed in ICUs, was reported as 0.02 mSv, approximating to 5 days background radiation.[1,13] Generally, higher exposures of radiation are received from CT scans, with median chest and abdominal exposures reported as 7 mSv and 8 mSv, respectively.[9,13] However, when surveyed, it was highlighted that some health care workers have a limited understanding of the doses associated with procedures that use ionising radiation and, therefore, have a misunderstanding of the associated risks.[14-19]

Under the current international regulatory framework, it is considered that there is no safe level of radiation and

ABSTRACT

Objective: Ionising radiation is a valuable tool in modern medicine including for patients in an intensive care unit (ICU). However, clinicians are faced with a trade-off between benefit of information received from procedure versus risks associated with radiation. As a first step to understanding the risk and benefits of radiation exposure to ICU patients, we aimed to assess the cumulative levels of ionising radiation patients receive during their ICU stay.

Design: Retrospective audit.

Setting: A single tertiary care ICU in South Australia.

Participants: This audit included 526 patients admitted to the ICU at Flinders Medical Centre, Adelaide, SA, for longer than 120 hours (long stay) over a 12-month period from April 2015 to April 2016.

Main outcome measures: Cumulative radiation exposure to ICU patients.

Results: The 526 patients audited underwent 4331 procedures totalling 5688.45 mSv of ionising radiation. The most frequent procedure was chest x-ray (82%), which contributed 1.2% to cumulative effective dose (CED). Although only 3.6% of the total procedures, abdominal and pelvic computed tomography (CT) contributed the most to CED (68%). Over 50% of patients received less than 1 mSv CED during their stay in the ICU. However, 6% received > 50 mSv and 1.3% received > 100 mSv CED. Trauma patients received significantly higher CED compared with other admission diagnoses, and CED increased with length of stay.

Conclusion: Most ICU patients received low CED during their stay, with the majority receiving less than the recommended limit for members of the public (1 mSv). These results may educate clinicians regarding radiation exposures in ICU settings, highlighting the relatively low exposures and thus low risk to the patients.

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that all radiation can be considered harmful. Currently, recommended limit for members of the public has been set at 1 mSv per year, while occupationally exposed workers can receive up to 20 mSv per year above background.[20] For medical exposures, all treatments must be clinically justified on an individual's needs for successful diagnosis and treatment. The International Commission on Radiation Protection (ICRP) states a cancer risk of 5.5% per Sievert;[20] thus, when extrapolated down to diagnostic levels, a whole body 10 mSv CT scan would equate to an approximate 0.05% increase (1/1800) in cancer risk. When added to the average risk of cancer by the age of 85 years, the cancer risk from a CT scan would increase from 40% to 40.05%.[21] However, it is important to recognise that the ICRP, as well as other governing bodies,[22,23] state that epidemiological methods do not have the power to isolate cancer risks for exposures below 100 mSv.[20]

As a first step, it is important that we accurately determine the level of radiation exposure of patients in the general ICU cohort, including an assessment of the exposure due to each procedure, to inform clinicians and thereby aid their assessment of the risk–benefit ratio when prescribing diagnostic radiation.

Objective

The aim of this study was to conduct a retrospective audit of daily and cumulative radiation exposure of all patients admitted for more than 120 hours to a 32-bed mixed surgical and medical, metropolitan, tertiary level ICU over a 12-month period.

Method

Study cohort

The study cohort included patients admitted to the ICU at Flinders Medical Centre, Adelaide, SA, between 1 April 2015 and 1 April 2016 with an ICU length of stay of more than 120 hours. Patients with shorter stays were excluded to remove routine post-surgery stays. This audit was reviewed and approved by the South Adelaide Clinical Human Research Ethics Committee (OFR # 131.16), in line with the requirements of the National Statement on Ethical Conduct in Human Research, and the requirement of informed consent was waived.

Data collection

Hospital records from the Open Architecture Clinical Information System (OACIS), the Australian Outcomes Research Tool for Intensive Care (AORTIC) database and the

Table 1 Summary of patient demographics and clinical characteristics

Demographic and clinical characteristics	Values (%)
Total number of patients	526
Age (years), median (IQR)	65 (51–76)
Sex	
Male	306 (58.2%)
Ethnicity	
Aboriginal	31 (5.9%)
Caucasian	477 (90.7%)
Asian	5 (1%)
Other	3 (0.6%)
Unknown	10 (1.9%)
APACHE III score, median (IQR)	72 (57–86)
ICU stay (days), median (IQR)	7 (6–13)
ICU mortality	54 (10.3%)
Admission diagnosis	
Medical	
Cardiovascular	91 (17.3%)
Respiratory	94 (17.9%)
Gastrointestinal	45 (8.6%)
Neurological	46 (8.7%)
Sepsis	52 (9.9%)
Trauma	24 (4.6%)
Metabolic	25 (4.8%)
Haematological	6 (1.1%)
Renal/genitourinary	14 (2.7%)
Other disorders	1 (0.2%)
Musculoskeletal	5 (1.0%)
Surgical	
Cardiovascular	50 (9.5%)
Respiratory	7 (1.3%)
Gastrointestinal	34 (6.5%)
Neurological	13 (2.5%)
Sepsis	8 (1.5%)
Renal/genitourinary	2 (0.4%)
Gynaecological	1 (0.2%)
Musculoskeletal	8 (1.5%)
Haematological	0 (0.0%)
Metabolic	0 (0.0%)

APACHE = Acute Physiology, Age, Chronic Health Evaluation; ICU = intensive care unit; IQR = interquartile range.

Table 2 Distribution of procedure frequency and cohort total dose

	Contribution to frequency (*n* = 4331 procedures)	Contribution to total dose (*n* = 5688.45 mSv)
Conventional x-ray	85.2%	2.3%
Computed tomography	12.5%	93.1%
Fluoroscopy	2.2%	4.3%
Nuclear medicine	0.1%	0.3%

Table 3 Exposures from each modality divided by body region scanned

	Median effective dose (mSv) Median (IQR)	Range of effective dose (mSv)
Conventional x-ray		
Head/neck	0.01 (0.01–0.03)	0.01–0.03
Chest	0.02 (0.02–0.02)	0.02–0.06
Abdominal and pelvic	0.75 (0.75–1.50)	0.14–3.75
Extremities	0.00 (0.00–0.00)	0.00–0.02
Computed tomography		
Head	1.64 (1.59–1.79)	1.06–5.20
Neck	4.14 (3.29–5.76)	1.61–12.83
Chest	7.53 (5.07–11.64)	0.98–36.30
Abdominal and pelvic	21.88 (14.05–31.72)	1.55–78.82
Extremities	0.97 (0.31–1.79)	0.25–2.14
Spine	9.66 (5.76–21.70)	5.76–21.70
Fluoroscopy		
Cerebral	2.67 (2.05–3.25)	0.11–13.95
Oesophageal	0.02 (0.01–0.26)	0.01–1.14
Pulmonary	5.30 (0.70–11.16)	0.23–12.89
Cardiovascular	0.02 (0.00–0.23)	0.00–28.70
Gastrointestinal	3.86 (0.94–7.36)	0.24–27.78
Urinary	0.02 (0.02–0.02)	0.02–0.02
Peripheral	0.00 (0.00–0.02)	0.00–0.06
Nuclear medicine		
Gastrointestinal	2.34 (2.32–2.52)	2.32–2.52
Urinary	5.12 (5.06–5.19)	5.06–5.19

IQR = interquartile range.

radiological picture archiving and communication system (PACS) were used to collect demographic information, clinical data and radiology reports for each patient.

All ionising forms of radiation were recorded, including conventional x-rays, CT scans, fluoroscopy and nuclear medicine.

Calculation of effective dose

Effective doses for each procedure were calculated using the values from patient radiology reports and reported conversion factors by Deak et al[24] and Hart and Wall.[25] In short, values for dose area product (DAP) or dose length product (DLP) produced from the radiology reports were collected and converted to effect dose (mSv) via multiplication by tissue-specific conversion factors (online Appendix, available at cicm.org.au/Resources/Publications/Journal). For conventional x-rays, accepted diagnostic reference levels were used for each individual exam due to lack of information in the reports, except in cases in which sufficient information enabled calculation of effective doses.

As this study focuses on initial management and intensive care treatment, radiological examinations were only included if they were performed during the time between admission and discharge from the ICU. No radiological procedures were recorded before or after the ICU stay.

Statistics

All outcomes measured in this audit were not normally distributed; therefore, data were expressed as median (interquartile range [IQR]) and tested using non parametric tests. The dichotomous variable sex was assessed by Mann–Whitney U test and categorical variables, including patient ethnicity, length of stay and admission diagnosis, were assessed by Kruskal–Wallis analysis with post hoc Mann–Whitney U test. Scale variables, such as age and Acute Physiology and Chronic Health Evaluation (APACHE) III score, were assessed using Spearman rank order correlations. Statistical significance was dictated by $P < 0.05$

Results

This study cohort included 526 patients who underwent 4331 procedures totalling 5688.45 mSv of ionising radiation. The median age was 65 years (IQR, 51–76 years), with a median length of ICU stay of 7 days (IQR, 6–13 days) and an overall mortality of 10.3% (Table 1). Patients were admitted with either non-operative (medical) or post-operative (surgical) diagnoses, with respiratory or cardiovascular complications being the main reason for admission.

All patients who received some diagnostic radiography (98.5%) received at least one conventional x-ray. Of those patients, 248 (48%) received only conventional x-rays. A CT scan was received by 255 patients (49.3%); 74 patients (14.3%) received a fluoroscopic exam, and only six patients (1.2%) underwent nuclear medicine. The median CED of the cohort was 0.91 mSv (IQR, 0.08–11.37 mSv). There was no difference in median CED between sexes ($P = 0.131$) or ethnicities ($P = 0.964$).

Distribution of procedure dose

As described in Table 2, the most common modality performed in this ICU was a conventional x-ray, accounting for 85.2% of the 4331 procedures, of which the chest x-ray was the most frequent procedure, comprising 82% of all procedures performed. However, because conventional x-rays produce a relatively low dose of radiation, they only accounted for a 2.3% contribution to CED, 1.2% specifically for chest x-rays. Conversely, CT scans contributed the most to CED (93.1%), with the highest contribution coming from abdominal and pelvic scans, representing 68.8% of the overall 5688.45 mSv. Both the fluoroscopic exams and nuclear medicine accounted for minimal percentages of both number of procedures and total CED.

The highest median effective dose was produced from abdominal and pelvic CT scans (21.88 mSv), which also gave the highest individual exposure of any procedure (78.82 mSv) (Table 3). There was large variation between doses for the same procedure, sometimes up to 1000-fold (eg, with gastrointestinal fluoroscopy).

Patient cumulative radiation exposure

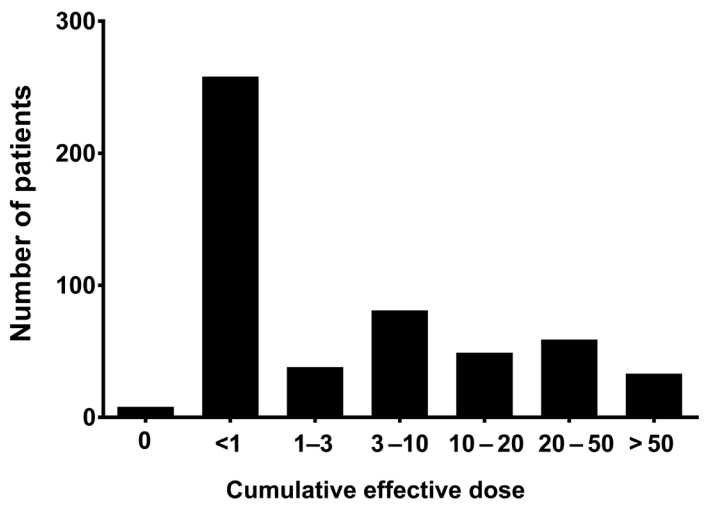
In this cohort, 50.5% of patients received under 1 mSv CED during their ICU stay, with nine patients receiving no ionising radiation (Figure 1). Conversely, 33 patients (6.3%) received more than 50 mSv, of which seven (1.3%) received more than 100 mSv. The highest CED was 199.89 mSv.

Admission diagnosis also contributed to CED. A patient admitted with trauma received significantly more radiation compared with medical and surgical admissions (Figure 2, A). Finally, patients who had a longer length of stay in the ICU had greater CED (Figure 2, B). There was no correlation between age in years ($\rho = -0.059$; $P = 0.175$) or APACHE III score ($\rho = 0.008$; $P = 0.859$) to CED.

Discussion

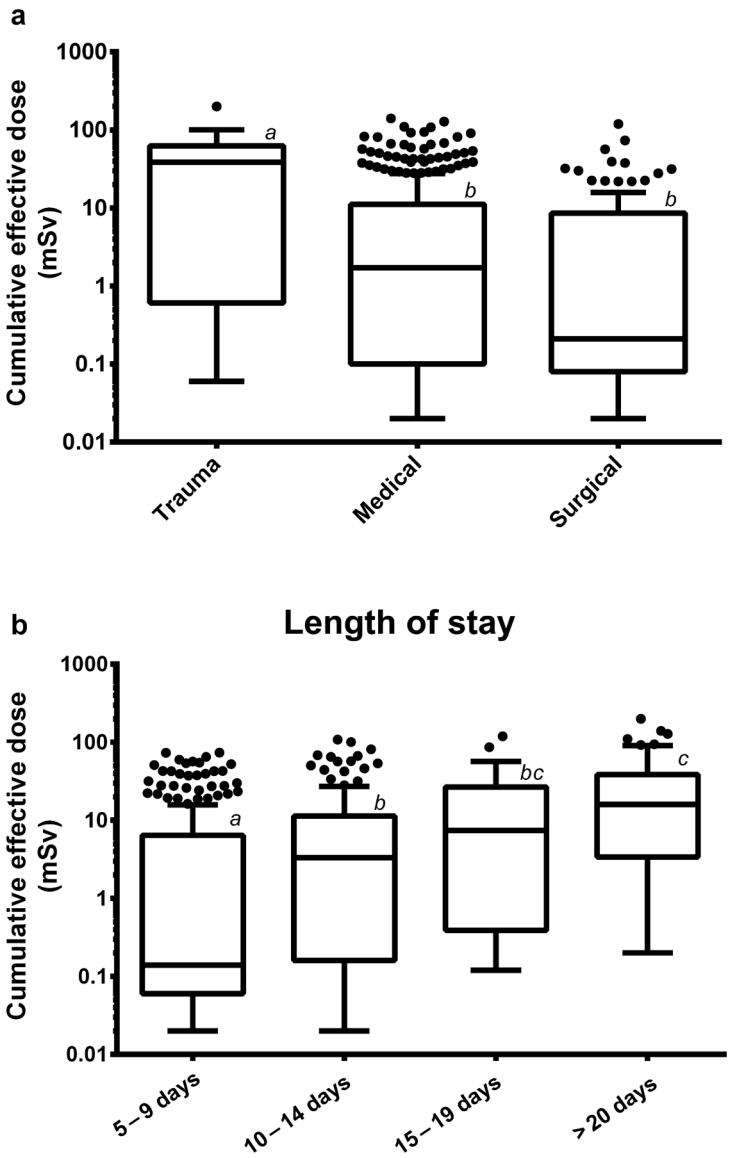
This study is the first to assess cumulative radiation exposures for a large, critically ill cohort without exclusions, based on significantly extended ICU stays, specific diagnosis categorisation, or requirements of at least one CT scan or fluoroscopy procedure.[4-11] Although this study excluded stays shorter than 5 days to remove routine post-surgical stays and thereby focus on those patients intentionally in the ICU, the study did include all radiological exams that used ionising radiation, not just high dose procedures, and included all admission diagnoses, not just trauma or emergency patients. Therefore, this study is more representative of a typical ICU population and its ionising radiation exposure than some previous reports. Among previous studies, the median CED was largely overestimated

Figure 1. Distribution of patient exposure grouped by cumulative effective dose*



* The majority of patients received less than 1 mSv exposure to ionising radiation. Bars represent absolute count of total cohort.

Figure 2. Patient factors that contribute to cumulative effective dose*



* Tukey box and whisker plots of (**a**) admission diagnosis and (**b**) length of stay against cumulative effective dose, with italicised superscripts denoting statistically significant differences ($P < 0.05$) by Kruskal–Wallis analysis with post hoc Mann–Whitney U test. Patients with an admission diagnosis of trauma had significantly higher cumulative effective dose (CED) compared with medical or surgical diagnoses. CED was higher for longer intensive care unit stays. Box plots represent median and interquartile range (IQR), and whisker plots represent 1.5 × IQR below and above the lower and upper quartiles respectively. Single data points represent outliers.

due to these inclusion criteria and ranged from 1.5 mSv to 104 mSv. However, most patients from this study received less than 1 mSv CED during their stay in the ICU. These exposures are less than both the internationally recommended exposure limit for members of the public (1 mSv), and the man-made portion of the average Australian's yearly radiation exposure (1.7 mSv).[20,26] Nevertheless, these patients would have received this exposure over a shorter time period (median stay, 7 days; IQR, 6–13 days) compared with the yearlong period of the exposure limit for members of the public and the average exposure for Australians.

Only 6% of patients received more than 50 mSv, and 2% received above 100 mSv — the upper limit of the low dose radiation spectrum. The health-related risks associated with exposures at these levels are negligible, with most studies showing no harmful effects below 100 mSv. The most accepted risk assessment model, uses the linear no-threshold model and predicts that for every 10 mSv of radiation, the excess relative risk of cancer incidence increases 0.05%.[20] This is on top of the baseline cancer incidence of 40–42% in Australia and the United States and 50% for the United Kingdom.[21,27,28] Thus, patients receiving above 100 mSv cumulatively have a postulated increased risk of cancer from 40–42% to 40.05–42.05%. However, the radiation protection guidelines overcompensate this risk by using modelling based on the atomic bomb survivors and misleading epidemiological studies, which inaccurately extrapolate the risk of low dose radiation from high doses.[29,30] Therefore, although some guidelines calculate increased cancer and other health-related risks through harnessing the radiation protection modelling,[20] it is the position of many governing bodies to refrain from making such bold statements when dealing with exposures below 100 mSv,[20,22,23] to

which most diagnostic radiography exposures are found.[13] Long term, population-based follow-up of patients will be required to further decipher this perceived risk.

From this cohort, both trauma categorisation and length of ICU stay were associated with a larger CED. An admission categorisation of trauma typically encompasses patients with multiple sites of major injury, including fractured bones and internal bleeding, leading to scans of most regions of the body. Due to the severity of the injury, secondary follow-up scans are also likely, resulting in increased CED. The length of ICU stay is predominately dictated by the health status of the patient, with sicker or more critical patients associated with longer ICU stays. Continuous monitoring and rediagnosis occurs in these patients, typically using diagnostic radiation, which additively contributes to higher CED. These, along with a variety of other factors, have also been previously reported in the literature as having associations to larger CED in ICUs, including active malignancies, readmission to the ICU, number of radiology exams, CT scans, and fluoroscopy minutes.[6-9]

Consistent with ICUs and hospitals around the world, chest x-rays were the most frequent individual procedure but contributed very little to CED.[6,9,11,31-33] The universal high frequency is likely due to clinical practice and ease of access, with most ICUs having portable x-ray machines. While daily routine chest x-rays were common practice, it was reported than only 2.3% result in a change of management, most often adjustment of antibiotic treatment, implanted devices or central lines.[34] Therefore, practice is moving to clinically indicative administration, saving hospital and patient costs, radiation exposure, and time.[35,36]

The median dose of each modality calculated in this cohort is largely consistent with previously published literature, except for the abdominal CT scan.[13] Typically, abdominal scans result in the highest effective dose of this modality, due to the large number of radiosensitive organs within this region.[6,9-11,13,20,31-33] However, the average abdominal CT scan in this audit was almost three times higher than reported by Mettler and colleagues.[13] This variation could be due to the defining regions of the scans. In the study ICU, it was clinical practice to scan both abdominal and pelvic regions together rather than separately, thereby increasing scan time and radiation exposure to those organs.

This retrospective audit is of a single, medium sized tertiary centred study and, thus, these results are limited only to this centre. No conclusions can be made regarding ionising radiation exposures to ICU patients in other centres without completion of a multicentred approach. It is therefore difficult to discuss these results as being universal across centres in Australia or elsewhere; however, in the study centre, most patients received negligible doses of ionising radiation.

Another limitation was that a CT scan was counted as per prescribed regardless of number of actual scans during the procedure. Some CT procedures, such as CT angiograms, require multiple phases to observe how the contrast is circulated around the body. At different time periods, different organs are better visualised based on where the contrast is during circulation. Therefore, these procedures can contain multiple scans — for example, a pre-contrast scan, an arterial scan, a venous scan, a delayed scan etc — that are completed at various time intervals after contrast injection, causing the patient to receive a higher dose. Given that some dose reports additively counted the scans as one procedure, separation of these multiphase scans was not possible and, thus, all multiphase CT procedures were reported as one, which explains the large variation in CT dose.

Conclusion

Medical radiography is a necessary component of medicine, particularly in ICU settings. This audit demonstrates that the exposure ICU patients receive from radiography in a western, tertiary hospital mixed ICU is relatively small, posing a negligible risk against the potential life-saving benefits. However, further studies should be undertaken to identify if these results can be replicated in other tertiary care centres, around Australia and internationally, using similar study criteria.

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Competing interests

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