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RESEARCH ARTICLE

Risk of ionizing radiation exposure from CT scans in the Neuro ICU - a patient safety blind spot? [version 1; peer review: peer review discontinued]

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V1 First published: 10 Oct 2016, 5:2489
<https://doi.org/10.12688/f1000research.9680.1>
Latest published: 10 Oct 2016, 5:2489
<https://doi.org/10.12688/f1000research.9680.1>

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Abstract

Introduction: The exposure to ionizing radiation has increased significantly with the wide availability of computed tomography (CT) scans and portable imaging technology. We examine the pattern of use of inpatient diagnostic imaging and radiation exposure in the neuro-intensive care unit (Neuro ICU, N-ICU) patient population at a large academic medical center.

Methods: We retrospectively evaluated all patients admitted to the Neuro ICU at our academic medical center from January 1 to December 31, 2013. The number and type of CT studies was collected, and the corresponding estimated radiation dose was calculated. We limited the evaluation to CT scans, which accounts for the majority of radiation exposure. Data were electronically collected and cross-referenced to the patients' electronic medical records (EMR) and radiology records. Radiation dose estimates were calculated based on published reference values and conversion factors (CT head (2mSv)), CT angiography of the head and neck (7-10 mSv), Ct Chest /Abd/pelvis (10 mSv), CT cerebral perfusion analysis (3.3 mSv).

Results: In the calendar year 2013, we had a total of 2353 admission encounters (F=1078). The mean age on admission was $56.55Y \pm 16.7$. The mean length of ICU stay was 6.3 days. Mechanical ventilation was initiated on 420 patients with a mean length on mechanical ventilation 5.09 days. 2028 CT scans were completed of which approximately 60% were head CT without contrast (n=1209). 379 patients had multiple CT studies. The mean number of studies was 3.8 ± 2 . The number of patients with more than three studies during their ICU stay was 159. The maximum number of studies on a single patient was 21.

Conclusion: Patients in the Neuro ICU are at a risk for significant exposure to ionizing radiation. Radiation exposure must be factored into the culture of quality and patient safety in the ICU.

Keywords

Radiation exposure, neuro intensive care, CT scans, Dose estimation, ALARA

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Competing interests: No competing interests were disclosed.

Grant information: The author(s) declared that no grants were involved in supporting this work.

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How to cite this article: Kumar AB and Neeley RC. **Risk of ionizing radiation exposure from CT scans in the Neuro ICU - a patient safety blind spot? [version 1; peer review: peer review discontinued]** F1000Research 2016, 5:2489 <https://doi.org/10.12688/f1000research.9680.1>

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Introduction

Computed tomography (CT) scans have become an integral part of the evaluation and management of patients with neurologic injury. The use of CT imaging has doubled every 2 years since the early 1980s to nearly 70 million scans worldwide in 2007^{1,2}. Widespread availability and ease of obtaining CT scans has tremendously aided diagnostics in hospitalized neurologic patients worldwide. This comes with an insidious risk of potential exposure to excessive quanta of ionizing radiation. The last decade has seen an exponential increase in the number of publications related to all aspects of quality and patient safety in the intensive care unit (ICU), including ionizing radiation exposure³. However in spite of the recent publications highlighting the various risks, radiation exposure to patients seems to be in a blind spot of clinical decision-making, especially in the ICU. We seek to explore the patterns of radiation exposure to patients admitted to the neuro-intensive care unit (Neuro ICU) to better understand and review the methods and systems to implement to minimize radiation exposure in the ICU.

Specific aim

To describe the patterns of use of diagnostic CT imaging in a cohort of neuro intensive care patients during a single ICU admission.

Methods and materials

The institutional review board approved our retrospective, quality improvement study (IRB # 141320 A QI project to determine pattern of CT scan usage and information to reduce the exposure of patients to ionizing radiation in the NCU). We included all adult patients who were admitted to our medical center Neuroscience intensive care unit between January 1, 2013 and December 31, 2013.

We retrospectively analyzed data on all CT scans that were completed on patients during their intensive care unit stay. The patient-specific dose of radiation delivered was not universally available on all patients at this time. We used previously published estimates of the doses of radiation based on individual types of diagnostic studies to calculate the arithmetic sum of estimated radiation exposure during the patient's ICU stay. The radiation doses for CT scans used in our analysis were from previously published data from Mettler *et al.*⁴.

Measuring absorbed radiation

Radiation dose is measured by a number of units, including Sieverts (Sv) and Grays (gy). The Sievert reflects the effective dose and represents the stochastic biologic effects of ionizing radiation. The effective dose refers to the radiation risk averaged over the entire body because different tissues have different sensitivities to radiation. The Gray is the radiation measure used to reflect the absorbed dose. In our analysis we used the reported doses in Sievert units.

Results

In the calendar year 2013, we had 2353 ICU admissions. A majority of the patients were admitted from the Neurology - Stroke service, general neurology service and the Neurosurgery service.

A total of 2028 CT scans were completed in this time period. 59.5% or 1208 studies were CT Head without contrast studies. The majority of these studies were done using a portable CT scanner (Model NL 3000, Neurologica Corp. Danvers MA, USA) in the N-ICU itself. A profile of the types and number of CT scans done in 2013 are shown in [Table 2](#) (profile of types of CT scans).

Table 1. A list of common radiology procedures in the Neuro ICU.

Ionizing Radiation	No ionizing radiation
X ray: <ul style="list-style-type: none"> • Chest X ray • Abdominal X ray • Kidney Ureter Bladder (KUB) • Spine 	Ultrasound <ul style="list-style-type: none"> • Vascular ultrasound Studies • Echocardiography • Carotid studies • Transcranial Doppler
CT scans <ul style="list-style-type: none"> • CT brain with and without contrast. • CT chest abdomen pelvis w/wo contrast. • CT Chest -Pulmonary embolism protocol 	Magnetic resonance Imaging <ul style="list-style-type: none"> • MRI Brain • MR Angiography • MR Venography
Interventional Procedures <ul style="list-style-type: none"> • CT angiography • Embolization and coiling of aneurysms, AVM, fistulas etc. • Stenting and angioplasty procedures for stenosis, aneurysms, etc 	
Nuclear Medicine Procedures <ul style="list-style-type: none"> • Tc99 scans 	
Positron Emission Tomography -PET scans	

Table 2. Profile of CT scans completed in patients in the Neuroscience ICU in 2013.

TYPE OF CT SCAN COMPLETED	NUMBER OF PATIENTS
CT head without contrast	1208
CT Angiography of head and neck	157
CT Perfusion Head and Neck	64
CT Angiography Chest: Pulmonary Embolism protocol	34
CT abdomen and pelvis only	27
CT chest-abdomen-pelvis with contrast	43
Outside institution CT scans	188

The frequency distribution of patients with two or more CT scans in the ICU is shown in [Figure 1](#). 16.1% (379 of 2352) of patients had more than two CT scans during their ICU stay with the mean number of scans in this cohort being 3.8 ± 2 scans. 285 patients out of 2353 (12.11%) had ≥ 3 CT scans during their ICU course and the maximum number of scans done on a single patient was 21. In the multiple scan cohort, 148 patients were

admitted by the Neurosurgical service and 111 patients were admitted by the Neurology and Stroke services. 123 (43.85%) were female patients in the high CT exposure cohort.

Discussion

We believe that the pattern of CT scan usage and radiation exposure is not unique to our institution. Advances in neuroimaging have been instrumental in improving patient care and reducing both morbidity and mortality for perioperative neurocritical care patients. A brief list is shown in [Table 2](#) (Imaging modalities radiation vs no radiation). In our practice, CT of the head without contrast was the most frequently completed study.

Currently, CT scans represents about 7% of all radiologic procedures in the world but accounts for more than 40% of the collective effective dose of radiation. Many factors have been suggested as explanations for the sharp increase in CT use, including increased scanner availability; favorable financial reimbursements for imaging procedures; and shifts in the practice of medicine including more time constraints and promotion of defensive medicine⁵.

The per-capita annual effective dose from medical procedures in the United States is among the highest in the world and is estimated to have increased six fold in the last 25 years⁶⁻⁸. Our analysis shows

Figure 1. A graph showing patients who had more than 2 CT scans in the ICU during their admission.

that a sizable percentage of patients hospitalized in Neuro ICU's are exposed to radiation primarily from CT scans. These total estimated doses would be greater if exposure from other imaging modalities including X-rays and angiographic procedures were included.

Interpreting the risk and effect of exposure to radiation is complex and often cannot be explained just by the arithmetic sum of exposures from standard procedures. For example if a patient has 3 CT scans of the brain and if each CT scan of the brain without contrast has a reported exposure of 1mSV (per published reports), the cumulative radiation exposure is not always the product of exposures times the number of studies.

Cumulative dose by definition refers to the total dose resulting from repeated exposures of ionizing radiation to an occupationally exposed worker to the same portion of the body, or to the whole body (if the whole body is exposed at once during the procedure), over a period of time. To further confound the picture, the effective radiation dose is not intended to be a measure of deterministic health effects.

Consequences of radiation exposure

The topic of radiation exposure risks is controversial because the effects are uncertain. It has been known for several years that survivors of focused exposure to high doses of ionizing radiation (*e.g.* nuclear power plant accidents, nuclear explosion survivors, etc.) experience a higher-than-normal risk of malignancy several years after the initial exposure. Higher incidence of hematologic malignancies and certain solid tumors (esophagus, stomach, colon, liver, lung, non-melanoma skin, female breast, urinary bladder, brain and central nervous system and thyroid) is the most widely reported long term risks of radiation⁹. Controversy exists about the long-term effect of exposure to smaller doses of radiation from clinical imaging modalities. There is no consensus currently about the long-term effects of radiation exposure in ICU's when patients are critically ill. This is in part because of the perception that the reason for ICU admission (*e.g.* septic shock, ARDS etc.) carries a higher mortality risk than the long-term effects of radiation exposure. This however does not negate us from identifying and addressing methods and processes of reducing the risk of radiation exposure in hospitalized patients.

Measuring absorbed radiation

Delivery and absorption of radiation doses are reported in variety of measures including air kerma, entrance surface dose, dose-area product, dose-length product, and administered activity. The effective organ absorbed doses are estimated by using validated anthropomorphic phantoms with internal dosimeters or specialized software such as the Monte Carlo system¹⁰. The Biological Effects of Radiation model (or BEIR), specifically the BEIR VII method is a dominant model used to estimate this risk.

National Research Council Biologic Effects of Ionizing Radiation report a projected risk of 4,100 cases of lung cancer per year could be related to CT scans alone¹¹. The Life Span Study (LSS) cohort of atomic bomb survivors continues to be a cornerstone study that evaluates quantitative risk estimates that underlie radiation

protection¹². The mean radiation dose of atomic bomb survivors was estimated at 40 mSv¹³. Recent publications that have compared radiation effects from Hiroshima survivors and those exposed to radiation from medical procedures¹⁴. Extrapolating broadly based on this type of exposure is risky, primarily because of the differences in the type of radiation exposure. Atomic bomb survivors received radiation to the whole body over a very short period of time versus patients undergoing diagnostic studies.

Monitoring and dose tracking

There have been institutional efforts across the USA to influence practice patterns to decrease the exposure to ionizing radiation. One approach is to eliminating unnecessary ordering of routine CT scans especially when they do not change treatment decisions. An alternate approach to limit radiation exposure in general is to substituting imaging that does not use radiation, when possible.

With the advent of the patient safety monitoring systems in hospitals across the USA, there is a push towards implementing radiation dose tracking programs and modifications of radiology protocols to operate under the ALARA principle (As Low as Reasonably Achievable)¹⁵. As recent as April 2014, the USA Congress approved a bill, which includes verbiage about reporting the dosage of radiation especially from CT scans and about implementing decision support mechanisms to reduce exposure¹⁶.

Comprehensive dose tracking is valuable to a dose-reduction program in several ways. First, dose tracking allows parsing of dose information by examination type, examination protocol, scanner type and location, time of acquisition, and even the performing technologist or radiologist¹⁷. The State of California and the European Union have implemented a dose tracking mechanism in which CT studies must have their dose tracked in the radiologist's report, including the dose-length product (DLP) and volume CT dose index (CTDIv). The dose report provides both a CT dose index (volume) (CTDIvol) in mGy, a measure of the energy output administered to a single axial "slice" of a patient, and a DLP in mGy-cm, an estimate of the total dose administered over the entire scan range (z-axis)¹⁸. It is important to note however that the CTDI values that are currently reported are not, individual patient dose estimates. The more widespread adoption of radiation exposure reporting is anticipated in the future.

Several commercial dose-tracking systems are available, including DoseMetrix (Primordial Design Inc, San Mateo, CA, USA), DoseWatch (GE Healthcare, Little Chalfont, UK) DoseMonitor (PACSHealth, Scottsdale, AZ, USA), and other platforms. The open-source, Radiance (www.radiancedose.com) is the most well known freeware dose-tracking software, which was developed at the University of Pennsylvania¹⁸. Other efforts include, the International Atomic Energy Agency's transportable tracking system of an individual's medical radiation exposure Smart Card/ SmartRadTrack (previously Smart Card) (<http://rpop.iaea.org/RPOP/RPOP/Content/News/smart-card-project.htm>). The Society of Pediatric Radiology in collaboration with the American Association of Physicists in Medicine, American College of Radiology and the American Society of Radiologic Technologists initiated the educational campaign 'Image Gently' with a goal to

reduce radiation exposure in pediatric patients (www.imagegently.org). The Image Gently campaign and its adult patient counterpart Image Wisely (www.imagewisely.org) seek to raise awareness of the methods to lower radiation dose in medically necessary imaging.

At our medical center multiple systems are in place to reduce the radiation exposure to patients. Protocols are crafted to optimize imaging while minimizing radiation. Iterative reconstruction on two of our scanners automatically reduces the radiation dose for head CT 20% and temporal bone CT greater than 20%. Low dose protocols are used with screening studies including chest CT for lung nodules and sinus CT. A dose report including DLP is now available with most CT studies at our institution. This report can be used to compare to diagnostic reference levels and ensure that any single study does not exceed recommended radiation levels. However in reality, the reduction in radiation exposure that can be achieved by the judicious selection of patients for CT has the potential to achieve a greater overall reduction than can be achieved through attempts at dose reduction through modulation of the peak kilovoltage and tube current alone¹⁹.

Current limitations, future areas of need and directions

Currently there are no uniform standards to report radiation exposures for individual patients that can be easily interpreted by clinicians and are visible in the medical records.

Most non-radiologists have limited expertise and background to interpret the radiation exposure data from imaging modalities. Patient safety reports beyond incident reporting systems that specifically track radiation exposure events such as skin changes, hair loss etc., similar to transfusion reaction tracking, tracking patient falls, hospital acquired infection tracking are also not widely available. Above all, there is a tremendous need to increase the awareness of the non-trivial risks of radiation exposure in non-radiology specialties including amongst intensivists.

The immediate future needs include:

- Implementing a visible standardized method of tracking cumulative doses of radiation in inpatients and in electronic medical records (similar to tracking allergies to medications and transfusion reactions).

- A universally accepted and standardized format to report dose information that can be easily understood and interpreted by non-radiologists.
- Education of clinicians and patients regarding the potential risks of radiation exposure and the pattern of cumulative risks.
- More studies about the role of radiation exposure in the ICU and the future risk of malignancy.

Conclusions

Patients in Neuro ICUs commonly undergo multiple imaging studies, which require exposure to ionizing radiation. With increased utilization, improving the benefit-to-risk ratio has become a major challenge in medical imaging. A concerted push to educate the non-radiology medical practitioners will likely be a key step moving forward. Effective and standardized dose tracking and reporting mechanisms are currently not widely available but are eagerly anticipated in the near future.

Data availability

All data were provided within the manuscript.

Author contributions

Study design, data collection, and manuscript preparation (ABK).

Data analysis, interpretation of data, manuscript preparation (RCN, ABK).

Approval of final manuscript (ABK, RCN).

Competing interests

No competing interests were disclosed.

Grant information

The author(s) declared that no supporting grants were involved in supporting this work.

Acknowledgement

We thank Dr. Cari Buckingham, Division of Neuroradiology for her support, expertise and guidance. We also acknowledge Mary Ann Keenan, Medical physicist, Vanderbilt University Medical Center for her input and discussion.

References

1. Smith-Bindman R, Lipson J, Marcus R, *et al.*: **Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer.** *Arch Intern Med.* 2009; **169**(22): 2078–2086.
[PubMed Abstract](#) | [Publisher Full Text](#) | [Free Full Text](#)
2. Yee MV, Barron RA, Knobloch TA, *et al.*: **Radiation exposure of ventilated trauma patients in intensive care: a retrospective study comparing two time periods.** *Eur J Emerg Med.* 2012; **19**(4): 231–234.
[PubMed Abstract](#) | [Publisher Full Text](#)
3. Gelfand AA, Josephson SA: **Substantial radiation exposure for patients with subarachnoid hemorrhage.** *J Stroke Cerebrovasc Dis.* 2011; **20**(2): 131–133.
[PubMed Abstract](#) | [Publisher Full Text](#)
4. Mettler FA Jr, Huda W, Yoshizumi TT, *et al.*: **Effective doses in radiology and diagnostic nuclear medicine: a catalog.** *Radiology.* 2008; **248**(1): 254–263.
[PubMed Abstract](#) | [Publisher Full Text](#)
5. Committee on Tracking Radiation Doses from Medical Diagnostic Procedures; Nuclear and Radiation Studies Board; Division on Earth and Life Studies; *et al.*:

- Tracking Radiation Exposure from Medical Diagnostic Procedures: Workshop Reports.** Washington (DC); 2011.
[PubMed Abstract](#) | [Publisher Full Text](#)
6. Mettler FA Jr, Bhargavan M, Faulkner K, *et al.*: **Radiologic and nuclear medicine studies in the United States and worldwide: frequency, radiation dose, and comparison with other radiation sources--1950-2007.** *Radiology.* 2009; **253**(2): 520-531.
[PubMed Abstract](#) | [Publisher Full Text](#)
 7. **The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103.** *Ann ICRP.* 2007; **37**(2-4): 1-332.
[PubMed Abstract](#) | [Publisher Full Text](#)
 8. Schauer DA, Linton OW: **NCRP Report No. 160, Ionizing Radiation Exposure of the Population of the United States, medical exposure--are we doing less with more, and is there a role for health physicists?** *Health Phys.* 2009; **97**(1): 1-5.
[PubMed Abstract](#) | [Publisher Full Text](#)
 9. National Research Council (US) Committee on Health Effects of Exposure to Low Levels of Ionizing Radiations (BEIR VII): **Health Effects of Exposure to Low Levels of Ionizing Radiations: Time for Reassessment?** Washington (DC); 1998.
[PubMed Abstract](#) | [Publisher Full Text](#)
 10. El Naqa I, Pater P, Seuntjens J: **Monte Carlo role in radiobiological modelling of radiotherapy outcomes.** *Phys Med Biol.* 2012; **57**(11): R75-97.
[PubMed Abstract](#) | [Publisher Full Text](#)
 11. Berrington de González A, Mahesh M, Kim KP, *et al.*: **Projected cancer risks from computed tomographic scans performed in the United States in 2007.** *Arch Intern Med.* 2009; **169**(22): 2071-2077.
[PubMed Abstract](#) | [Publisher Full Text](#)
 12. Preston DL, Pierce DA, Shimizu Y, *et al.*: **Dose response and temporal patterns of radiation-associated solid cancer risks.** *Health Phys.* 2003; **85**(1): 43-46.
[PubMed Abstract](#) | [Publisher Full Text](#)
 13. Preston DL, Pierce DA, Shimizu Y, *et al.*: **Effect of recent changes in atomic bomb survivor dosimetry on cancer mortality risk estimates.** *Radiat Res.* 2004; **162**(4): 377-389.
[PubMed Abstract](#) | [Publisher Full Text](#)
 14. McCunney RJ, Li J: **Radiation risks in lung cancer screening programs: a comparison with nuclear industry workers and atomic bomb survivors.** *Chest.* 2014; **145**(3): 618-624.
[PubMed Abstract](#) | [Publisher Full Text](#)
 15. Brenner DJ: **Slowing the increase in the population dose resulting from CT scans.** *Radiat Res.* 2010; **174**(6): 809-815.
[PubMed Abstract](#) | [Publisher Full Text](#)
 16. **Protecting Access to Medicare Act of 2014.** Second Session edn; 2014.
[Reference Source](#)
 17. Duong PA, Little BP: **Dose tracking and dose auditing in a comprehensive computed tomography dose-reduction program.** *Semin Ultrasound CT MR.* 2014; **35**(4): 322-330.
[PubMed Abstract](#) | [Publisher Full Text](#)
 18. Cook TS, Zimmerman SL, Steingall SR, *et al.*: **RADIANCE: An automated, enterprise-wide solution for archiving and reporting CT radiation dose estimates.** *Radiographics.* 2011; **31**(7): 1833-1846.
[PubMed Abstract](#) | [Publisher Full Text](#)
 19. Hadley JL, Agola J, Wong P: **Potential impact of the American College of Radiology appropriateness criteria on CT for trauma.** *AJR Am J Roentgenol.* 2006; **186**(4): 937-942.
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