Diagnostic radiation exposure of critically ill patients in the intensive care unit

***Meropi D A Mpouzika, RN, MSc, PhD,** Lecturer, Nursing Department, School of Health Sciences, Cyprus University of Technology, Limassol, Cyprus.
Andreas Karabinis, MD, PhD, Professor, Surgical Care Unit, Onassis Cardiac Surgery Center, University of Athens, School of Medicine, Athens, Greece.
George Tsiaousis, MD, MSc, Department of Nursing, Cyprus University of Technology, Limassol, Cyprus
Paraskevi Spirou, RN, Registered Nurse, George Gennimatas General State Hospital of Athens, Greece
Eleonora Papadimitriou, RN, Registered Nurse, George Gennimatas General State Hospital of Athens, Greece
Konstantinos Tsironas, RN, Registered Nurse, George Gennimatas General State Hospital of Athens, Greece
Elizabeth D E Papathanassoglou, RN, MSc, PhD, Associate Professor, Faculty of Nursing, University of Alberta, Edmonton, Alberta, Canada

Key Words: computed tomography ❖ cumulative effective dose ❖ intensive care unit ❖ radiation exposure ❖

***E-mail:** meropi.mpouzika@cut.ac.cy

SUMMARY

- Hospitalized patients, especially intensive care unit (ICU) patients, can receive excessive doses of ionizing radiation as part of their diagnostic work-up.
- One hundred and twenty-two patients admitted in a polyvalent ICU were consecutively enrolled and the total cumulative effective dose (CED) in all ionizing-radiation diagnostic modalities were recorded.
- ICU patients receive significant radiation doses (median CED/patient was 4.08) from imaging studies, mainly CT scans. The number of CT scans, the length of ICU stay, and the admission diagnosis were associated with patient CED, but only the former two were independent predictors of it.

INTRODUCTION

Ionizing radiation-based diagnostic radiology together with fluoroscopy-guided interventions have resulted in a significant increase in medical radiation exposure in the past decades (Brenner & Hall, 2007; Fazel et al., 2009; Dainiak 2013). While the so-called "deterministic" effects of exposure to medical radiation are relatively easy to quantify, the long-term, "stochastic" effects (mainly carcinogenesis) are less predictable, as they have no threshold and tend to increase with dose accumulation over one's lifespan (Sodickson et al., 2009). The latter effects comprise the main risk conferred by low-dose diagnostic studies, such as x-rays and CTs.

Among the measures of radiation exposure currently available, the one most widely accepted and used is the cumulative effective dose (CED), typically expressed in milliSieverts (mSv). It represents a whole-body estimate of the radiation received at a particular body site (e.g. brain during a brain CT). The annual effective dose received by the average inhabitant in Greece was reported to be 4.5 mSv (Hellenic Committee on Nuclear Energy. Annual Report, 2015), of which 2.7 mSv came from natural, 'background' exposure and 1.8 mSv from medical exposure. Although the majority of medical radiation procedures take place on an outpatient basis, it has been shown that average patient exposure during the course of a single hospital stay (for patients that undergo at least one X-ray) exceeds 5mSv (Loose et al., 2010). Furthermore, among inpatients undergoing at least one ionizing-radiation procedure, Lutterman et al (2014) demonstrated an increase in exposure for patients whose hospitalization included an admission to the intensive care unit (ICU) compared to the non –critically ill (mean exposures: 17.9 vs. 11.3 mSv, p = 0.01). Literature on radiation exposure of the critically ill remains scant and exposure estimates display considerable variation. This group of patients, however, deserves special attention, because of the severe, even life-threatening course of their illness and frequent multi-organ involvement. They, therefore, undergo numerous radiological examinations during their ICU stay, other justified and other not.

Proper quantification of ICU patients' exposure to radiation could be the first step towards minimizing it, since ICU clinicians would need to adequately justify each one of the ordered radiologic studies. It is noteworthy that, regardless of specialty and years of professional experience, non-radiology ordering physicians appear to have little knowledge of dose estimates and radiation risks and tend to ignore relevant guidelines (Heyer et al., 2007; Singh et al., 2015).

We therefore sought to determine: a) the CED for patients admitted in a polyvalent ICU (compared to the national annual exposure per capita), b) the exact contribution of the usually ordered radiologic examinations to the total ICU exposure, and c) independent predictors of patient CED, which would help recognize patients most likely to receive excessive radiation doses and be at a higher risk of stochastic effects.

METHODS

Patient selection and sample

This was a prospective study conducted at a tertiary hospital in the metropolitan area of Athens, Greece. Patient recruitment took place from November 2013 through July, 2014. The desired sample size was determined to be 120 participants, in order to achieve adequate accuracy of point estimates and coefficients of determination > 0.15. All patients admitted to the polyvalent ICU of the hospital were eligible for study participation, according to the following inclusion criteria: 1) age > 18 years; 2) length of stay > 24 hours. All patients had above zero CED, as they underwent at least the routine chest X-ray required upon admission. Admission diagnoses were grouped into: 1) surgical (includes trauma patients), 2) neurosurgical, and 3) medical, whereas disease severity was assessed with a number of indices: 1) Acute Physiology and Chronic Health Evaluation (APACHE II) score, 2) Multiple Organ Dysfunction score (MODS), and 3) Multiple Organ Failure (MOF) score. Each index was determined upon ICU admission. Length of stay (LOS) was the time (in days) from ICU admission to discharge or death. Ethical approval of the study protocol was obtained from the Ethics Committee of the hospital.

Diagnostic imaging studies and dose estimation

Three types of ionizing radiation imaging procedures were performed at the ICU patients enrolled in the study: 1) single X-ray scans (including chest; abdominal; pelvic; and X-rays of the extremities), CT scans (head; chest; abdominal; and pelvic CT scans), and CT angiographies of the brain. Single scans were performed with the use of mobile radiography systems at the bedside (portable lead shields would be placed around the respective ICU bed to offer radio-protection to neighboring patients), while CTs and CT-angiographies were carried out at the Radiology Department of the hospital with the use of a multidetector 128-slice (2 x 64) dual source CT system (Siemens Definition, Germany).

The number and type of imaging procedures that participants underwent were recorded daily on a separate file, without treating physicians being aware of the study, so that ordering habits would not be influenced. Previously reported effective doses, as described for each type (and body site) of imaging study performed (Mettler et al., 2008), were used to calculate the daily CED for each study participant. Daily exposures were then summed up at patient discharge (or death) to provide total patient CED.

Statistical analysis

All continuous variables were tested for normality. Normally-distributed ones were expressed as mean ± standard deviation. Variables with skewed distributions were first appropriately transformed, in an attempt to achieve normality. If, however, normality was not achieved, non-parametric statistical tests would be used. Univariate analysis was undertaken to determine significant associations with patient CED. Linear regression analysis was then performed, in order to decide which of the univariately significant predictors of patient CED were independently linked to it. Non-normally distributed variables were: length-of-Stay (LOS), CED per patient, number of CT scans per patient. The latter were presented as median with interquartile range and treated as non-normally distributed variables. For the purpose of multivariate analysis we used log- and square-root transformation. The Statistical Package for Social Sciences, version 22, was used (Chicago, IL) and the limit of two-sided statistical significance was set at 0.05.

RESULTS

Patient characteristics

We enrolled 122 patients consecutively admitted in the ICU, according to inclusion criteria. Table 1 depicts the demographic data of enrolled patients, as well as disease-severity indices and LOS. Among admission diagnoses, neurosurgery-related ones were somewhat more frequent than surgical / trauma or internal medicine conditions.

Imaging studies and resultant CED

We identified a total of 1098 imaging procedures performed on study participants during the course of their ICU stay (see Table 2). Single X-ray scans were, as expected, the most frequent (in absolute numbers) imaging modality used, exceeding 7 scans per patient. Chest X-rays, in particular, represented the vast majority of scans. Each patient underwent, by average, approximately one brain CT scan during the ICU stay (mean number of head/brain CT per patient = 1.07, SD 1.37) whereas approximately one out of three underwent a chest CT or/and an abdominal one. Head/brain CT represented 60% of total CT scans performed, whereas pelvic CTs were the most infrequent. CT angiographies were as rare (8 in total). In terms of resultant CED however, abdominal CTs had the largest contribution among all modalities to the study group's CED (almost 37% of total exposure). Chest and brain CTs followed (32 and 25% respectively). All in all, 90.9% of total exposure was attributed to CT-scans and 6.6% to CT-angiographies, leaving only 2.5% of exposure to X-rays.

CED per patient – Univariate and multivariate associations

The median CED received by patients was 4.08 mSv (IQR 0.06-12.06) and demonstrated a wide range, with patients receiving from only 0.02 mSv up to 98.54 mSv. Patient CED showed no association with: age (Spearman $r = -0.055$, $p = 0.545$); gender (male median 4.1 mSv, IQR 0.075-12.04, vs. female 2.08 mSv, IQR 0.06-12.1, $p = 0.608$); or death as an outcome (the subgroup of 36 patients who died had comparable CED to those who were discharged alive, $p = 0.809$, Mann-Whitney's U test). The total number of CTs performed on a patient displayed a strong association with his/her radiation exposure (Spearman's $r = 0.879$, $p < 0.001$). Length of stay also demonstrated a significant correlation, but of moderate strength, with patient CED (Spearman $r = 0.467$, $p < 0.001$). Another significant correlation was between patient CED and admission diagnosis: Neurosurgical patients received significantly more radiation than Internal Medicine or Surgical/Trauma patients (Kruskal-Wallis test, $p < 0.001$). The neurosurgery group was also found to have a statistically significantly longer LOS ($p = 0.003$, see Table 3) and more CT scans performed, whereas patients with medical diagnoses had borderline higher MODS score upon admission ($P= 0.046$ for Medical vs. Neurosurgery). Still, mortality was comparable among all diagnoses (chi-square test, $p = 0.501$). Finally, disease severity as expressed by admission scores of MOF, MODS and APACHE II had no statistically significant correlation with patient CED (respectively, $p = 0.911$, 0.826, 0.275). As expected, these scores were well correlated with each other (all $p < 0.001$).

In an attempt to determine which of the three factors with statistically significant association with patient CED, that is number of CT scans, LOS and admission diagnosis, remain significant in multivariate analysis, we used linear regression with logarithmically transformed patient CED as the dependent variable. Since number of CT scans per patient and LOS were significantly skewed, too, we appropriately transformed them. Number of CT scans was the major predictor of patient CED; LOS retained its statistical significance, whereas admission diagnosis ceased to influence CED (Table 4).

DISCUSSION

In the present study, we demonstrated that the median CED received by a single patient during an ICU stay (of a median duration of over 20 days) was just above 4 mSv, which almost equals the annual dose received by the average inhabitant in Greece. Furthermore, we showed that this exposure was mainly driven by the performed CT scans, whereas single X-rays, albeit numerous, had only minimal

Table 1. Characteristics of participants (n = 122). MOF: multiple organ failure, MODS: multiple organ dysfunction, APACHE II: Acute Physiology and Chronic Health Evaluation II, CED: cumulative effective dose

Characteristics		Measure
Age (years)* (mean, SD)		55.93, 17.86
Gender	Male: female (n, %)	79: 122 (64.8: 32.2)
Admission diagnosis (n, %)	Surgical/trauma	42 (34.4)
	Neurosurgical	50 (41.0)
	Medical	30 (24.6)
Disease severity upon admission (mean, SD)	MOF	4.61, 2.16
	MODS	5.95, 2.62
	APACHE II	21.41, 7.85
Length of stay (days) (median)		23.5 (IQR 9-42, min-max 2-179)
Mortality (n, %)		36, 29.5
CED per patient (mSv) (median)		4.08 (IQR 0.06-12.06, min-max 0.02-98.54)

Table 2. Radiologic examinations received by participants. CED: cumulative effective dose, CT: computed tomography, mSv: milliSievert

Type of radiological examination		Examinations per patient n (%)	CED (mSv) and percentage within groups n (%)
X-ray n = 874 (mean per patient 7.21, SD 6.58)	Thorax	847 (96.91)	16.94 (61.11)
	Extremities	16 (1.83)	0.08 (0.29)
	Abdominal	10 (1.15)	10 (36.08)
	Pelvic	1 (0.11)	0.7 (2.52)
CT scan n = 216 (mean per patient 1.88, SD 2.17)	Brain	131 (60.65)	16.94 (61.11)
	Thorax	41 (18.98)	0.08 (0.29)
	Abdominal	38 (17.59)	10 (36.08)
	Pelvic	6 (2.78)	0.7 (2.52)
CT-angio-graphy n = 8 (mean per patient 0.04, SD 0.2	Brain	5 (62.5)	30 (40)
	Pulmonary	3 (37.5)	45 (60)

Table 3. Comparison of subgroups of patients with different admission diagnoses. LOS: length of ICU stay, CT: computed tomography, CED: cumulative effective dose, mSv: milliSievert , MOF: multiple organ failure, MODS: multiple organ dysfunction, APACHE II: Acute Physiology and Chronic Health Evaluation II. *Medical vs Neurosurgery only.

Parameter	Surgical/ Trauma	Neuro-surgical	Medical	Significance p
Number of patients	42	50	30	
LOS days median (IQR)	12.5 (4-36)	31.5 (18.5-43)	23 (8-45)	0.003
CT scans per patient mean (SD)	1.02 (2.26)	2.98 (1.91)	1.23 (1.63)	< 0.001
Patient CED (mSv) median (IQR)	0.06 (0.04-8.55)	8.1 (4.15-12.1)	1.16 (0.06-18.9)	< 0.001
MOF mean (SD)	4.9 (2.55)	4.24 (1.49)	4.79 (2.46)	
MODS† mean (SD)	6.19 (2.73)	5.27 (1.3)†	6.72 (3.7)†	0.046*
APACHE II mean (SD)	20.45 (8.15)	20.76 (6.0)	23.86 (9.74)	
Mortality n (%)	15 (35.7%)	14 (28%)	7 (23.3%)	

Table 4. Linear regression analysis for the cumulative effective dose of the participants. Dependent variable: log/transf. of the cumulative effective dose. CT: computed tomography.

Independent variables	Standardized Beta coefficient	Significance p
Length of stay (log/ transf.)	0.121	0.033
Admission diagnosis group	0.06	0.648
Number of CT scans per patient (sqrt/transf.)	0.855	< 0.001

contribution to total CED. ICU patients most likely to receive excessive doses were patients with a longer ICU stay and multiple CT scans.

Our reported median CED of approximately 4.1 mSv per ICU patient needs to be viewed in relation to CED reported elsewhere. Moloney et al. (2016) reported a lower median CED in a sample of 421 patients (1.5mSv, IQR 0.04-6.6); higher CED were recorded in trauma patients versus medical or surgical ones (respective median CED 7.7, 1.4 and 1.6 mSv). This study, however, included 23 pediatric ICU patients (aged < 17 years), who demonstrated a significantly lower exposure than adults (median CED 0.07 mSv, IQR 0.01-4.7). Still, a subset of patients (trauma patients with a longer ICU stay) did have excessive exposure, comparable to the values reported in our study. Rohner et al. (2013) reported a higher median CED of 9.35 mSv from a cohort of 74 surgical ICU patients. Pre-ICU admission exposure, however, was included by design in this study, which could have markedly increased observed exposure. Finally, Lutterman et al. (2014) measured cumulative radiation exposure in 200 inpatients, a subgroup of which were admitted during their hospital stay in the ICU; those patients had a relatively high mean CED of 17.9 mSv, while 5.5% of them exceeded 50 mSv. There are some factors that need to be taken into consideration when one tries to compare exposures from different studies. One is the type of measure, mean or median, of the central tendency of observed CED values; patient CED tends to be non-normally distributed, due to the presence of outliers, patients, that is, who receive extreme doses of radiation. Therefore, median values differ significantly (are usually much lower) from mean values. A second factor is the setting: what types of patient does the study ICU admit and to what diagnoses arevthe labels 'surgical', 'neurosurgical' or 'medical' assigned. Third, the median length of stay is of importance; studies with significantly different LOS should not be directly compared, since longer ICU stay could be correlated, as herein, with more exposure.

Still, there is a concordant finding among all of the above studies and our own, and that is the major contribution of performed CT scans to overall patient exposure. Our study found CT scans to contribute by 90.9% to total exposure; respective percentages in the studies of Lutterman et al. (2014), Moloney et al. (2016), Rohner et al. (2013) and were 82.1, 97, and 79. This fact underlines the need to avoid unnecessary CT scans, when diagnostic information of comparable value can be effectively derived by imaging modalities of minimal or no radiation. For example, the use of bedside lung ultrasound has been proved in one study to reduce the number of chest CT scans by 47% in the critically ill with pleural effusions in a poly-valent ICU (Peris et al., 2010). In another study, conducted in a medical ICU this time, the introduction of point-of-care ultrasound strikingly reduced, among other imaging modalities, both chest and abdomen/pelvis CT scans (Oks et al., 2014).

Concerning admission diagnosis and its possible link with patient CED, multivariate analysis proved this association not to be independent of LOS or number of CT scans. Since neurosurgical diagnoses led to longer LOS and significantly more CT scans per patient, it appears plausible that the number of CT scans and LOS are the mediators underlying the observed univariate association between exposure and admission diagnosis.

As for the length of ICU stay, it has not been unanimously found in available literature to be a predictor of radiation exposure. The study by Moloney et al. demonstrated a rather small LOS for its patients (median value 5 days) (Moloney et al., 2016) and since LOS was independently linked to excessive exposure (> 15 mSv), the small median LOS explains the rather small median exposure of 1.5mSv. In our study, LOS was found to independently predict patient CED, though not as robustly as the number of performed CT scans per patient. However, LOS was marginally found not to play a significant role in predicting exposure in the study of Rohner et al. (2013). Although it seems logical for CED to increase with LOS, this is not always the case and the explanation could lie again in the non-uniformity of admission diagnoses and patient turnover rates among various ICUs.

When it comes to disease severity, our study suggested, in concordance with Moloney et al., that the usual scores implemented in everyday ICU clinical practice did not predict total patient exposure. The same goes for the eventual outcome (death or ICU discharge), which again failed to discriminate patients with high vs. low exposure. One could argue that graver disease should necessitate more diagnostic studies from ordering physicians. This is not necessarily so; in our study, neither mortality ($p = 0.433$) nor disease severity scores [respective signifivance (p) for MOF, MODS, and APACHE II, 0.455, 0.288, and 0.657] were associated with the number of CT scans per patient, the major contributor of patient CED.

Limitations

Our study has some limitations. The study sample comes from a single polyvalent ICU of a tertiary, general hospital; this makes results difficult to generalize to all ICUs, dedicated trauma, surgical or medical ones. Still, the central idea of significant, CT-driven exposure of ICU patients proves to be totally generalizable and the avoidance of unnecessary CT-use should be the message to all non-radiologists, ICU physicians included. Another limitation of our study derives from the fact that no actual exposure was measured (e.g. with the use of dosimeters), but dose estimates were produced based on reference doses according to each study type and body site. There is evidence that actual doses, measured with dosimetric methods, tend to be lower than dose estimates (Panuccio et al., 2011). Even within each type of CT examination, a significant variation of measured doses has been demonstrated among different radiology departments (Smith-Bindman et al., 2009). Until, however, better standardization is succeeded in the way dose estimates are produced in different institutions, CT scanners and patients, the dose estimation used in the present study appears to be widely accepted and the most easy-to-use, which is of particular importance when radiological awareness needs to be enhanced in non-radiologists.

CONCLUSIONS

The universal increase in healthcare consumers' radiation exposure could not leave ICU patients unaffected. Computed tomography plays a central role, since most of the exposure is attributed to it. The critically ill, representing a subgroup of patients with relatively high morbidity and mortality, usually undergo at least one CT scan during their ICU stay. As a result, they receive, within a few days, radiation equivalent to the yearly sum of medical and other radiation of the average individual. Despite the fact that absorbed doses lower than 100 mSV aren't seen to have acute harmful effects on tissues (ICRP, 2012) there is a lack of evidence about the long-term effects of radiation exposure. Until the availability of more results on this, awareness of ordering physicians in the ICU regarding the radiation exposures involved in their patients' management is the first step towards justification of all requested ionizing diagnostic studies. Strategies that should be taken into consideration: (1) the possible reduction of the radiation dose delivered, (2) the limitation of unnecessary CT examinations and the use of alternative diagnostic methods such as ultrasound (3) the implement of protocols regarding the recording of a personal medical identity card, showing the total amount of radiation the patient has received during his hospitalization

REFERENCES

Brenner DJ, Hall EJ (2007). Computed tomography - an increasing source of radiation exposure. The New England Journal of Medicine 357(22), 2277-2284.

Dainiak N (2013). Radiation dose and stochastic risk from exposure to medical imaging. Chest 144(5), 1431-1433.

Fazel R, Krumholz HM, Wang Y, Ross JS, Chen J, Ting HH, Shah ND, Nasir K, Einstein AJ, Nallamothu BK (2009). Exposure to low-dose ionizing radiation from medical imaging procedures. The New England Journal of Medicine 361(9), 849-857.

Hellenic Committee on Nuclear Energy. Annual Report, 2015. [Online] Available at: https://eeae.gr/. Accessed at 01 Oct 2016.

Heyer CM, Peters S, Lemburg S, Nicolas V (2007). Awareness of radiation exposure of thoracic CT scans and conventional radiographs: what do non-radiologists know? Rofo 179(3), 261-267.

ICRP. ICRP statement on tissue reactions/Early and late effects of radiation in normal tissues and organs – Threshold doses for tissue reactions in a radiation protection context. ICRP Publication 118. Ann. ICRP 41(1–2) (2012)

Loose RW, Popp U, Wucherer M, Adamus R (2010). Medical radiation exposure and justification at a large teaching hospital: comparison of radiation-related and disease-related risks. Rofo 182(1), 66-70.

Lutterman AC, Moreno CC, Mittal PK, Kang J, Applegate KE (2014). Cumulative radiation exposure estimates of hospitalized patients from radiological imaging. Journal of the American College of Radiology 11(2), 169-175.

Mettler FA Jr, Huda W, Yoshizumi TT, Mahesh M (2008). Effective doses in radiology and diagnostic nuclear medicine: a catalog. Radiology 248(1), 254-263.

Moloney F, Fama D, Twomey M, O'Leary R, Houlihane C, Murphy KP, O'Neill SB, O'Connor OJ, Breen D, Maher MM (2016). Cumulative radiation exposure from diagnostic imaging in intensive care unit patients. World Journal of Radiology 8(4), 419-427.

Oks M, Cleven KL, Cardenas-Garcia J, Schaub JA, Koenig S, Cohen RI, Mayo PH, Narasimhan M (2014). The effect of point-of-care ultrasonography on imaging studies in the medical ICU: a comparative study. Chest 146(6), 1574-1577.

Panuccio G, Greenberg RK, Wunderle K, Mastracci TM, Eagleton MG, Davros W (2011). Comparison of indirect radiation dose estimates with directly measured radiation dose for patients and operators during complex endovascular procedures. Journal of Vascular Surgery 53(4), 885-894.

Peris A, Tutino L, Zagli G, Batacchi S, Cianchi G, Spina R, Bonizzoli M, Migliaccio L, Perretta L, Bartolini M, Ban K, Balik M (2010). The use of point-of-care bedside lung ultrasound significantly reduces the number of radiographs and computed tomography scans in critically ill patients. Anesthesia and Analgesia 111(3), 687-692.

Rohner DJ, Bennett S, Samaratunga C, Jewell ES, Smith JP, Gaskill-Shipley M, Lisco SJ (2013). Cumulative total effective whole-body radiation dose in critically ill patients. Chest 144(5), 1481-1486.

Singh P, Aggarwal S, Singh Kapoor AM, Kaur R, Kaur A (2015). A prospective study assessing clinicians attitude and knowledge on radiation exposure to patients during radiological investigations. Journal of Natural Science, Biology and Medicine 6(2), 398-401.

Smith-Bindman R, Lipson J, Marcus R, Kim KP, Mahesh M, Gould R, Berrington de González A, Miglioretti DL (2009). Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Archives of Internal Medicine 169(22), 2078-2086.

Sodickson A, Baeyens PF, Andriole KP, Prevedello LM, Nawfel RD, Hanson R, Khorasani R (2009). Recurrent CT, cumulative radiation exposure, and associated radiation-induced cancer risks from CT of adults. Radiology 251(1), 175-184.