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# CUMULATIVE MEDICAL RADIATION: UNCOVERING KEY DRIVERS AND VULNERABLE POPULATIONS

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**Abstract**
The widespread adoption of advanced medical imaging technologies has dramatically improved diagnostic capabilities but has simultaneously raised concerns about cumulative radiation exposure from recurrent imaging procedures. This comprehensive review examines the growing evidence on high cumulative effective doses (CEDs) in medical imaging, identifying key patient populations at risk and analyzing the primary drivers of repeated imaging. Drawing on multinational data, we explore the prevalence of patients receiving CEDs exceeding 100 mSv—a threshold considered significant for radiation protection purposes. Certain clinical scenarios emerge as particularly associated with high cumulative radiation exposure, including trauma care, intensive care unit admissions, chronic conditions requiring regular monitoring, and emergency department revisits. The review discusses radiation protection principles, risk communication challenges, and practical strategies to optimize radiation exposure while maintaining diagnostic quality. By synthesizing current evidence, we provide insights for healthcare providers to identify high-risk patients and implement appropriate radiation management strategies while ensuring optimal patient care.

## INTRODUCTION

Medical imaging has revolutionized healthcare by enabling non-invasive diagnosis and monitoring of numerous conditions. Computed tomography (CT), in particular, has become a cornerstone of modern medicine due to its speed, accessibility, and exceptional diagnostic capabilities. However, the growing utilization of ionizing radiation-based imaging modalities has raised important questions about cumulative radiation exposure and potential long-term health effects, particularly in frequently imaged patients (Vassileva & Holmberg, 2021).

While the benefits of appropriate medical imaging typically outweigh potential radiation risks for individual examinations, the cumulative radiation exposure from multiple procedures over time presents a more complex risk-benefit consideration. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), medical exposure now constitutes the largest source of artificial radiation exposure to the general population in developed countries, surpassing natural background radiation for some individuals (UNSCEAR, 2020/2021).

Recent studies have highlighted the existence of a subset of patients who undergo recurrent imaging examinations and consequently accumulate substantial radiation doses. Multinational data has revealed that a small but significant percentage of patients receive cumulative effective doses (CEDs) exceeding 100 mSv—a threshold often cited for radiation protection purposes as being associated with a small but statistically significant increase in cancer risk based on epidemiological studies (Brambilla et al., 2020). Understanding the magnitude of recurrent imaging, identifying vulnerable patient populations, and recognizing the key drivers of repeated examinations are essential for implementing appropriate radiation protection strategies while maintaining high-quality patient care. This review aims to comprehensively examine the current evidence on cumulative radiation exposure from medical imaging, focusing on prevalence, high-risk scenarios, contributing factors, and potential approaches to optimization.

## Prevalence and Magnitude of High Cumulative Effective Doses

### Global Perspective on Recurrent Imaging

Multiple studies across different countries have sought to quantify the prevalence of patients receiving high cumulative effective doses from medical imaging. In a landmark study by Rehani et al. (2020) examining patients across 35 OECD countries, approximately 7 million patients were estimated to have received CEDs exceeding 100 mSv from recurrent CT examinations. This represented about 0.7% of all CT patients across the studied institutions, indicating a relatively small but significant subset of the patient population.

A separate multi-center European study by Brambilla et al. (2020) analyzed data from four countries (Italy, Belgium, Switzerland, and Germany) and found that between 0.7% and 1.9% of all patients undergoing radiological procedures accumulated effective doses of 100 mSv or higher during the study periods. The authors emphasized that this represents a concerning number of patients when scaled to national populations, potentially reaching tens of thousands of individuals in medium-sized countries.

In the Belgian context, a comprehensive analysis of 23 hospitals by Fitousi et al. (2020) identified approximately 0.14% of nearly 900,000 unique patients as CED outliers with doses exceeding 100 mSv. The median CED among these outliers was 125 mSv, with an interquartile range of 110-151 mSv. Notably, a gender disparity was observed, with males constituting 67% of high-dose cases compared to 33% females, suggesting potential differences in disease patterns, clinical presentations, or healthcare utilization between genders.

### Temporal Patterns and Dose Distribution

The timeframe within which patients accumulate high radiation doses varies considerably. While some patients may reach concerning dose levels over many years, others accumulate substantial doses within much shorter periods due to complex clinical scenarios requiring intensive imaging. Brambilla et al. (2021) reported that some patients received CEDs exceeding 100 mSv within a single episode of care, particularly those undergoing multiphase CT scans for complex conditions.

In terms of dose distribution, Rehani et al. (2020) found that while the majority of high-CED patients received between 100 and 200 mSv, a significant proportion accumulated much higher doses. In their multinational study, approximately 1.3% of high-dose patients (or about 0.01% of all patients) received cumulative effective doses exceeding 500 mSv, underscoring the extreme exposure in certain cases.

Yang et al. (2024) highlighted the significant contribution of CT to cumulative radiation exposure, noting that while CT examinations constituted only 12% of all imaging procedures in their institutional study, they contributed to over 75% of the total collective effective dose. This disproportionate contribution emphasizes the importance of focusing optimization efforts on CT protocols, especially for frequently imaged patients.

## Vulnerable Patient Populations and Clinical Scenarios

### Trauma Patients

Trauma care represents one of the most significant contributors to high cumulative radiation doses due to the comprehensive and often repeated imaging required to assess life-threatening injuries. Whole-body CT (WBCT) protocols, while valuable for rapid assessment of polytrauma patients, deliver substantial radiation doses in a single examination session (Martínez Chamorro et al., 2023).

Sierink et al. (2013) reported that the implementation of dedicated total-body CT protocols for multitrauma patients resulted in significantly higher initial radiation exposure compared to conventional selective imaging approaches. However, they also observed that the total radiation exposure throughout the hospital stay did not significantly differ between approaches, suggesting that selective imaging often leads to multiple follow-up examinations that ultimately result in similar cumulative doses.

A particular concern in trauma care is the phenomenon of repeat imaging following patient transfers between facilities. Young et al. (2012) found that trauma patients transferred to level I trauma centers frequently underwent repeat CT scans despite having imaging performed at the referring facility. This duplication was attributed to various factors, including perceived inadequate image quality, incompatible imaging formats, clinical deterioration, or institutional policies requiring in-house imaging. Mohan et al. (2010) reported that approximately 25% of CT scans performed prior to transfer were repeated after arrival at the receiving trauma center, contributing to unnecessary radiation exposure.

Pediatric trauma patients face particular concerns regarding radiation exposure due to their greater radiosensitivity and longer life expectancy, which provides more time for potential radiation-induced cancers to develop. Nabaweesi et al. (2018) found that injured children treated at non-pediatric trauma centers received approximately twice the radiation dose compared to those treated at pediatric trauma centers, highlighting the importance of pediatric-specific protocols and expertise in minimizing radiation exposure.

**Intensive Care Unit (ICU) Patients**

Patients in intensive care units represent another highly vulnerable population for cumulative radiation exposure. Due to their critical condition and the need for frequent monitoring, ICU patients often undergo multiple radiological examinations during their hospital stay, primarily portable chest X-rays and CT scans (Zanon et al., 2024).

Trotman-Dickenson (2003) described the central role of radiological examinations in ICU care, noting that daily chest radiographs were standard practice in many ICUs for monitoring endotracheal tube placement, central venous catheters, and disease progression. While more selective approaches are now recommended, frequent imaging remains common in critically ill patients.

Krishnan et al. (2018) conducted a comprehensive analysis of radiation exposure in medical ICU patients and found that the median cumulative effective dose was 1.5 mSv, with CT scans accounting for 71% of the total radiation exposure despite constituting only 17% of all imaging studies. Notably, patients with longer ICU stays, those with pulmonary conditions, and those requiring mechanical ventilation were identified as particularly prone to high cumulative radiation exposure.

Hill & Horner (2008) and more recently Toy et al. (2022) emphasized the challenges of performing optimal imaging studies in the ICU environment, where portable examinations often result in technical limitations that may necessitate repeat imaging, further contributing to cumulative dose. The critical nature of ICU patients' conditions often justifies extensive imaging despite radiation concerns, creating a complex risk-benefit scenario that requires careful consideration.

**Patients with Chronic Conditions**

Individuals with chronic diseases requiring regular monitoring represent a third major category of patients at risk for high cumulative radiation exposure. Stein et al. (2010) examined radiation exposure in patients with chronic and recurrent conditions and found that those with Crohn's disease, kidney stones, and pulmonary thromboembolic disease were particularly likely to receive high cumulative effective doses.

Brambilla et al. (2013) reported that patients with Crohn's disease received a median cumulative effective dose of 25 mSv over a 7-year follow-up period, with approximately 16% receiving CEDs exceeding 75 mSv. Similarly, patients with recurrent urolithiasis often undergo multiple CT examinations for each episode of renal colic. Katz et al. (2006) found that patients with suspected renal colic underwent an average of 1.3 CT scans per emergency department visit, with some patients receiving up to 18 CT examinations over the study period.

Rehani et al. (2020) conducted a detailed analysis of patients undergoing recurrent CT examinations for non-malignant diseases and identified several common conditions associated with high cumulative doses, including chronic obstructive pulmonary disease, interstitial lung disease, vascular diseases, and neurological disorders. They emphasized that many of these patients had legitimate medical indications for repeated imaging, highlighting the challenge of balancing diagnostic necessity with radiation protection principles.

**Emergency Department Frequent Users**

Emergency department (ED) frequent users constitute another population at risk for high cumulative radiation exposure. Hunt et al. (2006) and Hansagi et al. (2001) characterized frequent ED users as individuals who often have complex medical and social needs, including chronic diseases, mental health conditions, and limited access to primary care. These patients typically undergo multiple imaging studies during repeated ED visits, contributing to substantial cumulative doses over time.

Griffey & Sodickson (2009) specifically examined cumulative radiation exposure in emergency department patients undergoing repeat or multiple CT examinations. They found that patients with three or more ED visits were significantly more likely to receive high cumulative effective doses compared to patients with fewer visits. The authors noted that these frequent users often presented with non-specific symptoms such as abdominal pain, which frequently prompted CT imaging due to diagnostic uncertainty.

Lee et al. (2019) investigated the prevalence of repeat CT scanning within one month of ED visits for abdominal pain. They found that approximately 5% of patients underwent repeat CT examinations within 30 days, with older age, higher initial pain scores, and specific clinical conditions such as urinary tract infections and gastrointestinal disorders associated with increased likelihood of repeated imaging.

## Key Drivers of Repeated Medical Imaging

### Clinical Factors Driving Repeat Examinations

Multiple clinical factors contribute to the phenomenon of repeated imaging examinations. Disease progression monitoring represents a legitimate and necessary reason for sequential imaging, particularly in chronic conditions such as inflammatory bowel disease, interstitial lung disease, or vascular disorders. In these cases, repeat examinations are essential for assessing treatment response, detecting complications, and guiding management decisions (Brambilla et al., 2013).

Diagnostic uncertainty and inconclusive initial findings frequently necessitate additional imaging to clarify ambiguous results or investigate alternative diagnoses. Ahn et al. (2021) examined cases of emergency department revisits with repeat CT or MRI and found that diagnostic errors—including missed diagnoses, misinterpretations, or incomplete evaluations—were present in approximately 12% of cases, often necessitating repeat imaging during subsequent visits.

Clinical deterioration or new symptom development naturally prompts reassessment, frequently including repeat imaging to evaluate changing conditions. This is particularly common in dynamic clinical scenarios such as trauma, where patients may initially appear stable but later develop complications requiring comprehensive reevaluation (Haley et al., 2009).

Post-intervention monitoring represents another significant driver of repeated imaging, as patients undergoing surgical procedures, catheter-based interventions, or radiation therapy require follow-up studies to assess treatment efficacy and detect potential complications. This longitudinal imaging approach is standard practice in many clinical pathways but contributes substantially to cumulative radiation exposure (Rehani et al., 2020).

### System and Process Factors

Beyond clinical considerations, numerous system and process factors contribute to repeated imaging. Inadequate communication and information sharing between healthcare facilities frequently leads to duplicate examinations when patients transition between institutions. Young et al. (2012) reported that approximately 60% of transferred trauma patients underwent repeat imaging at the receiving facility, with incomplete transfer of prior imaging studies identified as a major contributing factor.

Medicolegal considerations and defensive medicine practices influence imaging decisions, with clinicians often ordering comprehensive examinations to minimize the risk of missed diagnoses. Tung et al. (2018) identified fear of malpractice litigation as a significant factor associated with imaging overuse in emergency departments, particularly for high-risk presentations such as chest pain, abdominal pain, and headache.

Protocol variations between institutions pose another challenge, as imaging protocols optimized for specific equipment or institutional preferences may not align across facilities. This misalignment often results in repeat examinations when patients move between healthcare systems, as receiving clinicians may perceive prior studies as inadequate or incompatible with local practice patterns (Mohan et al., 2010).

Limited access to prior imaging studies remains a persistent problem despite technological advances. When previous examinations are unavailable for comparison—whether due to interoperability issues, different electronic health record systems, or logistical barriers—clinicians often order new studies rather than delay care while awaiting historical images (Nol et al., 2005).

## Radiation Protection Considerations

### Cumulative Dose and Risk Assessment

The relationship between radiation exposure and potential health risks forms the foundation of radiation protection principles in medicine. The International Commission on Radiological Protection (ICRP) acknowledges that while effective dose was not initially intended for individual patient risk assessment, it remains a useful metric for comparing relative radiation detriment across different procedures and for estimating potential population risks (ICRP, 2007).

Current epidemiological evidence primarily supports a linear no-threshold model for radiation-induced cancer risk at doses above 100 mSv, with uncertainties at lower doses. The UNSCEAR (2020/2021) maintains that while theoretical risks exist at lower doses, they are small in comparison to the natural cancer incidence and difficult to detect epidemiologically. Nevertheless, the precautionary principle supports efforts to minimize unnecessary radiation exposure, particularly in vulnerable populations.

Martin & Barnard (2022) emphasize that while concerns about cumulative effective doses are justified, they should be contextualized against the clear medical benefits of necessary imaging procedures. They argue for a balanced approach that acknowledges both the potential risks of radiation exposure and the significant benefits of appropriate medical imaging, avoiding overly restrictive practices that might compromise patient care.

Cao et al. (2022) conducted a systematic review and meta-analysis of CT scans and cancer risks, reporting a positive dose-response relationship between CT exposure and cancer risk, with each 10 mGy increase in cumulative organ dose associated with a 5% increase in overall cancer risk. However, they noted substantial heterogeneity across studies and emphasized that individual risk assessment should consider patient-specific factors including age, sex, and clinical condition.

**Special Considerations for Pediatric Patients**

Children require particular attention in radiation protection discussions due to their higher radiosensitivity and longer life expectancy, which provides more opportunity for potential radiation-induced cancers to develop. Larson et al. (2011) reported a significant increase in CT utilization in pediatric emergency departments in the United States between 1995 and 2008, raising concerns about radiation exposure in this vulnerable population.

Ohana et al. (2018) specifically examined CT and MRI overuse in pediatric emergency departments and identified several common scenarios associated with potentially unnecessary radiation exposure, including minor head trauma, suspected appendicitis, and abdominal pain. They emphasized the importance of clinical decision rules, appropriate use criteria, and alternative imaging modalities such as ultrasound to reduce radiation exposure in pediatric patients.

Simanovsky et al. (2016) compared the diagnostic value of CT and ultrasound in evaluating acute abdominal pain in children younger than 10 years and found that ultrasound had high sensitivity and specificity for common conditions such as appendicitis. They advocated for an "ultrasound first" approach in pediatric abdominal imaging to minimize radiation exposure while maintaining diagnostic accuracy.

Howe et al. (2014) questioned the routine practice of repeat brain CT in children with mild traumatic brain injury, finding that it rarely altered management and likely resulted in unnecessary radiation exposure. They proposed more selective imaging approaches based on clinical assessment and risk stratification to reduce radiation burden in pediatric trauma patients.

**Optimization Strategies and Future Directions**

**Clinical Decision Support and Appropriateness Criteria**

Implementing evidence-based clinical decision support systems represents a powerful strategy for reducing unnecessary imaging. Mills et al. (2015) described the integration of clinical decision rules into electronic ordering systems to guide appropriate imaging selection based on specific clinical scenarios and patient characteristics. These tools help clinicians identify situations where imaging may not be necessary or where alternative non-radiation-based modalities might be sufficient.

Appropriateness criteria developed by professional organizations provide standardized guidance for imaging utilization across common clinical scenarios. Frush et al. (2024) emphasized the importance of these criteria in reducing unwarranted variation in imaging practices and encouraging evidence-based decision-making. They also highlighted the need for regular updates to incorporate emerging evidence and technological advances.

**Dose Tracking and Monitoring Systems**

Technological solutions such as dose tracking and monitoring systems enable healthcare institutions to identify patients with high cumulative radiation exposure. Fitousi et al. (2020) described the implementation of dose management systems across multiple Belgian hospitals, allowing for standardized effective dose calculations and the identification of patients exceeding dose thresholds. Such systems can generate alerts when patients approach or exceed predefined dose levels, prompting clinicians to consider radiation history in their decision-making.

Ria et al. (2024) demonstrated the value of characterizing imaging radiation risk in a population of patients with recurrent imaging. By analyzing dose data from nearly 9,000 patients, they developed a more nuanced understanding of effective dose distribution and identified specific factors associated with higher cumulative exposure. This approach enables more targeted interventions to reduce unnecessary radiation burden while maintaining diagnostic quality.

**Protocol Optimization and Technical Innovations**

Advances in CT technology have enabled significant dose reductions while maintaining or improving image quality. Iterative reconstruction algorithms, automatic exposure control, tube current modulation, and noise reduction techniques all contribute to the principle of optimization—achieving diagnostic-quality images at the lowest reasonably achievable dose. Mahesh et al. (2023) reported that these technological innovations have resulted in substantial dose reductions for common CT examinations over the past decade.

Protocol standardization and harmonization across institutions represent another important optimization approach, particularly for frequently imaged patient populations. Neef et al. (2024) described efforts to standardize trauma CT protocols across multiple centers, reducing unnecessary variation in radiation exposure while maintaining diagnostic efficacy. Such harmonization is particularly valuable for patients who receive care across different healthcare facilities.

**Risk Communication and Informed Decision-Making**

Effective communication about radiation risks and benefits is essential for informed decision-making by both clinicians and patients. Vassileva et al. (2022) conducted an IAEA-coordinated international survey on communication of radiation risk from imaging studies and found significant variability in practices across countries and institutions. They emphasized the need for consistent, balanced, and evidence-based risk communication to avoid both unwarranted fear and inappropriate dismissal of legitimate concerns.

Brower & Rehani (2021) highlighted the importance of contextualizing radiation risk discussions within the specific clinical scenario, considering factors such as patient age, life expectancy, and the potential benefits of imaging. They advocated for a patient-centered approach that acknowledges uncertainties while providing sufficient information for shared decision-making.

**Global Perspective and Health Equity Considerations**

**Regional Variations in Medical Radiation Exposure**

Significant regional variations exist in medical radiation exposure patterns, reflecting differences in healthcare systems, resource availability, and practice patterns. Mahesh et al. (2023) reported that while medical radiation exposure has stabilized or decreased in many high-income countries due to increased awareness and optimization efforts, it continues to rise in middle-income countries as access to advanced imaging technologies expands.

Bishr & Zaghloul (2018) highlighted the disparities in radiation-based medical technologies between high-income and low/middle-income countries, noting that limited access to diagnostic and therapeutic radiation facilities in many regions results in different patterns of cumulative exposure. In some contexts, the primary concern is not overutilization but rather insufficient access to essential imaging services.

Ng et al. (2021) examined the status of radiation protection in medicine across the Asia-Pacific region and identified substantial heterogeneity in regulatory frameworks, quality assurance programs, and professional education. They emphasized the need for harmonized approaches to radiation protection that acknowledge regional resource constraints while maintaining fundamental safety principles.

**Challenges in Low-Resource Settings**

In low-resource settings, unique challenges influence radiation protection practices and cumulative exposure patterns. Limited availability of alternative imaging modalities such as MRI or ultrasound may increase reliance on radiation-based techniques like CT, potentially contributing to higher cumulative doses for certain patient populations. Conversely, restricted access to advanced imaging may result in lower population exposure but potentially compromise diagnostic capabilities.

Inadequate quality assurance infrastructure and outdated equipment in some regions can lead to higher doses per examination, as older technologies may lack modern dose optimization features. This technical limitation compounds the challenge of managing cumulative exposure, as each imaging encounter may deliver higher radiation doses than would be typical with contemporary equipment (Vassileva & Holmberg, 2021).

Workforce training disparities also influence radiation protection practices globally. Alshihri et al. (2024) assessed awareness of medical ionizing radiation exposure among healthcare professionals in Saudi Arabia and found significant knowledge gaps, particularly regarding dose levels and potential risks. Similar knowledge deficiencies have been reported in various regions, highlighting the need for enhanced radiation protection education in healthcare professional training programs.

## CONCLUSION AND FUTURE PERSPECTIVES

This comprehensive review has examined the growing evidence on cumulative radiation exposure from medical imaging, identifying key patient populations at risk and analyzing the primary drivers of repeated examinations. The evidence clearly indicates that a small but significant percentage of patients—approximately 0.7-1.9% across various studies—receive cumulative effective doses exceeding 100 mSv, a level considered relevant for radiation protection purposes.

Several vulnerable patient populations emerge from the literature, including trauma patients, intensive care unit patients, individuals with chronic conditions requiring regular monitoring, and emergency department frequent users. These groups experience recurrent imaging for legitimate clinical reasons, yet their cumulative radiation exposure warrants careful attention and optimization efforts.

Both clinical and system factors contribute to repeated imaging, including disease progression monitoring, diagnostic uncertainty, inadequate information sharing between facilities, defensive medicine practices, and protocol variations across institutions. Addressing these drivers requires a multifaceted approach involving clinical decision support, dose tracking systems, protocol optimization, and enhanced communication practices.

Looking forward, several priorities emerge for research and practice in this field. First, prospective longitudinal studies with detailed dose reconstruction are needed to better characterize cumulative radiation exposure patterns across different patient populations and healthcare settings. Second, enhanced interoperability of medical imaging systems and electronic health records would facilitate improved access to prior examinations, potentially reducing duplicate imaging. Third, machine learning and artificial intelligence applications offer promising approaches for image optimization, protocol selection, and identification of high-risk patients who might benefit from enhanced radiation protection measures.

Finally, a balanced perspective on radiation risk is essential, recognizing both the potential concerns associated with high cumulative doses and the clear medical benefits of appropriate imaging. By maintaining this balance, healthcare providers can work toward optimizing radiation protection while ensuring that patients receive the imaging studies necessary for their care, ultimately enhancing both safety and clinical outcomes in medical imaging practices worldwide.

## REFERENCES

1. Ahn, Y., Hong, G. S., Park, K. J., Lee, C. W., Lee, J. H., & Kim, S. O. (2021). Impact of diagnostic errors on adverse outcomes: learning from emergency department revisits with repeat CT or MRI. Insights Imaging, 12, 160. https://doi.org/10.1186/s13244-021-01108-0
2. Alshihri, A. A., Hadadi, I., Alqahtani, B., Alshahrani, A., Alahmari, N., Assiri, M., et al. (2024). Assessing the awareness of medical ionizing radiation exposure among general public in Saudi Arabia: aseer region. King Khalid Univ J Health Sci, 9, 150–156.
3. https://doi.org/10.4103/KKUJHS.KKUJHS_23_24
4. Bishr, M. K., & Zaghloul, M. S. (2018). Radiation therapy availability in Africa and Latin America: two models of low and middle income countries. Int J Radiation Oncol Biol Phys, 102, 490–498. https://doi.org/10.1016/j.ijrobp.2018.06.046
5. Brambilla, M., De Mauri, A., Leva, L., Carriero, A., & Picano, E. (2013). Cumulative radiation dose from medical imaging in chronic adult patients. Am J Med, 126, 480–486.
6. https://doi.org/10.1016/j.amjmed.2012.10.025
7. Brambilla, M., Vassileva, J., Kuchcinska, A., & Rehani, M. M. (2020). Multinational data on cumulative radiation exposure of patients from recurrent radiological procedures: call for action. Eur Radiol, 30, 2493–2501. https://doi.org/10.1007/s00330-019-06528-7
8. Brower, C., & Rehani, M. M. (2021). Radiation risk issues in recurrent imaging. Br J Radiol, 94, 20210389. https://doi.org/10.1259/bjr.20210389
9. Cao, C. F., Ma, K. L., Shan, H., Liu, T. F., Zhao, S. Q., Wan, Y., et al. (2022). CT scans and Cancer risks: a systematic review and dose-response Meta-analysis. BMC Cancer, 22, 1238.
10. https://doi.org/10.1186/s12885-022-10310-2
11. Fitousi, N., Bosmans, H., Dewilde, S., Zhang, X-Q., Dedulle, A. S. L., & Jacobs, J. (2020). Analysis of cumulated effective doses in medical imaging. ECR 2020 EPOS.
12. https://epos.myesr.org/poster/esr/ecr2020/C-14578
13. Frush, D. P., Vassileva, J., Brambilla, M., Mahesh, M., Rehani, M., Samei, E., et al. (2024). Recurrent medical imaging exposures for the care of patients: one way forward. Eur Radiol, 34, 6475–6487. https://doi.org/10.1007/s00330-024-10659-x
14. Griffey, R. T., & Sodickson, A. (2009). Cumulative radiation exposure and cancer risk estimates in emergency department patients undergoing repeat or multiple CT. AJR Am J Roentgenol, 192, 887–892. https://doi.org/10.2214/AJR.08.1351
15. Haley, T., Ghaemmaghami, V., Loftus, T., Gerkin, R. D., Sterrett, R., & Ferrara, J. J. (2009). Trauma: the impact of repeat imaging. Am J Surg, 198, 858–862.
16. https://doi.org/10.1016/j.amjsurg.2009.05.030
17. Hansagi, H., Olsson, M., Sjöberg, S., Tomson, Y., & Göransson, S. (2001). Frequent use of the hospital emergency department is indicative of high use of other health care services. Ann Emerg Med, 37, 561–567. https://doi.org/10.1067/mem.2001.111762
18. Hill, J. R., & Horner, P. E. (2008). ICU imaging. Clin Chest Med, 29, 59–76.
19. https://doi.org/10.1016/j.ccm.2007.11.005
20. Howe, J., Fitzpatrick, C. M., LaKam, D. R., Gleisner, A., Vane, D. W. (2014). Routine repeat brain computed tomography in all children with mild traumatic brain injury may result in unnecessary radiation exposure. J Trauma Acute Care Surg, 76, 292–296.
21. https://doi.org/10.1097/TA.0000000000000119
22. Hunt, K. A., Weber, E. J., Showstack, J. A., Colby, D. C., & Callaham, M. L. (2006). Characteristics of frequent users of emergency departments. Ann Emerg Med, 48, 1–8.
23. https://doi.org/10.1016/j.annemergmed.2005.12.030
24. ICRP (2007). Publication 105. Radiation protection in medicine. Ann ICRP, 37, 3–5.
25. https://doi.org/10.1016/j.icrp.2008.08.001
26. Katz, S. I., Saluja, S., Brink, J. A., & Forman, H. P. (2006). Radiation dose associated with unenhanced CT for suspected renal colic: impact of repetitive studies. Am J Roentgenol, 186, 1120–1124. https://doi.org/10.2214/AJR.04.1838
27. Krishnan, S., Moghekar, A., Duggal, A., Yella, J., Narechania, S., Ramachandran, V., et al. (2018). Radiation exposure in the medical ICU: predictors and characteristics. Chest, 153, 1160–1168. https://doi.org/10.1016/j.chest.2018.01.019
28. Larson, D. B., Johnson, L. W., Schnell, B. M., Goske, M. J., Salisbury, S. R., & Forman, H. P. (2011). Rising use of CT in child visits to the emergency department in the United States, 1995-2008. Radiology, 259, 793–801. https://doi.org/10.1148/radiol.11101939
29. Lee, L. K., Reisner, A. T., Binder, W. D., Zaheer, A., Gunn, M. L., Linnau, K. F., et al. (2019). Repeat CT performed within one month of CT conducted in the emergency Department for Abdominal Pain:

a secondary analysis of data from a prospective multicenter study. Am J Roentgenol, 212, 382–385. https://doi.org/10.2214/AJR.18.20060
30. Martin, C. J., & Barnard, M. (2022). How much should we be concerned about cumulative effective doses in medical imaging? J Radiol Prot, 42, 011514. https://doi.org/10.1088/1361-6498/ac31c1
31. Martínez Chamorro, E., Ibáñez Sanz, L., Blanco Barrio, A., Chico Fernández, M., & Borruel Nacenta, S. (2023). Patients with severe polytrauma: management and imaging protocols. Radiología, 65, S11–20. https://doi.org/10.1016/j.rxeng.2022.09.008
32. Mills, A. M., Raja, A. S., & Marin, J. R. (2015). Optimizing diagnostic imaging in the emergency department. Acad Emerg Med, 22, 625–631. https://doi.org/10.1111/acem.12640
33. Mohan, D., Barnato, A. E., Angus, D. C., & Rosengart, M. R. (2010). Determinants of compliance with transfer guidelines for trauma patients: a retrospective analysis of CT scans acquired prior to transfer to a level I trauma center. Ann Surg, 251, 946–951.
34. https://doi.org/10.1097/SLA.0b013e3181d76cb5
35. Nabaweesi, R., Ramakrishnaiah, R. H., Aitken, M. E., Rettiganti, M. R., Luo, C., Maxson, R. T., et al. (2018). Injured children receive twice the radiation dose at nonpediatric trauma centers compared with pediatric trauma centers. J Am Coll Radiol, 15, 58–64. https://doi.org/10.1016/j.jacr.2017.06.035