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Authors	Crowley, C.;Ekpo, E.U.;Carey, Brian W.;Joyce, Stella;Kennedy, C.;Grey, T.;Duffy, B.;Kavanagh, Richard G.;James, Karl;Moloney, Fiachra;Normoyle, B.;Moore, Niamh;Chopra, R.;O'Driscoll, J. C.;McEntee, Mark F.;Maher, Michael M.;O'Connor, Owen J.
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Radiation dose tracking in computed tomography: Red alerts and feedback. Implementing a radiation dose alert system in CT

C. Crowley [a], E.U. Ekpo [b], B.W. Carey [a, c], S. Joyce [c, *], C. Kennedy [c], T. Grey [c], B. Duffy [c], R. Kavanagh [c], K. James [a, c], F. Moloney [a, c], B. Normoyle [d], N. Moore [e], R. Chopra [d], J.C. O'Driscoll [e], M.F. McEntee [e], M.M. Maher [a, c], O.J. O' Connor [a, c]

[a] Department of Radiology, Cork University Hospital, Wilton, Cork, T12 DC4A, Ireland
[b] Discipline of Medical Radiation Sciences, Faculty of Health Sciences, The University of Sydney, Lidcombe, New South Wales, 2141, Australia
[c] Department of Radiology, School of Medicine, University College Cork, College Road, Cork, Ireland
[d] Department of Radiography, Cork University Hospital, Wilton, Cork, T12 DC4A, Ireland
[e] Discipline of Diagnostic Radiography, School of Medicine, University College Cork, College Road, Cork, Ireland

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ABSTRACT

Introduction: This study investigates instances of elevated radiation dose on a radiation tracking system to determine their aetiologies. It aimed to investigate the impact of radiographer feedback on these alerts.
Methods: Over two six-month periods 11,298 CT examinations were assessed using DoseWatch. Red alerts (dose length products twice the median) were identified and two independent reviewers established whether alerts were true (unjustifiable) or false (justifiable). During the second time period radiographers used a feedback tool to state the cause of the alert. A Chi–Square test was used to assess whether red alert incidence decreased following the implementation of radiographer feedback.
Results: There were 206 and 357 alerts during the first and second time periods, respectively. These occurred commonly with CT pulmonary angiography, brain, and body examinations. Procedural documentation errors and patient size accounted for 57% and 43% of false alerts, respectively. Radiographer feedback was provided for 17% of studies; this was not associated with a significant change in the number of alerts, but the number of true alerts declined (from 7 to 3) ($\chi 2 = 4.14$; $p = 0.04$).
Conclusion: Procedural documentation errors as well as patient-related factors are associated with false alerts in DoseWatch. Implementation of a radiographer feedback tool reduced true alerts.
Implications for practice: The implementation of a radiographer feedback tool reduced the rate of true dose alerts. Low uptake with dose alert systems is an issue; the workflow needs to be considered to address this.
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Keypoints

1. Implementation of a radiographer feedback tool reduces the incidence of true dose alerts.
2. False dose alerts are often associated with patient-related factors, including high BMI.

Introduction

The use of computed tomography (CT) in medicine has increased significantly over the years and recent statistics show a 10–57% annual increase in the number of CT examinations.[1,2] This increased use is associated with higher exposure to ionizing radiation, and CT is the highest contributor to radiation dose from medical use.[3,4] In the United States, 49% of medical exposure to radiation is from CT procedures.[4] Effective dose, a determinant of

Abbreviations: AEC, Automatic exposure control; CT, Computed tomography; DLP, Dose length product; DRL, Diagnostic reference level; PACS, Picture Archive and Communication System.

* Corresponding author. Department of Radiology, Cork University Hospital, Wilton, Cork, Ireland.
E-mail address: stella.joyce@ucc.ie (S. Joyce).

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the potential effect of radiation for most routine CT procedures varies from 1 to 15 mSv and can be higher in circumstances where a repeat examination is required.[5–7] Increased awareness of the risks of ionizing radiation exposure has precipitated the establishment of justification and dose optimisation strategies by national and international regulatory bodies.[8,9] Whilst justification using evidence-based referral guidelines has reduced human exposure to radiation by reducing the number of imaging investigations performed, doses to patients undergoing CT investigations remain considerable and can dramatically vary across sites and patients.[5–7] This variation underscores the need to monitor and optimise patient dose data and scanning practices.

To optimise radiation exposure and dose variations, dose benchmarks called diagnostic reference levels (DRLs) have been established.[9] It is a European legal requirement to regularly monitor and audit doses delivered in clinical practice in order to identify high doses and implement dose reduction strategies.[10–12] Dose management systems have been developed to assist the process of dose auditing and reduction strategies. There are many products available including DoseWatch (GE Healthcare), DoseWise (Philips), Teamplay (Siemens), DoseTrack (Sectra), DoseMonitor (PACS Health) and open-source packages such as OpenREM.[13,14] These technologies systematically collect, monitor and analyse dose-related data, and have great potential to increase dose awareness. However, implementation has not been studied to any great extent.

Automated radiation dose monitoring of patient doses occurs in real-time, and feedback is provided to radiographers and imaging personnel when the radiation exposure exceeds preset limits by issuing a *red alert*.[13,14] The ability of these dose-tracking systems to automatically collect, store and analyse high volume dose data makes them suitable for dose monitoring. The implementation of these dose monitoring systems into clinical practice is a considerable challenge. The data collected by the equipment needs to be proof tested, filtered, overseen and acted upon by CT users. This represents a significant change to work practices and governance responsibilities. However, one of the challenges facing CT providers using these devices is the triage of true alerts (unjustified) from justifiable (false alert) high radiation exposures. It is imperative that unnecessarily high exposures are separated from justifiable exposures using dose-tracking devices. True alerts are likely to be the first sign of a system or protocol error. Identification of false alerts can be used to optimise dose calculations, clean data and provide feedback to operators. Therefore, this study aimed to investigate red alerts issued by DoseWatch dose tracking software and to determine the causes of false alerts so that they can be used to tailor mitigation strategies. It also aimed to establish the effects of the implementation of a radiographer feedback tool on the rate of red alerts in CT imaging and to assess how the doses that trigger a red alert compare with national benchmarks.

Materials and Methods

The study was performed following receipt of approval from the local ethics committee. CT dose data was gathered during two six-month periods (31st December 2014 to 30th June 2015; period 1 and 1st July 2016 to 31st December 2016; period 2). This time interval was necessary to facilitate implementation of the radiographer feedback tool within the department; an additional computer monitor, for use solely by radiographers to access DoseWatch within the CT suite, was installed. It further allowed for the organisation of appropriate educational sessions regarding the feedback tool, at time slots convenient for all radiographers.

Dose data pertaining to CT examinations performed using a GE Discovery 750HD CT scanner (General Electric Healthcare, Waukesha, WI, USA) was acquired. In an effort to ensure acquirement of data truly representative of our department, all CT examinations that triggered a high radiation dose (twice the median for that study description), termed *red alerts* on DoseWatch (General Electric Healthcare, Waukesha, WI, USA), were retrieved for the final analysis.

Dose management and red alerts

Dose management was performed automatically by a monitoring software package, DoseWatch. Briefly, DoseWatch is a software program which monitors and archives dose related data including scanning parameters, radiation dose and study descriptions. The software calculates the median exam dose length product (DLP) for each CT study description and has an automated dose warning system, which is programmed to alert the radiographer when twice the median dose length product for a protocol has occurred. In essence, it triggers a "*red alert*" when an imaging investigation yields a dose value in excess of a predefined dose threshold as shown in Fig. 1.

Data extraction and synthesis

The Picture Archive and Communications System (PACS) database (IMPAX 6, Agfa Healthcare, NV, Belgium) was used to identify the radiographers that performed the imaging investigations, patient status (inpatient or outpatient), and to access the study descriptions used for acquiring the images. This PACS information together with demographic information, scanning parameters, and radiation dose data from DoseWatch were extracted for analysis. Data extracted included date of birth of the patient, time of CT investigation, patient status and examination study description. Dose data extracted included CT dose index volume ($CTDI_{vol}$), which is the dose per volume of tissues imaged, and dose length product (DLP), which is a measure of dose across the length of region scanned. Data pertaining to CT studies that triggered a red alert are presented as total DLP.

Patient positioning information was reported as distance from the isocenter of the CT scan in the X and Y axes i.e. sagittal and coronal patient planes. At first, dose data was extracted from DoseWatch as multiple radiation events for each CT examination. $CTDI_{vol}$ values for radiation events were summed into a single event per CT examination. Deviation from the isocenter (0) in the X and Y-axes was used as an estimate of patient malpositioning. This data was then condensed from all radiation events and analysed.

Analysis of red alerts

During the first six month period, information was gathered without an intervention or radiographer input. For the second six month period radiographer feedback was invited. This entailed the training of all radiographers on how to access dose data. They were also informed of potential reasons for high CT dose events. Individual training sessions on the feedback tool, conducted by the lead CT radiographer, were held with all radiographers. Group teaching sessions were also organised. Radiographers were provided with a list of potential causes of high doses (Table 1) and asked to select the cause of high doses for each of the CT red alerts. DoseWatch data was available to 22 departmental radiographers; twenty-one of these radiographers had conducted CT scanning during the initial phase of the study, prior to implementation of the feedback tool, with an additional radiographer employed by the department in the intervening time period.

Feedback from radiographers on the causes of high doses for each examination was provided through a feedback tool on a dedicated computer where DoseWatch could be easily accessed. A free text comment box was provided within this tool for radiographers to enter any other justification for red alerts if known. Data

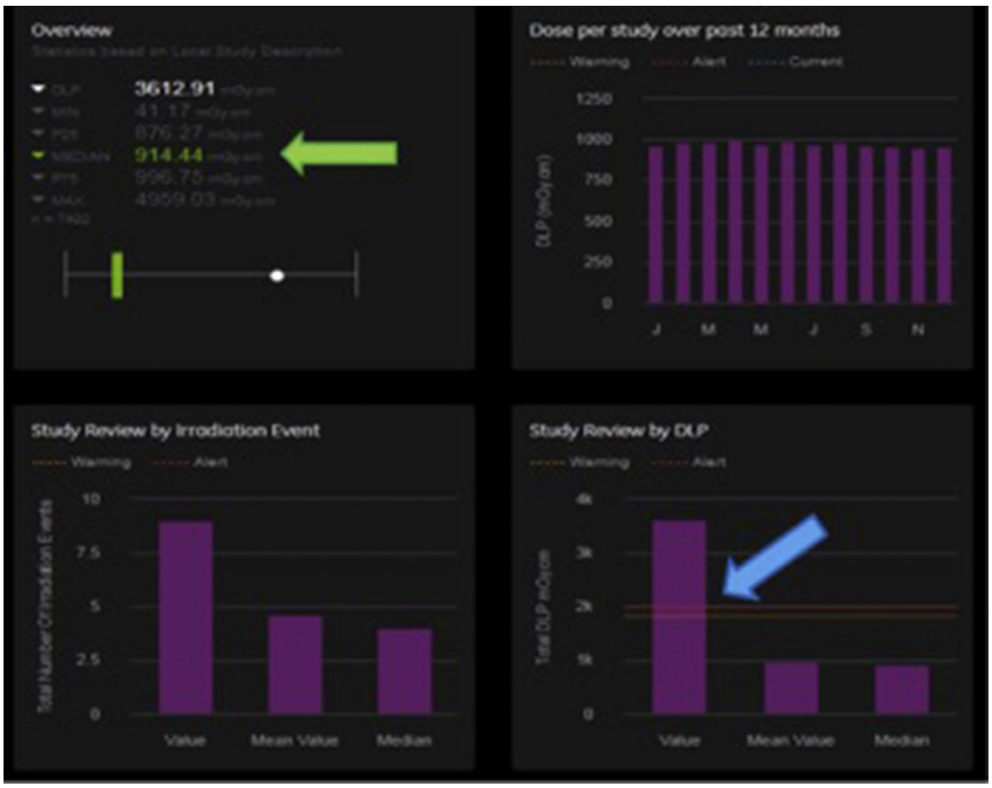


Figure 1. An example of the dose data made available by DoseWatch from a CT examination. The green arrow demonstrates the median DLP for the selected CT study description, and the blue arrow shows that for this examination, the dose length product surpassed the threshold (i.e. over twice the median) and so a red alert (horizontal red bar) was issued. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 1
List, provided to radiographers, documenting potential causes of exposure to high radiation doses, which may have resulted in a red alert being issued.

Potential causes of high radiation doses which result in a CT red alert
Large patient size
Addition of extra study (including: (i) additional phase of imaging required)
Wrong study label/incorrect study protocol selection (including: (i) two anatomical regions appropriately imaged, without changing study protocol; (ii) appropriate continuation to angiography, without changing study protocol)
Repeat required (including: (i) patient movement during initial imaging investigation resulting in suboptimal image quality; (ii) failed injection due to IV line or pump issue)
Foreign body in range increasing dose (eg. hip prosthesis or spinal board)
Malpositioning (including: (i) one or both arms by the patient's side; (ii) kyphoscoliotic patients; (iii) trauma patients; (iv) isocenter misalignment)
Scanning beyond the agreed desired region of interest
Other; please specify

recorded by the CT radiographers in the feedback tool was gathered and used to identify the causes of red alerts.

Two other radiology personnel (radiology fellow and radiology lecturer) retrospectively assessed CT examinations in consensus for the causes of the alerts issued; this enabled confirmation of the information provided by the radiographers in the feedback tool and to establish whether the red alerts triggered by the DoseWatch software were true or false. A red alert was considered to be a true alert if the high dose value could not be ascribed to factors including patient size, incorrect identification/labeling of a study, requirement for repeat imaging necessitating addition of another study (without changing the study protocol), arms by the sides, or foreign body. An alert was considered a false alert if the high dose could be attributed to a justifiable cause. With the exception of arms by the side, malpositioning was not considered a factor for initial justification of red alerts. Subsequent detailed review of all true red alerts included an assessment of malpositioning and an evaluation of extent of patient deviation from the isocenter.

Statistical analysis

The data collected was exported into Microsoft Office Excel 2011 (Microsoft Corporation, CA, USA) for analysis. Descriptive analyses were used for continuous variables whilst frequency analyses were performed for categorical variables. A Chi–Square test was used to assess whether there were differences in "red alerts" following the introduction of a radiographer feedback tool. We then stratified "red alerts" according to the radiological investigation performed and the age of the patient scanned.

Results

A total of 11,298 CT examinations were examined for red alerts (Period 1: 4368; Period 2: 6930). Of these, 563 red alerts were identified (Period 1: 206; Period 2: 357). The most common CT examination triggering a red alert was CT pulmonary angiography (CT PA) (n = 111); followed by CT brain (CT B) (n = 109), CT abdomen and pelvis (CT AP) (n = 58), CT thorax, abdomen and pelvis (CT TAP) (n = 44), and CT thorax (CT T) (n = 16) during both time periods. The distribution of red alerts across the most common CT examinations that triggered a red alert for each of the two periods is demonstrated in Table 2.

Effect of radiographer feedback tool

There was no statistically significant change in the incidence of red alerts following introduction of radiographer feedback (4.7% in Period 1 and 5.1% in Period 2 ($p = 0.30$)). The number of red alerts triggered by CT pulmonary angiography ($p < 0.001$) and CT brain ($p < 0.001$) decreased significantly. There were no statistically significant differences in the number of red alerts triggered by CT abdominopelvic ($p = 0.76$), and CT thorax ($p = 0.12$) examinations; however, the red alerts for CT thorax abdomen and pelvis increased significantly ($p = 0.004$) between the time intervals.

True red alerts

There were seven true alerts prior to implementation of the radiographer feedback tool, with three demonstrated after introduction of the tool. The extent to which DLP exceeded the dose alert threshold (twice the median) for these 10 examinations was assessed (Table 3). The total DLP for almost all of the seven true alerts exceeded the dose alert threshold by less than 10%. For example, CT abdominopelvic studies exceeded the threshold between approximately 0.6% (1021 mGy cm) and 9.2% (1179 mGy cm). The greatest transgression was a CT kidneys ureters bladder study performed during Period 1, which had a total DLP that exceeded the threshold by 21.6%.

Further analysis demonstrated variable causes for true alerts. During Period 1, two CT KUB examinations resulted in a true red alert; both were conducted with an increased milliamperage (mA) setting compared with standard departmental protocol. As both patients had a subjectively increased BMI on imaging review, it is likely that the supervising radiographers escalated the mA in an effort to ensure diagnostic quality images.

Two CT thorax examinations resulted in a true red alert during Period 1. The first patient had a significant kyphosis; Delta X and Delta Y values were recorded as 23.45 mm and 45.82 mm, respectively. The second case presented a haemothorax and left lung collapse; increased modulation was demonstrated, to achieve the desired noise index. This resulted in an increased radiation dose exposure.

Finally, three CT AP examinations triggered a red alert during Period 1. The first, conducted on a 24-year-old male, demonstrated evidence of scanning beyond the desired anatomy of interest; CT range commenced 9 cm above the right hemidiaphragm, and terminated 5 cm below the right greater trochanter. No explanation was provided to conclude on the rationale for this.

A further CT AP was conducted with an increased kilovoltage (kV) compared with standard CT AP departmental protocol. The involved patient had a known diagnosis of bowel obstruction, with a significantly distended abdomen; a decision was likely made by the radiographer to increase scanning parameters in order to ensure diagnostic images.

The final CT AP during Period 1 had an unexplained red alert; scanning parameters were in line with standard departmental protocols, with no significant pathologies to account for an increase in dose modulation. Delta X and Delta Y values were recorded as 6.54 mm and 15.82 mm, respectively.

Of the three CT examinations to result in a true red alert during Period 2, just one, a CT KUB, was unexplained. Scanning parameters were correct, with no additional protocols added, and the patient did not have a subjectively increased BMI. Delta X and Delta Y values were recorded as 1.09 mm and 23.45 mm, respectively.

The CT TAP resulting in a true red alert was associated with the imaging of a kyphotic patient. Delta X and Delta Y values were 14.73 mm and 41.45 mm, respectively.

The final CT AP was protocoled for a four-year-old female child, with a background of spastic quadriplegia. She had presented with abdominal pain, and clinical examination had been poorly tolerated. Total examination DLP was 53.1 mGy cm. CT is rarely performed in this age group in our institution. Therefore, the red alert reference thresholds are more prone to error as the denominator for such calculations is small.

False red alerts

The causes of false alerts observed during the two time periods are demonstrated in Fig. 2. Patient size (larger BMI) was the most frequent determinant of false alerts in Period 1. The numbers of false alerts issued secondary to large patient size, or the addition of an extra study without changing the study protocol, were similar during Period 2. A total of 20 red alerts were caused by a combination of extra study and large patient size.

Malpositioning

Isocenter misalignment was defined as the deviation from the isocenter (0) in the X and Y-axes. This was usually evident in the Y-axis in all examinations; median Delta Y values of 16.36 mm and 23.45 mm were recorded during Period 1 and Period 2, respectively.

Table 2
Top eight CT investigations that triggered a red alert on DoseWatch; CT Code Stroke and CT Pulmonary Angiogram were responsible for the highest rates of red alerts.

Type of CT investigation	Period 1		Period 2	
	Red alert (n/total)	Rate (%)	Red alert (n/total)	Rate (%)
Pulmonary angiogram	57/240	23.7	54/408	13.2
Brain	34/292	11.6	75/2939	2.5
Abdomen and pelvis	22/468	4.7	36/830	4.3
Thorax, abdomen and pelvis	9/378	2.4	35/531	6.6
Thorax	9/196	4.6	7/322	2.2
Brain; pre and post IV contrast	12/111	10.8	9/74	12.2
Brain; code stroke	8/22	36.3	9/82	11
Kidneys, ureters, bladder	4/96	4.2	4/167	2.4

Table 3
True alerts that triggered a red alert on DoseWatch in Period 1 and Period 2. The total DLP was recorded for each examination which resulted in a true alert, and the subsequent percentage by which the total DLP was above the alert threshold was calculated.

Type of CT investigation	Period 1		Period 2	
	Total DLP (mGy.cm)	% above alert threshold	Total DLP (mGy.cm)	% above alert threshold
Kidneys, ureters, bladder	540.85	21.56	469.56	9.51
Kidneys, ureters, bladder	478.28	7.38	–	–
Abdomen and pelvis	1178.61	9.21	530.13	1.43
Abdomen and pelvis	1030.31	1.52	–	–
Abdomen and pelvis	1021.05	0.59	–	–
Thorax	504.7	0.62	–	–
Thorax	497	1.33	–	–
Thorax, abdomen and pelvis	–	–	1354.94	5.75

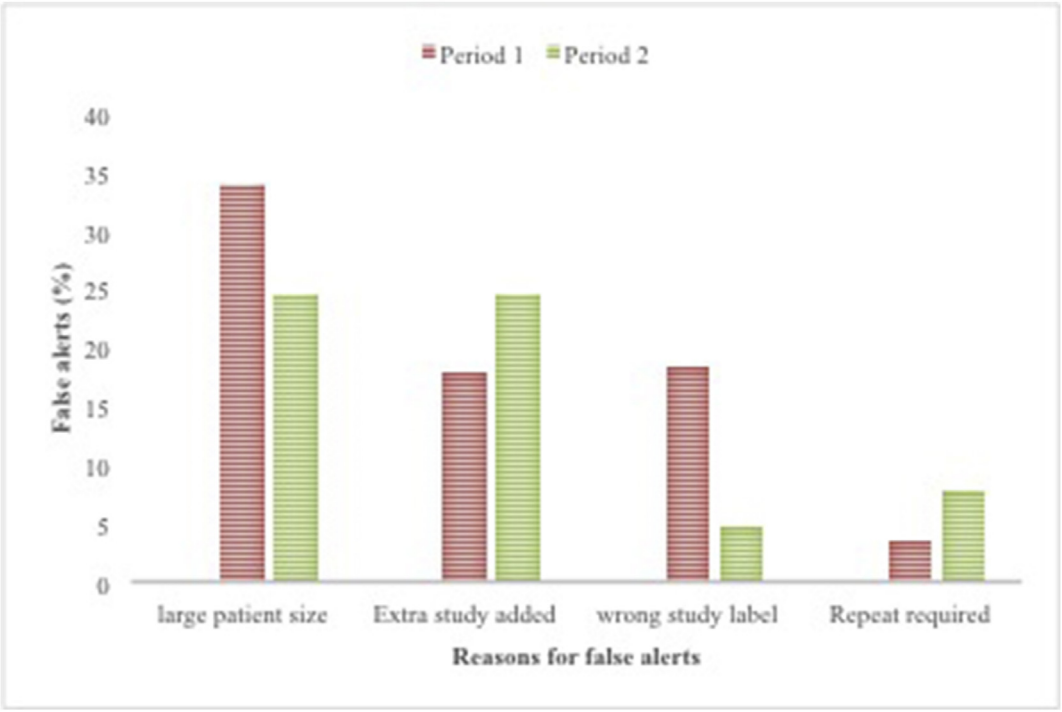


Figure 2. The causes of false alerts triggered by CT examinations, and their percentage contribution to false alerts. High BMI was the most common cause of a false alert being issued. Note that some CT examinations had more than one cause for a false alert. Period 1: without radiographer feedback; Period 2: following the introduction of a radiographer feedback tool.

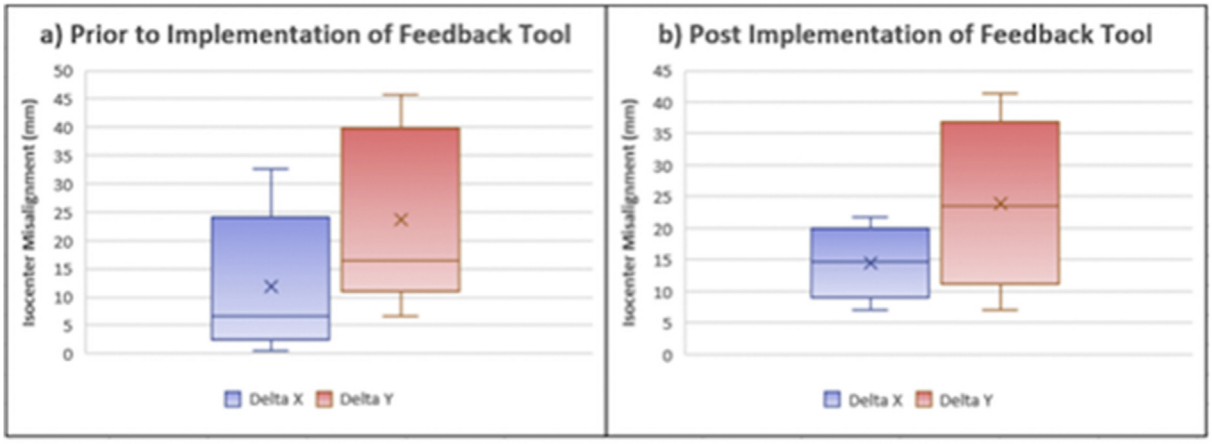


Figure 3. Box plots demonstrating isocenter misalignment for a) Period 1 and b) Period 2. Median values are represented by the horizontal lines within the box. The lower boundary of the box is the 25th percentile value, while the 75th percentile value is represented by the upper boundary of the box. The lower whisker is the lowest datum within 1.5 times the IQR below the 25th percentile; the upper whisker is the highest datum within 1.5 times the IQR of the 75th percentile. No outliers are demonstrated.

Corresponding median Delta X values were 6.54 and 14.73, respectively (Fig. 3). Isocenter misalignment was most evident with CT thorax and CT thorax, abdomen and pelvis. This may also have influenced the increasing number of red alerts observed with increased age. Seventy-eight percent of alerts were observed in patients aged 46 years or older (Fig. 4). This observation is also likely due to the age of the population undergoing imaging. Isocenter misalignment was not directly assessed as a cause for red alerts as there is little data to indicate what would be an acceptable margin for misalignment in practice.

Radiographer feedback

A low uptake (17.1%) of dose feedback from DoseWatch by radiographers was observed. Furthermore, just four entries were made by radiographers within the free text justification box.

Based on the analysis of radiographer experience in Period 1, we observed that 61% of the studies that triggered a red alert were performed by less experienced radiographers, compared with 49% of studies in Period 2. Across both time periods, true alerts occurred more commonly among radiographers covering CT on a part-time basis, with specialist commitments in other areas of the radiology department, compared with full-time CT radiographers. Fifty-seven percent (n = 4) and 66.6% (n = 2) of CT examinations resulting in true alerts were conducted by part-time CT radiographers during Period 1 and Period 2, respectively.

Discussion

The collection of clean accurate radiation dose related data is important as the first step in a long process which can ultimately lead to dose optimisation. The present paper demonstrates many practical findings associated with the implementation of a radiation monitoring system in clinical practice which is an increasingly common radiology workplace requirement but which has been studied very little to date. The majority of alerts issued by the dose monitoring system were false alerts, which could be justified, i.e. there was a reason why the dose was in excess of double the median for that protocol description. With the aim of ensuring that true red alerts do not become masked by those alerts deemed justifiable, it must always be sought to decrease the number of departmental false alerts as far as feasible.

Our detailed analysis revealed that anthropometric and procedural errors led to incorrect triggering of *red alerts* in the dose monitoring tool examined. Procedural errors accounted for 57% of false alerts in the two periods. Patient size, which accounted for 43% of false alerts, is an important factor in the selection of exposure parameters that influence dose. Increased radiation doses associated with large patient size is a reflection of the use of automated tube current modulation. In order to avoid such false alerts dose-monitoring thresholds would need to be subdivided based on patient weight measured at the time of imaging. In a similar way, subdivision of dose data pertaining to intracranial intervention using dose monitoring systems has been advocated as a method of providing more representative information since aneurysm embolisation in the posterior circulation entails higher radiation doses than the anterior circulation.[15]

False alerts due to procedural errors can be mitigated by CT operators through more careful selection of CT study descriptions. For example, the performance of an additional phase of imaging, or imaging of an additional body part under another protocol description was a common finding among dose alerts. It is acknowledged that certain imaging CT examinations can be technically challenging for radiographers necessitating repetition of an examination (e.g due to patient motion or failure to image during contrast opacification of the pulmonary artery during a CT pulmonary angiography examination) in order to adequately complete the test. In addition, the large number of study descriptions available in our hospital from which to choose (over 250) will also tend to cause heterogeneous study selection practices. Nevertheless, it is

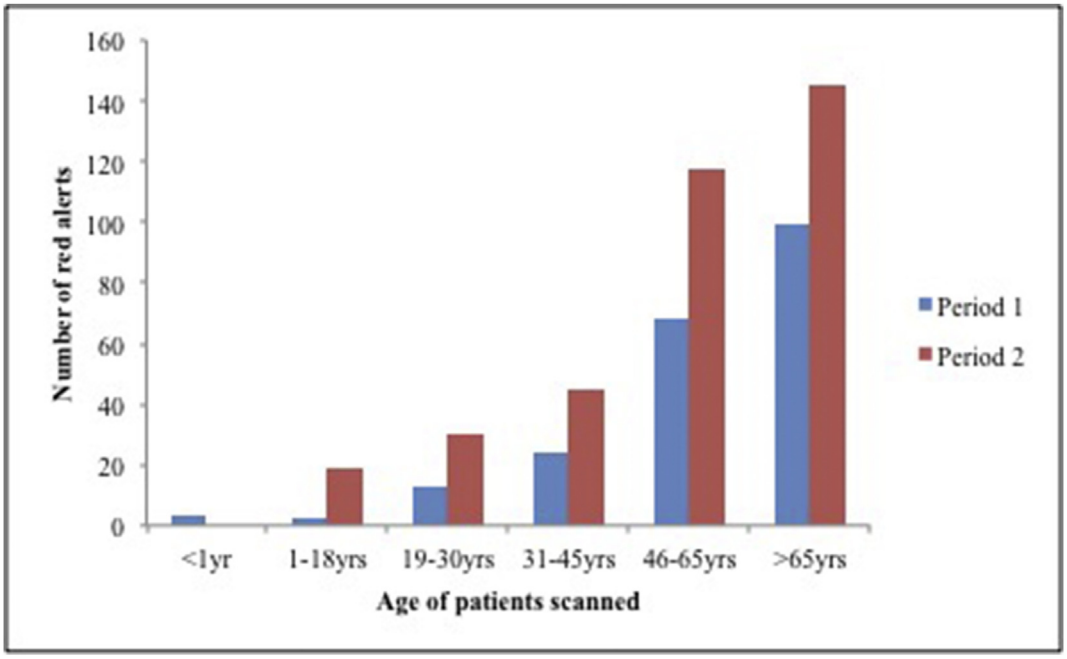


Figure 4. Age distribution of red alerts triggered by DoseWatch during the two time periods; the highest frequency of red alerts occurred for patients greater than 65 years of age. Period 1: without radiographer feedback; Period 2: following the introduction of a radiographer feedback tool. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

important that the cause of the alert is established for quality control purposes, as recurring alerts may be the first sign of a system malfunction, which would require attention and correction (injection pump or protocol inaccuracies for example). DoseWatch provides a feature which allows CT operators to document the cause for the red alert, and in our cohort the findings of the review concurred with radiographers' assessments in all cases.

In an effort to attain data representative of our entire patient cohort, no exclusion criteria were applied to the CT examinations conducted within the department during both study periods. Though the actual numbers were small, some paediatric CT examinations were included; only a single paediatric case was noted to have triggered a red alert. The recorded DLP of 53.1 mGy cm compared very favorably with the European DRL threshold limit of 150 mGy cm described for abdominal CT examinations performed in middle childhood,[16] in children aged from 4 to 9 years. A red alert was likely triggered in this case due to the relative lack of data held on DoseWatch. As discussed later, a recognised limitation of DoseWatch is the potential skewing of dose data in cases where a limited number of departmental comparison studies exist.

All causes of red alerts were included for final study analysis, including those beyond control of the scanning radiographer such as patient malpositioning; this rationale was multi-factorial. Firstly, inclusion of all red alerts for analysis facilitated confirmation of the causes of all alerts, including false red alerts, by an additional blinded reader. This decreased the potential for a true red alert to be erroneously categorized as justified. Additionally, we hope that the release of these results, highlighting a broad scope of potential causes for false red alerts, will assist other institutions. Published data regarding red alerts remains quite limited, and although dose monitoring systems facilitate dose comparisons within institutions, this remains difficult between institutions (both nationally and internationally) unless specific dose comparison databases are maintained.

The number of unjustified true dose alerts issued during the period of radiographer feedback reduced but the small numbers (seven versus three) limit the conclusions which can be confidently drawn. Further evaluation of those true alerts concluded that just two examinations had no clear rationale for the excessive radiation dose exposures.

The low rate of justification feedback was disappointing and is a reflection of the challenges to the introduction of additional work practices in an already busy working environment. Our department is a busy Level I trauma center and also a tertiary cancer referral center. Radiographers are already under extreme pressure to maximize scanner time, care for very ill patients, and on-call scanning occurs throughout the night. Many of the radiographers who perform on-call CT imaging do not work routinely in CT during daytime hours. Options are certainly available to encourage engagement with the feedback tool; regular reminders delivered via the installed software, in addition to frequent updates and information regarding the feedback tool may promote uptake. Radiographers could also be encouraged to participate in the audit process, reinforcing the importance of feedback. Ultimately however, we believe that the successful implementation of a dose monitoring strategy will require resource allocation for the time involved and streamlining of feedback in conjunction with software manufacturers.

Another factor which contributed to the occurrence of red alerts was patient malpositioning. As an umbrella term, kyphotic patients and patients unable to maintain their arms above their head were included within this category, in addition to isocenter misalignment. Whilst patient factors are often beyond the control of radiographers, isocenter misalignment must be corrected for as far as feasible. In some cases however, it should be acknowledged that isocenter misalignment may be unavoidable; no defined thresholds exist below which isocenter deviation may be justifiable.

We demonstrated isocenter misalignment as being more common in the y-axis. Mispositioning increases patient dose by between 33 and 38% regardless of patient size, particularly if this error is compensated by an increase in tube current[17,18] and particularly if mispositioning occurs in the vertical axis.[19] Malpositioning can be a reflection of patient discomfort during CT and is also affected by imaging in the prone position.[20] Many CT scanners are equipped with automatic exposure control (AEC) devices, which should notify the radiographer when a patient is incorrectly centered.[21] This information is also gathered by dose tracking systems and analysis can be useful for quality control purposes.

Individual monitoring has the advantage of being a real time process and not limited to certain audit cycles; therefore, monitoring has the potential to detect and precipitate responses to discrepancies in a more time efficient manner. Although dose monitoring software provides the opportunity to survey a much larger volume of CT dose data compared with manual methods (usually limited to small numbers), the present paper also demonstrates that dose data can frequently be incorrect due to reliance on the correct use of study descriptions. The calculation of dose levels is intended to be a dynamic process and correction of study descriptions should be reflected in a reduction in dose.

The current study suggests that dose-tracking devices may be helpful in real-time dose monitoring and assessing compliance to established dose benchmarks.[13] We observed intermittent issues with transmission of dose data to DoseWatch from the CT scanners, which could limit the ability to detect high doses in real time; the exact number of cases involved is unclear. Unless operators are vigilant, the failure of data to transfer may go undetected, as no warning was issued by DoseWatch when this occurred. This limitation, in addition to challenges related to CT study descriptions need to be addressed if feedback from dose tracking devices is to be used to perform dose optimisation.

The dose thresholds which determined when red alerts were issued were automatically calculated by the DoseWatch system. Although this has the benefit of reflecting local practices such as CT brain in our local practice, there are limitations to this. The accuracy of this data will be determined by the number of examination related dose data gathered. This will be less when the system is newly connected and if a particular study description is infrequently used. As the system is continuously gathering data, modifications to study protocols will change the thresholds. Therefore retrospective review of data can be confusing as doses that triggered an alert in the past may not do so at later time points if the DoseWatch system has updated thresholds in response to administration of higher radiation doses during CT. In addition, there was no information available regarding patients' body mass index or size at the time of imaging. It was therefore necessary to estimate patient size by visual assessment of the original image in PACS by two reviewers and confirmation that the l*arge patient* protocol was selected by the radiographer on the CT scanner. Although it must be mentioned that these features normally coexisted it would be preferable that BMI be recorded at the time of imaging. This is standard practice in many radiology departments but not ours to date. BMI data can also be used to approximate size specific dose estimates which take patient size into consideration when describing patient dose.[22] Quantitative measures of size would provide better data for the determination of the causes of red alerts. Also, due to difficulty with data transmission from the CT scanners to DoseWatch in Period 1, dose data of many brain and abdominopelvic CT examinations could not be retrieved for analysis.

The present paper assessed the causes of red alerts among the CT study descriptions most commonly associated with alerts. Other

study descriptions were not assessed. Amongst the CT study descriptions assessed the present paper has performed a relatively superficial assessment as to the causes of alerts and has not assessed image quality which would be important as part of the justification of the CT doses administered. Assessment of image quality in terms of noise, contrast resolution, spatial resolution, and satisfactory response to the indication for the study (e.g presence or absence of pulmonary embolus in the setting of CT pulmonary angiography) would entail much more in depth study analysis which would be more appropriate once data collection adequacy has been addressed.

Conclusions

The majority of dose alerts triggered by radiation dose tracking software in the present study were false justifiable alerts, due to patient-related factors, and documentation discrepancies during CT acquisition. The implementation of a radiographer feedback tool reduced the rate of true alerts; however, uptake was low and workflow processes need to be addressed to facilitate improved feedback from dose-tracking tools by radiographers. Understanding and mitigating the barriers to using the dose feedback tool by CT operators may be helpful in tailoring strategies to limit the number of false alerts and ultimately enable attention to be focused on dose optimisation.

Ethical approval and consent to participate

Ethical approval was granted by the regional ethics board, *Clinical Research Ethics Committee, University College Cork*.

Availability of data and materials

The majority of datasets analysed and generated during this study are included in this published study; on reasonable request, further datasets are available from the corresponding author.

Authors' contribution

CC, EUE were primary authors and drafted the manuscript; BC, CK, TG, BD, RK, KJ, FM collected and analysed data; BN, NM, RC designed and implemented the radiographer feedback tool; SJ, JOD, MFME, MM drafted and edited sections of the manuscript; OJOC was the primary editor and supervisor for the study.

Authors' information

Not applicable.

Conflicts of Interest

The authors declare that they have no competing interests.

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