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REVIEW

Computed tomography dose optimisation in cystic fibrosis: A review

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Abstract

Cystic fibrosis (CF) is the most common autosomal recessive disease of the Caucasian population worldwide, with respiratory disease remaining the most relevant source of morbidity and mortality. Computed tomography (CT) is frequently used for monitoring disease complications and progression. Over the last fifteen years there has been a six-fold increase in the use of CT, which has lead to a growing concern in relation to cumulative radiation exposure. The challenge to the medical profession is to identify dose reduction strategies that meet acceptable image quality, but fulfil the requirements of a diagnostic quality CT. Dose-optimisation, particularly in CT, is essential as it reduces the chances of patients receiving cumulative radiation doses in excess of 100 mSv, a dose deemed significant by the United Nations Scientific Committee on the Effects of Atomic Radiation. This review article explores the current trends in imaging in CF with particular emphasis on new developments in dose optimisation.

Key words: Cystic fibrosis; Dose optimization; Computed tomography; Dose; Ionising radiation; Kalydeco

Core tip: There is a growing reliance on the use of computed tomography (CT) in the management of cystic fibrosis (CF), as demonstrated by a six-fold increase in the use of CT in CF over the last fifteen years. There are concerns over repeated patient exposure to ionising radiation and the potential carcinogenic consequences. With the ever-increasing life expectancy of patients with CF and a predilection for certain cancers, it is important to be aware of cumulative radiation exposure from radiological imaging. Dose-optimisation, particularly in CT, is therefore essential.

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INTRODUCTION

Cystic fibrosis (CF) is the most common autosomal recessive disease of the Caucasian population worldwide, with an incidence of approximately 1 in 3000 live births[1]. This multisystem disorder is characterised by irreversible lung destruction, gastrointestinal malfunction and exocrine insufficiency. Respiratory disease remains the most relevant source of morbidity and mortality, and accounts for over 80% of deaths[2]. Consequently, thoracic imaging plays a pivotal role in monitoring disease complications and progression.

Computed tomography (CT) in particular has been increasingly used to evaluate CF patients. Over the last 15 years there has been almost a 6-fold increase in the use of CT scanning in CF[3]. This trend can be attributed to the widespread availability of CT, rapid acquisition time and the high sensitivity and specificity for lung and gastrointestinal disease. However, there are growing concerns over repeated patient exposure to ionising radiation and the potential carcinogenic consequences. With the ever-increasing life expectancy of CF patients and a predilection for certain cancers, cumulative radiation exposure from radiological imaging is receiving increasing scrutiny[4,5]. This review explores the current imaging trends in CF with particular emphasis on new developments in dose optimisation.

CT USE AND CUMULATIVE EFFECTIVE DOSE

During their lifetime, it is estimated that CF patients will have on average 3.2 thoracic CT scans (range 0-13)[6], which results in cumulative effective doses (CEDs) in excess of the general population. There are many reasons for this including the length of time patients suffer from the disease and the accuracy of CT in the setting of CF. Thoracic imaging often begins during infancy; as the earliest radiological manifestation of CF, mucous plugging, can be detected using radiological imaging. As the illness progresses, scanning is often required to assess deteriorating lung structure and function caused by chronic infection and inflammation secondary to bronchiectasis.

Quantification of CF bronchiectasis using CT bronchiectasis scores has been found to be more sensitive for assessing the degree of lung destruction, compared with pulmonary function test (PFT) parameters obtained through PFT[7,8]. In recent years studies have reported discordance between changes in CT score and PFTs within patient cohorts. In essence, both investigations look at different aspects of the disease; CT assesses structural change while PFT's evaluate lung function. In one paper, CT bronchiectasis scores deteriorated 70% faster than PFT parameters, including forced expiratory volume in one second in a third of adults and children studied, suggesting that CT is more sensitive than PFT assessment at detecting deterioration[7].

The poor sensitivity of PFT's for changes in lung function and the ability of CT to rapidly track declining lung function, has implications for use of CT imaging for disease management, and CT may provide useful information to inform management decisions such as when to escalate drug therapy or when lung transplantation is necessary[9-11]. Multiple studies have also demonstrated that CT is more sensitive than chest radiography in detecting pulmonary deterioration[12-15].

This increased utilisation of CT further increases the lifetime CED in these patients. A recent multi centre study of CT in CF patients between 1990-2005 showed that CT scores were a significant independent predictive factor for survival post-transplant[16]. Information gained from CT is therefore very useful, considering that up to one-third of CF patients will meet criteria for lung transplantation[13].

Assessment of disease severity by CT provides a more objective, reproducible and accurate representation of patient's disease burden. Clinical trials increasingly use CT to monitor response to antibiotics and gene therapy in the treatment of CF[17,18]. Although quantification of changes in disease severity by CT closely correlates with the frequency of infective exacerbations and disease progression[19,20], one must remain cognisant of the radiation dose incurred from this method of assessment[21]. Recent studies have shown that the dose from dose optimised CT scans is equivalent to one-third of one year's background radiation[22]. Perhaps the risk of sequential scanning is justified due to the high morbidity and reduced life expectancy related to CF[23,24].

The radiation dose incurred by patients with CF through medical imaging has recently been studied in Ireland, which has the highest worldwide incidence of CF[1]. During the 15-year study period, there was a 5.9 fold increase in all CT imaging[3,25] with an associated increase in CED among hospitalised CF patients[26,27]. In fact, the annual CED from medical imaging has been steadily increasing over the last 30 years. For instance the mean annual effective dose for CF patients has increased incrementally from 0.39 mSv to 0.47 mSv and then to 1.67 mSv per person per year over the last three decades. A similar study demonstrated comparable findings in a French context, where it was found that the mean CED in a cohort of CF patients was 19.5 mSv (range 2.24-78.5 mSv)[6]. Donadieu *et al*[6] also found that the patient age at the time of their first CT scan has decreased from 20 years in those born before 1980 to 1.9 years in those born after 1997 again reflecting the increased utilisation of CT in this patient group.

O'Connell *et al*[3] demonstrated that thoracic imaging accounted for 46.9% of the total CED, closely followed by abdominopelvic imaging, which was responsible

for 42.9% of CED. This may be representative of a trend to image the thorax, abdomen and pelvis together routinely as opposed the chest only. It may also reflect increasing use of CT scanning for investigating abdominal complications in CF patients, who are living longer as a result of improved respiratory treatments, which leads to improved life expectancy among CF patients; now extending to between 35 and 40 years[28]. These changing trends in radiation exposure among CF patients need to be closely monitored[29].

The expanding use of CT for guidance of medical management, particularly in patients with chronic relapsing illnesses such as inflammatory bowel disease and CF, has highlighted the need for strategies to optimise dose from imaging, especially CT. CT is responsible for only 15% of imaging procedures in inflammatory bowel disease but contributes over 75% of the CED[30]. The use of diagnostic imaging studies which result in exposure to ionising radiation in CF patients is of particular concern due to the greater vulnerability of younger patients to radiation induced injury due to their inherent radio-sensitivity[31], early onset of illness and greater risk of high cumulative exposures throughout their lifelong illness.

ROLE OF CHEST MAGNETIC RESONANCE IMAGING AND OTHER ALTERNATIVES IN PATIENTS WITH CF

Although CT is considered the gold standard for assessing CF patients, there may be a role for use of complementary imaging modalities such as pulmonary magnetic resonance imaging (MRI)[32]. MRI is less sensitive for detection of small airways disease (SAD) but is superior for assessing functional change such as changes in pulmonary perfusion[33,34]. Many authors advocate a role for the use of MRI in the follow-up of morphological changes in CF, however[35-37], the combination of MRI with inhaled hyperpolarised helium is also gaining in popularity[38-42]. The utilisation of inhaled agents such as hyperpolarised helium or xenon gives functional information regarding gas exchange. Obvious disadvantages are cost and time for acquisition in addition to limited usefulness in the ventilated or critical patient.

Fluorodeoxyglucose positron emission tomography - CT has been utilised with some success in delineating areas of active infection from fibrosis[43,44]. However access, cost and radiation dose are clear constraints hence mainstream use cannot be advocated.

RADIATION RISK FROM MEDICAL IMAGING

There is no proven association between radiation exposure in the diagnostic range and the development of malignancy. Predictions of the effects of medical-induced exposure to low-dose ionising radiation are largely based on data from the survivors of atomic bomb blasts or nuclear accidents. For the purpose of risk estimation, cancer incidence in this cohort was extrapolated from doses greater than 100 mSv to doses of a few mSv[45], using a linear no-threshold model. However, this model is being challenged as it conflicts with the current understanding of the biological mechanism of radiation-induced injury. Recently, The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), reported uncertainty in relation to the health effects of low-dose radiation. Based on findings from the nuclear accident in Fukushima 2012, doses of 100 mSv per year were deemed to have no observable acute or chronic effects on cancer incidence rates or public health[46].

The risk of radiation-induced cancer at doses less than 100 mSv is believed by some to be too small to be distinguishable from other risk factors for development of cancer[47,48]. However, a recently published retrospective cohort study, studied the risk of leukaemia and brain tumours associated with CT scans performed during childhood. Based on the findings of the study, the authors estimated that in the 10 years after the first CT scan was performed in patients younger than ten years, that one excess case of leukaemia and one excess case of a brain tumour per 10000 head CT scans occurred[49]. This association is particularly pertinent in CF where the average age at first CT scan is 1.9 years[27]. Some studies have suggested that there is an exponential increase of radiation induced cancer with decreasing age at initial exposure, namely, there is an estimated 14% lifetime cancer mortality risk per Gy in patients first exposed under the age of 14 years compared to a 5% risk in those first exposed in their 50's[50,51].

It is vital that the radiologist, referring physician and technologist ensure that the immediate benefits of CT are likely to outweigh the long-term risks before performing a CT scan. Refinements in CT scanner hardware and software and development of low-dose scanning protocol can lead to substantial reductions in radiation exposure from CT scanning while preserving image quality. These efforts are ensuring that CT scans can now be performed at much lower doses and that image quality is preserved in-spite of radiation dose reductions.

OPTIMISATION OF CT PARAMETERS

There is major industry and clinical impetus to develop and implement strategies that will reduce the effective doses incurred by patients undergoing CT without sacrificing diagnostic capabilities. The balance between image quality and radiation dose is particularly important where dose reduction is contemplated. Image noise is inversely related to X-ray beam energy and is an important determinant of image quality[52]. There are several scanning parameters that affect the radiation dose associated with CT, namely: Tube current, tube voltage, scanning length, collimation, table speed, table

pitch, gantry rotation time and shielding[53].

Modifications of tube current and tube voltage have direct effects on radiation dose but also on image "mottle" or noise. There is thus a "balancing act" between radiation exposure imparted and image quality, which can impact ability to detect and characterise pathological processes on the CT images. In most CT scanners, tube current is adjustable in increments from 20 mAs to approximately 400 mAs. In practice, reduction in tube current is the most practical means of reducing CT radiation dose, with a 50% reduction in tube current leading to a 50% reduction in dose[54]. This strategy increases image noise and so must be validated prior to clinical use. Lucaya *et al*[55] studied the effects of image acquisition using 50 and 180 mAs in CT scanning of the chest in children and young adults. Imaging with 50 mAs lead to a 72% reduction in dose but no difference in image quality compared with imaging at 180 mAs[55]. Another group have shown that high-resolution CT images of lung parenchyma acquired at 40 mAs yield anatomic information equivalent to that obtained at 400 mAs, without significantly affect subjective image quality[56].

Tube voltage affects both image noise and tissue contrast[57]. For instance, in abdominal CT, most scans can be optimally performed at 120 kVp instead of 140 kVp, resulting in a 20%-40% reduction in radiation dose[58]. The cross sectional dimensions of patients must be taken into consideration as the attenuation of the incident X-ray beam depends on the anatomical region being evaluated[59]. Essentially, larger patients require a higher tube voltage. This also applies to tube current where Donnelly *et al*[60] have shown that acceptable image quality can be produced at 50% reduced tube current in patients weighing less than 81.6 kg. However, above this weight, images are too noisy. Therefore, scanning parameters should be tailored towards the patient characteristics, especially body mass index, in order to reduce dose.

Multiple other user-defined controllable parameters of CT imaging have an impact on radiation dose. In helical scanners, beam collimation, table speed and pitch are interlinked parameters that affect the diagnostic quality of an image. Pitch is defined as the ratio of table feed per gantry rotation to the nominal width of the X-ray beam[54]. A faster table speed results in a higher pitch and scanning at a higher pitch is more dose effective[61]. Technological advances such as sixty-four and one hundred and twenty eight detector row scanners have resulted in higher scanning speeds. For instance, a four row scanner with a 0.8 s gantry rotation time requires 16 s to scan the entire abdomen. An eight row scanner, on the other hand, covers the same length in eight seconds[62]. Sixty-four slice scanners can acquire a whole body scan in less than 10 s and static organ imaging in 1 s[63]. This emphasises the importance of being aware that if tube rotation time is decreased (faster gantry rotation) radiation exposure decreases.

Furthermore, there is a general tendency to increase the area of coverage to include regions beyond the actual region of interest[64]. This increases the scanning length and thus unnecessarily increases doses that patients receive. It is essential for referring physicians to be mindful of this when requesting CT scans and for operators to restrict CT examinations to anatomical area that requires investigation. In addition, radiosensitive structures frequently lie close to the beam pathway. Adequate shielding is crucial, especially in the paediatric and young adult population whose organs are inherently more radiosensitive[65]. Beaconsfield *et al*[66] studied the effect of shielding regions of the body that are not included directly in the path of the X-ray beam during CT. They reported that with lead protection, thyroid and breast radiation doses were reduced by an average of 45% and 76% respectively[66]. This is particularly relevant in CF where an intrinsic risk of malignancy may be coupled with repetitive exposure to ionising radiation, rendering them particularly vulnerable.

Automatic exposure control

There have been many recent technological advances aimed at dose optimisation, including automatic exposure control (AEC). Automatic tube current modulation (ATCM) is a type of AEC, that works on the premise that pixel noise on a CT scan is attributable to quantum noise in the projections[67]. By adjusting the tube current to follow the changing patient anatomy, quantum noise projections can be adjusted to maintain a desired level of noise and improve dose efficiency[54]. Modern scanners use either one of two methods of ATCM - namely Z-axis modulation or angular modulation. In Z-axis modulation the tube current is adjusted to a user selected noise level[68]. Angular modulation on the other hand, attempts to render all images with similar noise regardless of patient size and anatomy[69]. The main advantage of ATCM is a reduction in dose with minimal compromise to image quality. This was highlighted by Greess *et al*[70] who reported a mean dose reduction of 22.3% for CT scanning of the neck, thorax and abdomen in children without loss of image quality.

Special attention is required in patients with metallic prostheses, *i.e.*, heart valves or anatomical shielding. As ATCM adapts the tube current based on density and attenuation in the region, there is potential for an increase in tube current when metal is in the field of interest[71]. In the presence of metallic prostheses, the use of *z*-modulation has been reported to result in a 34.1% increase in the mean tube current time product for abdominopelvic CT. It is important to acknowledge that this is still substantially less dose than when using fixed tube scanning - *i.e.,* there is a reduction in dose of almost 30% with ATCM as opposed to fixed tube scanning[72]. With that said, it is imperative that we are aware of the presence of metallic prostheses in the scanning field so that an increase in radiation dose with *z*-modulation technique can be avoided by selection of lower maximum milliamperage thresholds or by using

higher noise index or mixed modulation methods[73].

Radiation exposure can be further optimised by using X-ray filters, noise reduction filters and newer methods of image reconstruction such as iterative reconstruction (IR), which we will discuss in greater detail at a later stage in this article.

IR

As we have already explored in this review, increased image noise and reduced image quality are potential unfortunate consequences of reducing CT radiation dose. Standard CT scanners use filtered back projection (FBP) for image reconstruction. However, newer algorithms using IR have been introduced to reconstruct image data using a system of models which improve image noise. IR uses raw data as a building block whereby it transforms the measured value of each pixel to a new ideal estimate for that pixel[74]. This method uses matrix algebra and is repeated until the final estimated and ideal pixel values ultimately converge[75]. The use of IR extracts noise from CT images acquired at reduced exposure preserving image quality and interpretability[76]. The main advantage is that IR allows significant reductions in radiation dose while maintaining satisfactory image quality when compared to traditional FBP[74,77].

Hybrid IR, which combines both IR and FBP in a predefined ratio for image reconstruction, has been well validated in coronary CT angiography and for low dose CT scanning of the abdomen and pelvis in chronic conditions such as inflammatory bowel disease[78]. Multiple commercially available hybrid IR packages are available - these include adaptive statistical iterative reconstruction (ASIR) (GE Medical Systems, Milwaukee, WI, United States), adaptive iterative dose reduction (AIDR) (Toshiba Medical Systems, Tochigi, Japan), image reconstruction in image space (Siemens Healthcare, Erlangen, Germany), sinogram-affirmed IR (Siemens Healthcare) and iDose (Philips Healthcare, Best, Netherlands). Craig *et al*[30] compared hybrid IR of low-dose CT abdomen-pelvis datasets with conventional-dose CT in Crohn's disease and reported a 74% radiation dose reduction with IR. IR operates on list-mode data as opposed to histogrammed projection data and can generate an image following just one pass through the scan[79]. This results in a shorter scanning time and a reduction in radiation-exposure associated with CT thorax to a level approaching that of a plain radiograph[80]. The use of low dose CT with IR is ideal for imaging CF patients and in particular, the paediatric CF population.

In relation to thoracic imaging, ASIR has been shown to significantly reduce subjective and quantitative image noise on both standard and reduced dose chest CT[81]. Dose reductions of 46%-80% for thoracic CT can be achieved without compromising image quality[82,83]. In practice, this translates to substantial dose reductions in paediatric CT imaging without substantial compromise in image quality, a strategy that can be applied to imaging in CF[84].

Next generation imaging reconstruction will be performed using "pure" IR such as model-based iterative reconstruction (MBIR, Veo, GE Healthcare), iterative model reconstruction (Philips Healthcare), advanced modeled iterative reconstruction (ADMIRE, Siemens Healthcare) and AIDR 3D (Toshiba Medical Systems). Pure IR generates high quality images[85] with an even greater reduction in dose than hybrid IR, for example in excess of 80% dose reduction[86]. MBIR facilitates ultra-low dose chest imaging and a number of studies suggest that image quality can be maintained at doses approaching those of a chest radiograph[87,88]. However, the prolonged processing time currently limits its use in routine clinical practice especially for emergency cases. In the case of outpatient imaging for chronic disease assessment, such as in the setting of CF, an hour of reconstruction time is acceptable for the benefits gained.

DOSE OPTIMISATION PROTOCOLS

The purpose of CT dose optimisation is to obtain a diagnostic image with the least amount of radiation. Dose optimisation strategies are a priority among imaging specialists. Thoracic CT is particularly suited to dose optimisation protocols due to the high inherent contrast and low radiation absorption of the lung[89]. Recent studies have explored the utilisation of low dose protocols for thin-section CT in the assessment of CF. O'Connor *et al*[90] compared two non-contiguous thin-section protocols: Protocol A (1 mm section with an effective dose 0.19 mSv) and protocol B (0.5 mm section with an effective dose 0.14 mSv) reconstructed using FBP and using a 4-slice CT scanner. Diagnostic acceptability was graded as almost excellent for both protocols, however, the 0.5 mm section was found to be inferior for mediastinal assessment[90]. This study emphasised the fact that low-dose thin section CT is a viable option for accurately evaluating pathological changes in the lungs of CF patients even at doses approaching those of a chest radiograph.

As described above, recent advances in the area of radiation dose optimization and CT have focussed on refinement of IR techniques to allow diagnostic quality images to be acquired at significantly reduced radiation doses. IR when applied to thoracic imaging in CF patients should potentially allow contiguous chest imaging at chest X-ray doses which would improve scanning time and reduce the requirement for repeated patient breath-holds, which has potential for error. Contiguous CT scanning through the chest will facilitate 3D reconstruction that allows more comprehensive characterisation of distribution of lung changes, facilitates comparison with previous chest radiography and may offer potential for virtual bronchoscopy. Most recently, Singh *et al*[91] showed that ASIR reconstructed chest CT images can be obtained at 40 mAs/3.5 mGy

and still be diagnostically satisfactory.

Thin-section protocols have great potential for use in the paediatric CF population where an effective dose reduction of 26% can be achieved without compromising image quality[92]. There may also be a role for low-dose protocols in non-CF bronchiectasis, which accounts for 10% of referrals to tertiary respiratory centres[15]. In 50% of these new referrals, patients are misdiagnosed with asthma until the true diagnosis is confirmed at CT[93,94]. Once a diagnosis of CF is established, some experts suggest that low-dose CT should be performed bi-annually for assessment of lung parenchyma and bronchoalveolar structures in place of chest radiography[95].

Furthermore, substantial reductions in radiation dose can be achieved using only end expiratory CT in CF as opposed to combined end inspiratory and end expiratory CT. Loeve *et al*[96] reported a 75% reduction in effective dose when using low-dose (0.4 mSv, 110 kV) end expiratory CT alone while maintaining high inter-observer correlation of CF CT scores. Expiratory chest imaging can provide useful detail when air trapping is suspected, as this may not be appreciated on inspiratory CT[97]. Expiratory CT identifies SAD and ideally should be controlled by spirometry[98,99]. SAD is recognised by the presence of hypo-dense areas within areas of mosaic attenuation and it is estimated that one third of hypo-dense regions persist over a 2 year period, which suggests irreversibility[12]. This may be used as a separate marker of pulmonary disease in conjunction with CT bronchiectasis scores.

As a large proportion of CF patients are in the paediatric age group, compliance with scanning methods can be difficult to achieve. Methods of optimising patient cooperation help maximise the information obtained from CT by reducing breathing artefact and the need for repeat imaging. Training in breath holding techniques, lateral decubitus positioning or spirometry may prove beneficial in this regard. In children less than 5 years old, sedation may be required to avoid multiple scans due to movement or inability to follow instructions[100].

Surprisingly, there are no clear data on how CT-guided decision making affects outcome in CF patients[101]. Owing to the accurate depiction of disease progression, however, low-dose CT scans are regularly used to guide management in clinical practice. In many dedicated CF centres, dose-optimised CT is performed bi-annually. PFT's are often used in conjunction with CT as part of a multi-modal assessment, especially between CT scans. Disease models that encompass age, gender, CT and PFT's can be used as a guide to predict frequency of infective exacerbations or the rate of decline in lung function. Although these models are not yet fully validated, they represent a move towards personalised treatment. For instance, some "low-risk" patients may only need CT scans every three years as opposed to "high-risk" patients who may need annual scanning. The 2009 CF guidelines do not recommend any specific scanning frequency or interval but recommend CT in symptomatic patients who fail to respond to basic intervention[102]. Ideally, CF management should be personalised and based on risk stratification.

SCREENING IN RESPIRATORY DISEASE

Dose optimisation scanning techniques have facilitated the use of CT as first line imaging and are gaining popularity for screening of benign and malignant respiratory conditions. Most notably, The American Association for Thoracic Surgery recently published guidelines on screening for lung cancer, which recommend annual dose-optimised CT screening for patients aged 55-79 year with a greater than 30 years' pack history[103-105]. These guidelines were derived from the National Lung Screening Trial, which established the ability of dose-optimised CT to decrease lung cancer specific mortality by 20% in a screened population[104]. As the role of CT in the medical arena expands, so does the need for dose-optimisation strategies so that low dose scanning becomes commonplace.

PHYSICIAN AWARENESS

Increasing concern has recently been expressed in the literature that the knowledge of referring doctors regarding the radiation doses incurred during diagnostic radiological procedures is inadequate[106]. Lee *et al*[107] found that 75% of physicians underestimate the dose from a CT scan. This is interesting considering the integral and expanding role that CT plays across all medical specialities and the utilisation of CT in the hospital setting where CT accounts for 15% of the workload of an average radiology department[108]. This shortcoming is also evident in medical students. O' Sullivan *et al*[109] assessed medical students' awareness of radiation exposure associated with diagnostic imaging and found that only two-thirds of students knew that CT used ionising radiation. This lack of awareness becomes particularly pertinent when one considers the number of patients who receive inappropriate or repeat examinations[64,110]. Fortunately, education in clinical radiology positively impacts on knowledge of radiation exposure associated with diagnostic imaging, which supports the Eurotom 97 directive for the integration of radiation protection instruction into medical school curriculum[111]. As seen in the "Image wisely" and "Image gently" campaigns, a three-tiered approach to radiation protection is strongly recommended: The as low as reasonably achievable principal, justification of the imaging procedure and dose limitation[112,113]. In short, the best way to reduce the radiation dose to patients is to avoid unnecessary CT exams and to look for alternative diagnostic imaging modalities which either avoid radiation exposure or result in less exposure than modalities[114]. Education of medical undergraduates and postgraduates is fundamentally important to ensure

that radiation protection issues are considered when physicians choose the diagnostic imaging studies for their patients.

A new initiative on this front is the introduction of patient radiation dose tracking[115-117]. This entails detailed automated recording of all medical radiation exposures received by patients. This information can be included in individual radiology reports and medical files plus can be used to calculate lifetime cumulative exposures. This knowledge would then be available at the image requesting stage to keep clinicians aware of the patients past radiation exposures. Another powerful aspect of dose tracking is for quality assurance purposes within the imaging department, such that per study doses can be reduced to defined international standards.

THE CHANGING FACE OF CF

There is a constant stream of novel approaches to the management of CF. Most notably, the development of the first disease modifying drug in CF, Kayldeco, has opened up a new realm of possibilities using genomically-guided medicine[118]. In 2012, Kayldeco was approved by the food and drug administration for use in CF patients with the *G551D* mutation. Although this particular mutation is only found in approximately 5% of CF patients, it represents a significant breakthrough as it targets the underlying genetic defect within the *CFTR* gene[119]. Drug trials have demonstrated that Kalydeco can markedly improve lung function; lower sweat chloride levels and help patients gain weight[120]. Research is ongoing into the possible benefits of Kayldeco in the most common CF mutation: Delta F508, which accounts for 70% of mutations. Results from a phase 2 trial of Kalydeco in combination with VX-809 show a marginal improvement in lung function in people who are homozygous for delta F508[68,121]. These developments have the potential to significantly improve quality of life for CF patients, however, the beneficial effects on the architecture of the lung, as seen on radiological imaging, have not yet been documented. This is an area of potential future research and another reason for optimisation of CT scanning protocols.

RECOMMENDATIONS

There is a growing reliance on the use of CT in the management of CF, as demonstrated by the six-fold increase in the use of CT in CF over the last fifteen years.

Dose-optimised CT reduces the chances of patients receiving cumulative radiation doses in excess of 100 mSv, a dose deemed significant by UNSCEAR.

Longitudinal studies are needed to define appropriate scanning intervals and to assess the impact of CT scanning on disease outcome in CF patients.

Physicians are developing tailored approaches to disease surveillance, where scanning intervals are based on risk stratification in order to maximise benefit.

CONCLUSION

As modern treatments continue to extend the life expectancy of CF patients, cumulative radiation exposure from medical imaging is of increasing significance. Medical professionals are challenged with identifying CT dose-reduction strategies that strike an acceptable balance between image quality and diagnostic acceptability. Dose optimisation strategies have to be continually developed and refined in all patients, but particularly those with chronic diseases such as CF, who will require radiological imaging throughout their lifetime.

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