

BMJ Open Radiation dose from common radiological investigations and cumulative exposure in children with cystic fibrosis: an observational study from a single UK centre

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ABSTRACT

Objectives Cumulative radiation exposure is associated with increased risk of malignancy. This is important in cystic fibrosis (CF) as frequent imaging is required to monitor disease progression and diagnose complications. Previous estimates of cumulative radiation are outdated as the imaging was performed on older equipment likely to deliver higher radiation. Our objectives were to determine the radiation dose delivered to children during common radiological investigations using modern equipment and to identify the number of such investigations performed in a cohort of children with CF to calculate their cumulative radiation exposure.

Design, setting and participants Data including age at investigation and radiation exposure measured as estimated effective dose (EED) were collected on 2827 radiological studies performed on children at one UK paediatric centre. These were combined with the details of all radiological investigations performed on 65 children with CF attending the same centre to enable calculation of each child's cumulative radiation exposure.

Results The mean EED for the common radiological investigations varied according to age. The range was 0.01–0.02 mSv for chest X-rays, 0.03–0.11 mSv for abdominal X-rays, 0.57–1.69 mSv for CT chest, 2.9–3.9 mSv for abdominal and pelvic CT, 0.20–0.21 mSv for sinus CT and 0.15–0.52 mSv for fluoroscopy-guided procedures. The mean EED was three to five times higher for helical compared with axial chest CT scans. The mean annual cumulative EED for our cohort of children with CF was 0.15 mSv/year with an estimated cumulative paediatric lifetime EED (0–18 years) of 3.5 mSv.

Conclusions This study provides up-to-date estimations of the radiation exposure when using common radiological investigations. These doses and the estimates of cumulative radiation exposure in children with CF are lower than previously reported. This reflects the reduced EED associated with modern equipment and the use of age-specific scanning protocols.

Strengths and limitations of this study

- This study provides up-to-date information on the radiation dose associated with common radiological investigations.
- It also gives an accurate estimation of cumulative radiation exposure for children with cystic fibrosis (CF) if modern radiological equipment and protocols are used.
- This study is limited by the lack of a historical cohort to compare the results to.
- The estimated cumulative radiation exposure is only applicable to other centres/countries that have similar policies regarding radiological investigations in children with CF.

INTRODUCTION

Since their discovery in 1895, X-rays have been used with ever increasing levels of sophistication to perform radiographs and CT scans. These investigations have revolutionised medical care but their benefits must be balanced against possible adverse effects, one being the increased risk of malignancy associated with cumulative radiation dose.^{1–3} This is especially important in children as they are more sensitive to radiation than adults.^{4,5} When discussing radiological investigations with a child and family it is vital that paediatricians know the radiation dose to which that child will be exposed. Unfortunately, calculating the radiation dose associated with radiographs and particularly CT scans is more complicated than most clinicians recognise. This is because it varies depending on the type of investigation, on the make and model of scanner, on the scan protocol and the scan sequence as well as on the age and size of the child.

Monitoring cumulative radiation exposure in children with cystic fibrosis (CF) is particularly important as they undergo many radiological investigations. At UK Paediatric CF Centres, chest radiographs (CXR, chest X-ray) are performed annually to monitor disease progression as recommended in clinical guidelines.⁶ There is no UK national guidance about the use of CT scans in children with CF. They are usually performed as required to assess the severity of lung disease and for the diagnosis of complications such as non-tuberculous mycobacterium lung disease. In some parts of Europe, chest CT scans are performed routinely, as often as every 2 years. Abdominal and sinus CT scans may be required for the diagnosis of complications and if a totally implanted venous access device (TIVAD) is required, it is inserted under fluoroscopy (real-time X-ray) guidance. The implementation of CF newborn screening programmes has reduced the age at which radiological investigations commence. At the same time, improvements in life expectancy have increased the time in which the stochastic (carcinogenic) risk associated with radiation exposure can be expressed.⁷

It is known that individuals with CF have an increased incidence of certain digestive tract malignancies later in life.⁸ Although a causal link has not been established between the increased cancer risk and total radiation exposure, it would be remiss not to record the cumulative radiation dose to which patients with CF are exposed. Previous studies have estimated this both in children and adults.^{9,10} The calculations were based on historical data using a catalogue of mean radiation doses for radiological and nuclear medicine examinations.¹¹ These estimates are now out of date and do not reflect the lower radiation doses associated with modern imaging equipment.¹² Knowledge of present day radiation exposure using the newest equipment is important to ensure that discussions between clinicians and families are based on accurate information.

Aims

The aims of this study were twofold:

1. To determine the radiation doses of common radiological investigations performed for any indication on children using modern equipment and protocols in our hospital.
2. To identify the number of radiological investigations performed in a cohort of children with CF to calculate each child's cumulative radiation exposure.

METHODS

We retrospectively reviewed the radiation dose delivered to children in our institution undergoing common radiological investigations. The measure of radiation exposure we used was the estimated effective dose (EED). This is the tissue-weighted sum of the equivalent doses in all specified tissues and body organs and represents the overall stochastic health risk. We combined these data with a review of the total number of radiological investigations in a cohort of children with CF of varying ages to

determine the burden of our imaging practices in children with CF.

Radiation dose associated with common radiological investigations

Data were obtained on all CXRs, abdominal X-rays (AXRs), chest CT scans, abdominal and pelvic CT scans, sinus CT scans and fluoroscopy-guided TIVAD insertion performed on children in our unit. This included: make, model and name of scanner or imaging instrument; name of protocol; name of the scan sequence (for CT scans); patient age at investigation and the EED (mSv). Four years of CT scan data were collected from April 2012 when the imaging department moved to a new hospital and acquired four new CT scanners (one Siemens Somatom Definition Flash (256-slice) and three Siemens Somatom Definition AS+ (128-slice)). Fluoroscopy data were collected over the same period. Data on CXR and AXR were only collected for 1 year as the numbers were much higher than for the other investigations. The mean EED associated with each investigation was calculated according to the age of the child (ranges: 0 to <1 year, 1 to <5 years, 5 to <10 years, 10 to <15 years and 15–18 years). The exact details of how the radiation dose was calculated are given in online supplementary appendix 1.

Number of radiological investigations performed on children with CF at our centre

We reviewed the patients' medical records and their picture archiving and communication system for all children (0–18 years) with CF who only attended the Royal Stoke University Hospital for their CF care. Those who had recently transferred their care to our centre were excluded. Sixty-five children were included with a mean (SD) age of 8.8 (5.5) years. The number of radiological investigations performed throughout the child's lifetime was recorded, as was the child's age at each investigation. These data were combined with the mean EED associated with each radiological investigation to determine the individual child's predicted cumulative radiation exposure if our current technology and protocols had been used. Linear regression was used to determine the likely cumulative EED delivered by the age of 18 years. The relative contribution of each investigation to the child's total radiation exposure was also calculated.

The aim of this review was to assess the cumulative radiation dose associated with CF radiological investigations using modern scanners. We therefore did not collect historical data obtained from older scanners. Children with CF may require radiological investigations for non-CF issues such as injuries and trauma. These investigations will be performed ad hoc and will vary greatly between patients so we did not collect this information.

RESULTS

Complete data were available on 2140 CXRs, 92 chest CT scans, 482 AXRs, 73 abdomen and pelvis CT scans, 24

Table 1 EED of radiation received by children undergoing various radiological procedures for any indication at our centre

		0 to <1 year	1 to <5 years	5 to <10 years	10 to <15 years	15 to <18 years
CXR	Number performed	179	789	542	213	417
	EED (mSv)	0.02	0.02	0.01	0.01	0.01
AXR	Number performed	69	115	99	100	99
	EED (mSv)	0.03	0.03	0.03	0.09	0.11
Chest CT	Number performed	9	28	29	16	10
	EED (mSv)	0.57	0.90	0.91	1.27	1.69
Abdomen and pelvis CT	Number performed	0	0	15	15	43
	EED (mSv)	–	–	2.9	3.4	3.9
Sinus CT	Number performed	0	0	0	10	14
	EED (mSv)	–	–	–	0.21	0.20
Fluoroscopy	Number performed	0	4	6	4	2
	EED (mSv)	–	0.52	0.20	0.15	0.19

Table includes 4 years of data for CT scans and fluoroscopy and 1 year of radiograph data. EED data are presented as mean.

AXR, abdominal X-ray; CXR, chest X-ray; EED, estimated effective dose.

sinus CT scans and 16 fluoroscopy-guided TIVAD insertions. The mean EED of radiation received by children undergoing each of these radiological investigations is given for the five age bands in [table 1](#). The EED for the chest CT scans is split into helical (volumetric) and axial (non-contiguous) scans in [table 2](#).

A summary of the total number of each type of radiological investigations performed in children with CF at our unit is given in [table 3](#), grouped into the same five age bands. These data were combined with those in [table 1](#) to calculate the relative contribution of each investigation to the child's total radiation exposure ([table 3](#)) as well as the cumulative lifetime radiation exposure for each child with CF ([figure 1](#)).

The mean annual cumulative EED was 0.15 mSv/year, this increased from 0.05 mSv/year in those aged 0 to <1 year to 0.20 mSv/year in those aged 15–18 years. The predicted lifetime radiation dose for a child aged 18 with CF at our unit is approximately 3.5 mSv ([figure 1](#)).

DISCUSSION

This study provides important information on the radiation dose received by children undergoing common radiological investigations. It can be used to help discussions between paediatricians and their patients about the risks and benefits of such investigations.

Table 2 Estimated effective dose of radiation received by children undergoing chest CT for any indication at our centre separated into helical and axial scans

		0 to <1 year	1 to <5 years	5 to <10 years	10 to <15 years	15 to <18 years
Helical CT chest	Number performed	9	28	24	10	5
	EED (mSv)	0.57	0.90	1.06	1.69	2.79
	Equivalent number of CXRs	29	45	106	169	279
Axial CT chest	Number performed	0	0	5	6	5
	EED (mSv)	–	–	0.22	0.58	0.59
	Equivalent number of CXRs	–	–	22	58	59
All chest CTs	Number performed	9	28	29	16	10
	EED (mSv)	0.57	0.90	0.91	1.27	1.69
	Equivalent number of CXRs	29	45	91	127	169

The EED data represent the mean dose per scan. CXR, chest X-ray; EED, estimated effective dose.

Table 3 The relative contribution of different radiological investigations to total radiation exposure in children with CF at our centre

Age of child		0 to <1 year	1 to <5 years	5 to <10 years	10 to <15 years	15 to <18 years
CXR	Number*	1 (1–2)	5 (3–8)	9 (4–20)	12 (10–15)	17 (5–22)
	% Total radiation†	100%	77%	23%	10%	7%
HRCT chest	Number*	0 (0–0)	0 (0–1)	1 (0–5)	2 (1–2)	2 (1–3)
	% Total radiation†	0%	19%	65%	84%	79%
AXR	Number*	0 (0–0)	0 (0–1)	0 (0–3)	0 (0–1)	0 (0–2)
	% Total radiation†	0%	4%	3%	0%	1%
Abdomen and pelvis CT	Number*	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–2)
	% Total radiation†	0%	0%	0%	0%	5%
Sinus CT	Number*	0 (0–0)	0 (0–0)	0 (0–1)	0 (0–1)	0 (0–1)
	% Total radiation†	0%	0%	0%	1%	2%
Fluoroscopy	Number*	0 (0–0)	0 (0–0)	0 (0–4)	0 (0–1)	1 (0–3)
	% Total radiation†	0%	0%	9%	5%	5%

*Total number of investigations performed on children that age presented as median (range).

†% Total radiation presented as mean.

AXR, abdominal X-ray; CF, cystic fibrosis; CXR, chest X-ray; HRCT, high-resolution CT.

We have shown lower radiation doses than those listed in the most frequently cited catalogue of radiation doses and lower estimates of cumulative radiation exposure for children with CF.¹¹ This can be explained by the use of up-to-date radiological equipment used at our centre which is associated with lower radiation exposure.¹² The ‘catalogue of radiation doses’ uses radiation data from 1992 and is likely to have included data from CT scans performed on single and dual slice scanners which would expose patients to much higher doses of radiation. We have shown that the radiation dose associated with CT scans increases with the child’s age. This differs from older reports which showed the opposite trend (2.85 mSv for CT chest in a 1 year old decreasing to 1.65 mSv for CT chest in a 15 year old).^{9, 11} This difference means that the EED of a chest CT in an infant at our centre is one-fifth of the previously published value (0.57 mSv compared with 2.85 mSv). This is again explained by the previous use of historical data. Using a modern multislice CT scanner, EED would be expected to be lower in younger children as the dose-saving features optimise radiation dose based

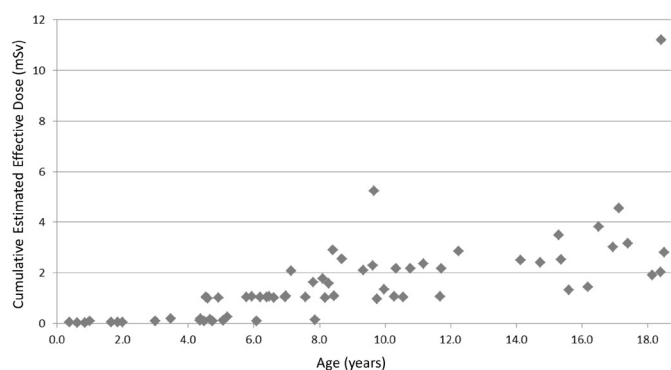


Figure 1 Cumulative radiation exposure associated with radiological investigations for 65 children with cystic fibrosis.

on patient size and the region scanned. These features include modulation of the tube current and voltage along with adaptive collimation, iterative reconstruction and most importantly the use of age-specific paediatric scan protocols.^{13–15} This trend of an increasing effective dose being associated with scans performed in older children along with a general overall reduction in the relative dose across age ranges has previously been reported.¹²

Of interest is the variation in the EED associated with different types of chest CT scan. The EED from helical CT scans was three to five times higher than the dose from an axial CT scan. Helical scans can be performed more quickly and therefore require less patient cooperation than axial CT scans. They are therefore particularly useful in younger children. They may also be more sensitive in detecting bronchiectasis.¹⁶ The radiation dose associated with helical scans is however higher than axial scans. To minimise the radiation exposure in children with CF, every effort should be made to ensure that the CT protocol and technique is tailored to the child and the clinical question that needs to be answered. If an axial scan is likely to provide enough accuracy, clinicians should consider waiting to request a CT scan until the child is old enough to cooperate with an axial scan. Radiologists should ensure they have maximal skill and patience with children to enable such a procedure to be successful. Attempts to limit the radiation dose delivered from CT scans are especially important in some European countries in which biennial CT scans are performed routinely. The further development of chest MRI as a radiation-free alternative to CT scans in the assessment of morphological lung changes is keenly awaited by CF clinicians.

This study shows if all radiological investigations are performed on up-to-date equipment, a typical 18-year-old patient with CF will be exposed to a cumulative EED of

approximately 3.5 mSv. Based on an estimated average cancer risk of 11% per Sv for patients aged 0–18 years, this relates to an additional lifetime cancer risk of approximately 1 in 2500.¹⁷ Another way of conveying this message relates to background radiation. In the UK, the average annual background radiation is 2.6 mSv.¹⁸ Therefore, we estimate that the cumulative radiological investigations performed on an 18 year old with CF add the equivalent to an additional 18 months background radiation. In children with CF, CXRs are the most frequently performed radiological investigation but beyond 5 years of age they are responsible for a minority of the child's total radiation exposure. In contrast, after 5 years of age, CT scans of the chest become responsible for the majority of the child's total exposure. In our cohort, abdominal CT scans were infrequently performed but when undertaken markedly increased the child's cumulative EED. This is well shown in figure 1 where the 18 year old with a cumulative EED of 11.2 mSv had two abdominal CT scans performed which contributed 65% of the radiation exposure.

CONCLUSIONS

Paediatricians need to be well informed on radiation doses produced by imaging technologies. Modern equipment has the potential to reduce the EED associated with such investigations. This effect is greatest for CT scans in younger children. Even if all investigations were performed on modern radiological equipment, the cumulative radiation dose for children with CF remains substantial and every effort should be made to keep it to a minimum. All scans should be optimised with regard to image quality and patient dose by using age-specific protocols. Paediatricians and radiologist should be aware of the risks and benefits of axial and helical CT scans. Lowering the cumulative lifetime radiation dose in children with CF will reduce their associated stochastic risks.

Contributors RW led the data collection and wrote the first draft of the paper. FJG conceptualised and designed the study, he also redrafted the article. PC, MJ and DT assisted with collecting the radiological data and calculation of the radiation dose. WDC, SAH and WL assisted with the clinical data. All authors reviewed and revised the manuscript and approved the final manuscript as submitted.

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