

Evaluating a Low-Cost Radiation-Risk Educational Leaflet for Foundation Doctors: A Two-Cycle Quality Improvement Study

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Review began 09/20/2026

Review ended 10/08/2026

Published 10/19/2026

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DOI: 10.7759/cureus.118200

Abstract

Background and aim: Justification of medical exposure to ionizing radiation involves weighing the anticipated clinical benefit against potential radiation detriment. The referring clinician contributes by supplying the clinical information on which that judgment rests. Referrers' knowledge of dose and malignancy risk has repeatedly been shown to be limited, and was neither taught nor assessed within one National Health Service (NHS) Foundation Programme. Reported interventions typically require protected teaching time and coordinated attendance. This project aimed to assess baseline radiation-risk knowledge, develop and distribute a low-cost educational leaflet through existing channels, and compare assessment performance before and after the intervention using anonymous, unlinked responses.

Methods: This anonymous two-cycle repeated cross-sectional clinical audit and quality improvement study assessed doctors in the first two postgraduate years of the United Kingdom Foundation Programme at one NHS Trust (48 planned eligible posts per cycle). Performance was assessed using the Royal College of Radiologists AuditLive 12-item radiation-awareness instrument, covering chest radiograph dose equivalents and fatal malignancy risk. After baseline measurement, we distributed an author-written three-page leaflet targeting the weakest domains via email, messaging, and print, without a dedicated budget, additional staffing, or a teaching session. Reassessment followed two to five days later. Missing responses were scored as incorrect. Scores were compared using a Welch t-test with Hedges' g, alongside seven robustness and sensitivity analyses. Responses were anonymous and unlinked, so respondent overlap is unknown.

Results: Cycle 1 yielded 18 responses from 48 planned eligible posts (37.5%), and cycle 2 yielded 16 responses (response rate: 33.3%). Mean assessment scores were 42.6% (SD: 16.6 percentage points) in cycle 1 and 80.2% (SD: 20.6 percentage points) in cycle 2. Median scores were 41.7% (Q1-Q3: 35.4%-50.0%) and 83.3% (Q1-Q3: 75.0%-91.7%), respectively. The mean difference was +37.6 percentage points (95% CI: +24.4 to +50.9 percentage points; Welch t=5.81, df=28.87; p<0.001), with Hedges' g +1.97 (approximate 95% CI: +1.14 to +2.81). Six sensitivity and adjusted analyses yielded mean differences of +34.8 to +39.8 percentage points, with all lower 95% confidence limits above +20 percentage points; the Mann-Whitney comparison was concordant. The two items addressed most directly by the leaflet showed the largest increases, each rising by 53.5 percentage points. Deficits persisted, with four items answered correctly by only 68.8% of respondents.

Conclusions: Radiation-risk assessment scores were substantially higher in the cycle following leaflet distribution. The design was not randomized, responses were unlinked, and reassessment was announced, conducted open-book, and completed two to five days later; no causal or durability inference is possible. The intervention is reproducible without a dedicated budget or teaching session. Persistent deficits support delayed reassessment in a broader staff group.

Categories: Radiology, Medical Education, Quality Improvement

Keywords: educational leaflet, foundation doctors, medical education, quality improvement, radiation awareness

Introduction

Diagnostic imaging using ionizing radiation is integral to acute clinical care, and its use continues to grow. The National Health Service (NHS) in England recorded 8.3 million computed tomography (CT) examinations in the year to March 2025, an increase of 8.7% compared with the previous year and a faster rate of growth than that observed for imaging activity overall [1]. Under the Ionising Radiation (Medical Exposure) Regulations 2017 (IR(ME)R), every medical exposure must be justified by weighing its benefit against the radiation detriment it may cause, with the referring clinician supplying the clinical information on which that judgment rests [2]. Radiological protection rests on the linear no-threshold model, under which no diagnostic exposure is assumed to be entirely free of stochastic malignancy risk [3]. Justification therefore depends on referrers having at least an approximate working knowledge of the doses and malignancy risks associated with the investigations they request.

How to cite this article

Myers D J (October 19, 2026) Evaluating a Low-Cost Radiation-Risk Educational Leaflet for Foundation Doctors: A Two-Cycle Quality Improvement Study. Cureus 18(10): e118200. DOI 10.7759/cureus.118200

Knowledge gaps have been reported across different stages of medical training. Shiralkar et al. identified poor awareness of radiation doses among doctors [4], while Mellis et al. reported inaccurate estimates of dose and cancer risk among medical students and referrers in Scotland [5]. Among 97 responding Irish medical interns, Lee and Lee found that 64% reported no formal radiation-safety training and 74% were unaware of legislation governing radiology prescribing, although the low response rate limits generalizability [6]. These findings support assessing radiation-risk knowledge early in postgraduate practice.

Educational interventions offer a potential means of addressing these gaps. The integrative review by Hankin and Jones reported improvements in measured knowledge following educational interventions, although delivery methods and assessments varied [7]. Scheduled teaching requires coordinated attendance, which may be difficult for foundation doctors working across different rotas and clinical settings. The Royal College of Radiologists (RCR) AuditLive template suggests displaying a local dose and risk chart as a poster or online reminder when the audit target is not met [8]. This project therefore evaluated a locally written leaflet distributed through existing electronic and print channels, without a dedicated teaching session.

Within the East Cheshire NHS Trust Foundation Programme, foundation doctors frequently request diagnostic imaging, yet radiation dose and malignancy risk knowledge was neither taught nor assessed locally despite these regulatory obligations. No adverse incident prompted this project; the shortfall lay in training provision rather than in any observed failure of practice. The RCR AuditLive standard specifies that IR(ME)R practitioners and those performing delegated practitioner functions should demonstrate knowledge of effective doses for relevant examinations and the approximate added malignancy risk, with a target of 100% of staff possessing the requisite knowledge [8]. Because the standard specifies no numerical pass mark for this assessment, performance is reported as a continuous participant-level score throughout.

This was a two-cycle, repeated cross-sectional assessment study conducted as a clinical audit and quality improvement project, with the following three aims: to measure baseline radiation-risk knowledge among foundation doctors in the domain covered by the standard; to develop a low-cost educational leaflet targeting the areas of weakest baseline performance, deliverable through existing communication channels without scheduled teaching; and to determine whether assessment scores following the intervention period differed from baseline. Because responses were anonymous and unlinked, the comparison is between two unlinked cross-sectional samples, analyzed using independent-samples methods, rather than a within-participant measure of change. Preliminary audit findings were presented as an e-poster at the Radiology Academic Network for Trainees (RADIANT) Annual General Meeting on June 16, 2026. The conference abstract was not published, and the present analysis supersedes that preliminary presentation.

Materials And Methods

Setting and design

This was an anonymous, repeated cross-sectional two-cycle clinical audit and quality improvement study conducted at East Cheshire NHS Trust, Macclesfield District General Hospital, United Kingdom. The eligible population comprised foundation year 1 (F1) and foundation year 2 (F2) doctors in the 2025/26 foundation program, including those rotating through general practice and psychiatry placements; absence for leave, on-call duties, or sickness did not remove eligibility. The denominator was 48 planned foundation posts, derived from local program charts; actual staffing was not verified. The source documentation has been retained and can be provided on request.

Baseline measurement (cycle 1) opened on October 21, 2025, and closed on November 6, 2025, following receipt of the final electronic response, after which the baseline data were analyzed. The intervention was distributed on November 9, 2025, and post-intervention measurement (cycle 2) ran from November 11, 2025, to November 14, 2025, two to five days later. Both cycles drew on the same eligible cohort, but responses were anonymous and could not be linked beyond grade; candidate numbers within the source workbook are row identifiers, not persistent participant identifiers, so the extent of respondent overlap is unknown and cannot be determined from the data.

Recruitment and data collection

Participation was voluntary, and no incentives were offered. The assessment was first circulated on October 21, 2025 by the trust postgraduate medical education administrator through trust email and the messaging groups used for routine foundation program communication. The accompanying email and assessment text explicitly described the purpose of data collection and stated that findings would be presented and disseminated as appropriate. Participants were also told they would receive an educational leaflet and a repeat assessment.

Both cycles offered electronic and paper response routes. The electronic route used Microsoft Forms (Redmond, WA: Microsoft Corp.), accessed through authenticated NHS accounts, and allowed one response per account. Paper assessments were distributed during separate grade-specific foundation teaching sessions and completed and returned immediately afterward. Respondents were explicitly asked not to respond more

than once. Beyond the electronic one-response-per-account control, duplicate prevention was honor-based; no duplicates were suspected, but the anonymous design precluded definitive verification.

No feedback on cycle 1 performance was given at any stage before cycle 2 closed - participants were not shown the marking scheme, were not told which of their individual answers had been correct, and were not given aggregate cycle 1 results. They were asked to read the leaflet before completing the cycle 2 assessment but could complete it at a time of their choosing within the collection period; therefore, the interval between reading and completion was self-determined and unrecorded. Cycle 2 was conducted open-book as follows: the leaflet had been distributed and was not withdrawn, and its use was neither prohibited nor monitored. Whether participants read the leaflet or consulted it or another source while completing the assessment was not recorded.

Assessment instrument and outcome

Measurement used the 12-item assessment accompanying the Royal College of Radiologists (RCR) AuditLive template "awareness of radiation risks by referrers and practitioners justifying radiological examinations" [8]. Wording and response options were unchanged except for electronic formatting and recording of foundation grade.

The assessment comprised eight dose items and four fatal malignancy risk items (Table 1). Dose was expressed in posteroanterior chest radiograph (CXR) equivalents, using 0.015 mSv for a typical United Kingdom CXR, with response options of 50, 200, 500, or >700. Risk options were 1:100,000, 1:10,000, 1:1,000, or 1:100. Candidates were instructed to select the nearest answer; no "zero" or "no ionizing radiation" options were provided.

Item	Content	Modality	Key	Cycle 1, n/18 (%)	Cycle 2, n/16 (%)	Change (percentage points)
1	Abdominal radiograph dose	Radiography	50	11 (61.1)	13 (81.3)	+20.1
2	Lumbar spine radiograph dose	Radiography	50	9 (50.0)	15 (93.8)	+43.8
3	CT kidneys, ureters, and bladder dose	CT	500	5 (27.8)	11 (68.8)	+41.0
4	CT abdomen and pelvis dose	CT	500	5 (27.8)	13 (81.3)	+53.5
5	CT chest dose	CT	500	8 (44.4)	13 (81.3)	+36.8
6	Isotope bone scan dose	Nuclear medicine	500	6 (33.3)	11 (68.8)	+35.4
7	MR angiography dose ^a	MR	50	10 (55.6)	11 (68.8)	+13.2
8	CT brain dose ^a	CT	200	5 (27.8)	11 (68.8)	+41.0
9	CT abdomen and pelvis fatal malignancy risk	CT	1:1,000	5 (27.8)	13 (81.3)	+53.5
10	CT head fatal malignancy risk	CT	1:10,000	9 (50.0)	14 (87.5)	+37.5
11	Lumbar spine radiograph fatal malignancy risk	Radiography	1:10,000	7 (38.9)	13 (81.3)	+42.4
12	Chest radiograph fatal malignancy risk	Radiography	1:100,000	12 (66.7)	16 (100.0)	+33.3
Aggregate	All items, by modality	Radiography (four items)	N/A	39/72 (54.2)	57/64 (89.1)	+34.9
Aggregate	All items, by modality	CT (six items)	N/A	37/108 (34.3)	75/96 (78.1)	+43.9
Aggregate	All items, by modality	Nuclear medicine (one item)	N/A	6/18 (33.3)	11/16 (68.8)	+35.4
Aggregate	All items, by modality	MR (one item) ^a	N/A	10/18 (55.6)	11/16 (68.8)	+13.2

TABLE 1: Item-level performance across cycles.

^aAmbiguously keyed; see the assessment instrument and outcome subsection for the keying decisions.

Descriptive data: doses are expressed as equivalents to posteroanterior chest radiographs. Modality groupings are those used in the original audit analysis. Aggregate rows express responses matching the historical key as a proportion of all scored item opportunities in that group, including missing responses scored as incorrect. No inferential testing was performed at item or modality level.

MR: magnetic resonance; N/A: not applicable

Foundation grade was recorded by route. The electronic form included a mandatory grade item completed by the respondent. For paper responses, grade was determined from distribution within separate grade-specific teaching sessions and was independently verified by the administrator. The outcome was the participant-level percentage score across all 12 items, one point for each response matching the historical key. Missing scored responses were treated as incorrect in the primary analysis; scored electronic items were optional, and a complete-response sensitivity analysis was performed.

The historical key was retained unchanged for reproducibility. It was derived locally from published United Kingdom dose data from the Health Protection Agency (HPA-CRCE-012) and International Commission on Radiological Protection (ICRP) risk coefficients (ICRP publication 103) [9,10]. For risk items, we selected the available denominator closest on a linear scale to the calculated one-in-N denominator. The separate dose-item keying decisions are described below. The dose data are those of the 2008 United Kingdom survey of medical and dental X-ray examinations, published in 2010, and predate subsequent reductions in computed tomography dose. The full derivation is retained in the original audit workbook and is available from the author on request. The key served only as an audit scoring device, not as a set of patient-specific or trust-specific clinical estimates.

The historical calculations used 0.014 mSv per posteroanterior chest radiograph; the leaflet prose used 0.015 mSv. The bone-scan dose of 6.3 mSv was taken from Mettler Jr et al., rather than HPA-CRCE-012, which excludes nuclear medicine [9,11]. Two items required explicit keying decisions. Magnetic resonance (MR) angiography, which uses no ionizing radiation, was keyed to the lowest option, 50 CXR equivalents, because no zero response was available. CT brain was keyed as 200 CXR equivalents as follows: the local estimate was approximately 114, within the second order-of-magnitude band represented by 200, although 50 is arithmetically closer. The leaflet's approximation of around 100 CXR equivalents did not resolve this ambiguity.

A floor effect also applied to the CXR fatal malignancy risk item. The local estimate was of the order of one in one million, below the lowest response option, so 1:100,000 was used as the nearest available answer. MR angiography and CT brain were included in the scoring sensitivity analyses described below. No corresponding item-omission analysis was included for the chest-radiograph risk item. No attainment threshold was applied, because the audit template specifies no pass mark [8]. The individual items, historical key, and descriptive performance by cycle are shown in Table 1.

Educational intervention

The intervention was a single three-page leaflet written by the author and dated November 9, 2025. It was developed after analysis of cycle 1 results and targeted the weakest baseline domains, principally CT dose magnitude and the fatal malignancy risk of CT abdomen and pelvis. It set out the IR(ME)R justification duty, approximate CXR-equivalent doses for common examinations, the linear no-threshold model, worked approximations of lifetime fatal malignancy risk, and the modification of risk by patient age and sex.

The leaflet used the historical general-population coefficient of 5.5% per sievert from ICRP Publication 103 as a fatal-cancer estimate [10]. Although this interpretation also appears in the Autorité de sûreté nucléaire's (ASN) 2024 annual report, ICRP defines the coefficient as detriment-adjusted cancer risk [10,12]. Recalculation using 5.1% per sievert left all historical keyed answers unchanged under the original linear nearest-denominator convention, including the lowest available risk option for chest radiography; consequently, participant scores and reported statistical results were unchanged. Beck's subsequent analysis distinguishes radiation detriment from fatal-cancer probability by incorporating fatal and weighted non-fatal cancer risks and relative life lost [13].

The leaflet included two figures created by the author from published dose and risk data, a national chart of radiation risk by patient age and sex reproduced from a published report, and a short bibliography. A version with the reproduced Health Protection Agency chart removed has been prepared for editorial review. The original leaflet has been retained as a record of the material distributed to participants. Its clinical content was not externally reviewed before distribution.

The leaflet was distributed on November 9, 2025, through the same channels as the assessment and as printed copies during weekly teaching. Ad hoc reminders were circulated through the foundation program messaging groups during the intervention and reassessment period, rather than on a fixed schedule; these prompted engagement with the leaflet and second assessment but contained no additional educational content. Recipient records were held by the administrator, but receipt, uptake, and engagement were not measured, so reach cannot be quantified.

There was no associated spoken teaching, lecture, presentation, or workshop. No mandatory completion requirement was present, and throughout the period of study no concurrent changes to local policy or imaging practice were made. No other relevant teaching activity was identified during the intervention period. No formal cost analysis was undertaken. The only resources used were the author's time to write the leaflet, the administrator's time to circulate it, and the trust's existing email, messaging, and printing facilities. The project received no funding and purchased no materials.

Data handling and statistical analysis

Paper responses were transcribed by the author and repeatedly self-verified, but were not independently double-entered; recorded grades were independently verified by the administrator. Submission timestamps were retained for electronic responses only and are excluded from any dataset prepared for sharing. Data were stored within the trust's Microsoft 365 (Redmond, WA: Microsoft Corp.) and the trust's email in accordance with local information governance policy. Sole live access was held by the author, with static anonymized copies provided after each cycle to the author's educational supervisor, a supervising consultant in emergency medicine who supervised the project from the outset. No patient information or clinical records were used at any stage.

Analyses were performed in Microsoft Excel, Microsoft 365 version 2607, build 20228.20190 (Redmond, WA: Microsoft Corp.). Student's t-test probabilities, critical values, and Welch-Satterthwaite degrees of freedom were calculated within the workbook. No sample size calculation was performed; the entire eligible cohort was invited in each cycle, and the achieved sample was determined by voluntary response. All tests were two-sided and interpreted against a significance threshold of 0.05. Scores were summarized using the mean

and sample standard deviation, and the median and interquartile range (IQR). These descriptive statistics were calculated using Microsoft Excel.

Responses were anonymous and unlinked, and the cycles were analyzed using independent-samples methods rather than paired methods. The primary comparison was a Welch unequal-variance t-test of participant percentage scores, reported as the cycle 2 minus cycle 1 difference in percentage points with a two-sided 95% confidence interval. The standardized difference was summarized using Hedges' *g*, with an approximate normal confidence interval calculated using the unbiased-form sampling-variance estimator with the approximate small-sample correction. The analysis plan was written after data collection had closed. It specified repeating the primary comparison with the MR angiography item omitted, the CT brain item omitted, and both omitted, with scores rescaled accordingly.

Robustness analyses comprised a Mann-Whitney U test with tie and continuity corrections; restriction to complete responses; ordinary least squares (OLS) models adjusting for foundation grade and for grade together with response mode; and the three scoring sensitivity analyses described above. Adjusted models are reported as exploratory, given the small sample, the unequal grade composition between cycles, and the single paper response in cycle 2. No multiplicity adjustment was applied because these analyses test the robustness of a single hypothesis rather than independent hypotheses.

Participant-level scoring, comparison of overall cycle scores, assessment by imaging examination, and comparison against the audit standard were planned prospectively. Analysis by foundation grade, the named inferential tests, the effect size estimator, regression models and the sensitivity analyses were all determined after data collection.

Governance, participation, and dissemination

This clinical audit and quality improvement project used an anonymous assessment completed voluntarily by NHS doctors in their professional capacity. It involved no patients, service users, patient records, identifiable participant information, biological material or additional clinical procedures. The project was conducted with consultant supervision from the outset and was subsequently registered with the East Cheshire NHS Trust Clinical Effectiveness Team (audit 3883).

Sections 4.2.6 and 4.2.8 of the UK Research Ethics Committee Policy Document state that research recruiting NHS staff as participants by virtue of their professional role, and research involving only anonymous information, do not require NHS Research Ethics Committee review; section 4.2.4 additionally places clinical audit outside the scope of that review [14]. The Health Research Authority/Medical Research Council decision tool was completed on the conservative basis that the project constituted research, and returned the same determination for sites in England. The Trust Clinical Effectiveness Team confirmed local governance approval for publication on August 17, 2026.

This article reports a further analysis of the fully anonymized audit and quality improvement dataset. No participants were re-contacted, and no additional data were collected. The accompanying email and assessment text explicitly described the purpose of data collection and stated that findings would be presented and disseminated as appropriate. Completing and submitting the anonymous assessment was treated as implied consent to collect, analyze, and publish aggregate, anonymized results. The electronic survey did not record identity; no response could be attributed to an individual, and the article contains no identifying information. Findings were disseminated through local educational and clinical-governance forums and were subsequently shared with participating foundation year 2 doctors.

Results

Response and data completeness

Cycle 1 yielded 18 (37.5%) responses from 48 planned eligible posts, and cycle 2 yielded 16 (33.3%) responses. Foundation year 1 (F1) doctors supplied 13 of 18 baseline responses but only five of 16 afterward, and paper responses fell from seven to one. All paper responses in both cycles were from F1 doctors. Table 2 gives the full composition and grade-specific response rates.

Measure	Cycle 1	Cycle 2
Planned eligible posts, n	48	48
Responses, n (%)	18 (37.5)	16 (33.3)
F1 respondents, n (% of 24 planned F1 posts)	13 (54.2)	5 (20.8)
F2 respondents, n (% of 24 planned F2 posts)	5 (20.8)	11 (45.8)
Electronic responses, n	11	15
Paper responses, n	7	1
Incomplete responses, n	1	1
Complete responses, n	17	15

TABLE 2: Response and sample composition by cycle.

Denominators are planned program posts, not verified occupied posts or teaching attendance.

F1: foundation year 1; F2: foundation year 2

All 34 responses were analyzed. Two were incomplete as follows: one cycle 1 respondent omitted seven of the eight dose items, and one cycle 2 respondent omitted the magnetic resonance (MR) angiography item. In the primary analysis, these omissions were scored as incorrect. Restricting to fully completed assessments leaves 17 responses in cycle 1 and 15 in cycle 2; the comparison repeated on those responses alone is reported below.

Overall score comparison

Mean assessment scores were 42.6% (SD: 16.6 percentage points) in cycle 1 and 80.2% (SD: 20.6 percentage points) in cycle 2. Median scores were 41.7% (Q1-Q3: 35.4%-50.0%) and 83.3% (Q1-Q3: 75.0%-91.7%), respectively. The mean difference (cycle 2 minus cycle 1) was +37.6 percentage points (95% CI: +24.4 to +50.9 percentage points; Welch $t=5.81$, $df=28.87$, $p<0.001$). Hedges' g was +1.97 (approximate 95% CI: +1.14 to +2.81). Table 3 presents the primary comparison, robustness, and sensitivity analyses.

Measure or analysis	Model/test	Cycle 1, n	Cycle 2, n	Total, n	Value	95% CI	Statistic	df	Two-sided p-Value
Cycle 1 mean score	Mean	18	N/A	18	42.6%	N/A	N/A	N/A	N/A
Cycle 1 standard deviation	SD	18	N/A	18	16.6 pp	N/A	N/A	N/A	N/A
Cycle 1 median score	Median	18	N/A	18	41.7%	N/A	N/A	N/A	N/A
Cycle 1 quartile interval	Q1-Q3	18	N/A	18	35.4%-50.0%	N/A	N/A	N/A	N/A
Cycle 1 interquartile range	Q3 minus Q1	18	N/A	18	14.6 pp	N/A	N/A	N/A	N/A
Cycle 2 mean score	Mean	N/A	16	16	80.2%	N/A	N/A	N/A	N/A
Cycle 2 standard deviation	SD	N/A	16	16	20.6 pp	N/A	N/A	N/A	N/A
Cycle 2 median score	Median	N/A	16	16	83.3%	N/A	N/A	N/A	N/A
Cycle 2 quartile interval	Q1-Q3	N/A	16	16	75.0%-91.7%	N/A	N/A	N/A	N/A
Cycle 2 interquartile range	Q3 minus Q1	N/A	16	16	16.7 pp	N/A	N/A	N/A	N/A
Primary Welch comparison	Welch t-test	18	16	34	+37.6 pp	+24.4 to +50.9 pp	t=5.81	28.87	2.7×10 ⁻⁶
Hedges' g	Hedges' g	18	16	34	+1.97	+1.14 to +2.81	N/A	N/A	N/A
Complete responses only	Welch t-test	17	15	32	+34.8 pp	+21.4 to +48.3 pp	t=5.35	24.63	1.6×10 ⁻⁵
Adjusted for grade	OLS	18	16	34	+34.9 pp	+20.6 to +49.2 pp	t=4.97	31	2.3×10 ⁻⁵
Adjusted for grade and response mode	OLS	18	16	34	+35.1 pp	+20.2 to +50.1 pp	t=4.81	30	4.0×10 ⁻⁵
MR angiography item omitted	Welch t-test	18	16	34	+39.8 pp	+27.0 to +52.6 pp	t=6.37	29.17	5.7×10 ⁻⁷
CT brain item omitted	Welch t-test	18	16	34	+37.3 pp	+23.6 to +51.0 pp	t=5.57	28.77	5.4×10 ⁻⁶
Both ambiguous items omitted	Welch t-test	18	16	34	+39.7 pp	+26.4 to +53.1 pp	t=6.08	28.80	1.3×10 ⁻⁶
Mann-Whitney U	Mann-Whitney U	18	16	34	N/A	N/A	U=29	N/A	7.1×10 ⁻⁵

TABLE 3: Primary comparison, robustness, and sensitivity analyses.

Descriptive statistics are reported separately for each cycle. The quartile interval gives the first to third quartiles (Q1-Q3); the interquartile range (IQR) is Q3 minus Q1. Quartiles use inclusive linear interpolation, equivalent to Excel QUARTILE.INC. Mean, median, and quartiles are percentage scores; SD and IQR widths are percentage points (pp). Mean differences are cycle 2 minus cycle 1 in pp. Positive (+) estimates and CI endpoints indicate higher cycle 2 scores; negative (-) values indicate lower cycle 2 scores. Hedges' g is a unitless standardized difference with an approximately normal 95% CI. The Mann-Whitney row reports a rank-based test and no mean-difference estimate. The primary comparison used an independent-samples Welch unequal-variance t-test with Welch-Satterthwaite degrees of freedom. Missing item responses were scored as incorrect. Adjusted OLS models are exploratory. No multiplicity adjustment was applied.

df: degrees of freedom; MR: magnetic resonance; N/A: not applicable; OLS: ordinary least squares

Six sensitivity and adjusted analyses yielded mean differences of +34.8 to +39.8 percentage points, with all lower 95% confidence limits above +20 percentage points; the Mann-Whitney comparison was concordant (Table 3). Restriction to complete responses gave a difference of +34.8 percentage points (95% CI: +21.4 to +48.3 percentage points). Adjustment for grade and response mode gave +35.1 percentage points (95% CI: +20.2 to +50.1 percentage points), while omission of both ambiguously keyed items gave +39.7 percentage points (95% CI: +26.4 to +53.1 percentage points). The rank-based comparison was concordant (Mann-

Whitney U=29; $p<0.001$). Figure 1 shows the distribution of participant scores.

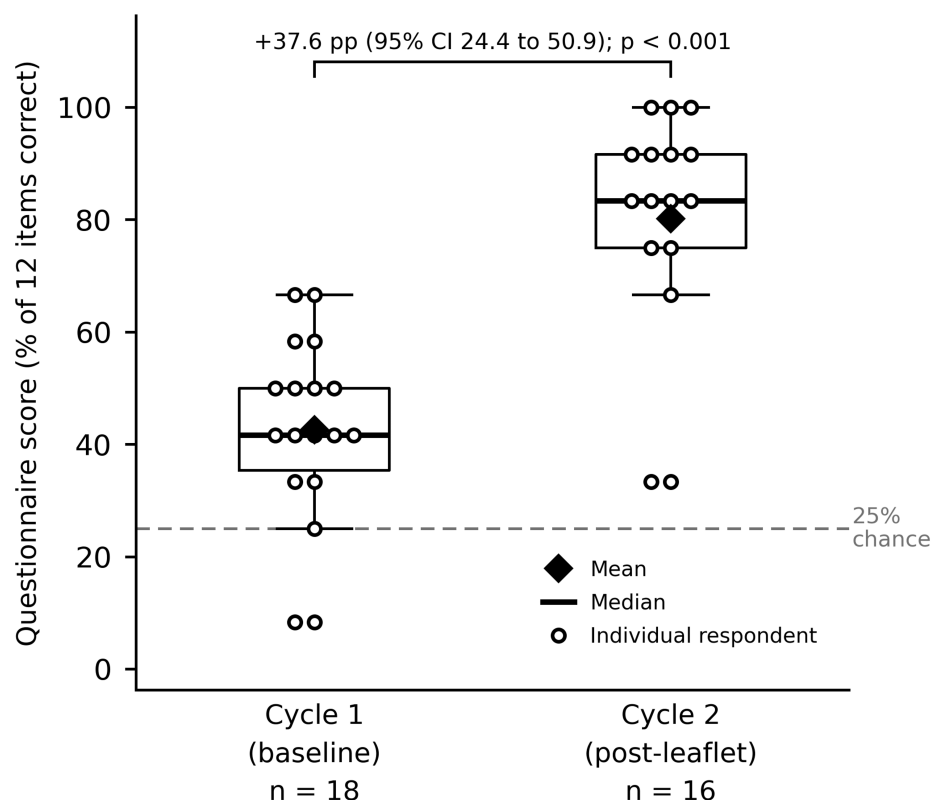


FIGURE 1: Distribution of participant questionnaire scores by cycle.

Participant-level percentage scores across the 12-item assessment, cycle 1 (baseline, $n=18$) and cycle 2 (following leaflet distribution, $n=16$). Each open circle is one respondent, horizontally offset where values coincide. Boxes span the interquartile range; the heavy horizontal line marks the median and the diamond the mean. Whiskers extend to the most extreme value within 1.5 times the interquartile range. The dashed line marks the 25% score expected from random selection among four options per item. Missing item responses were scored as incorrect. Cycles were anonymous and unlinked; the figure displays two cross-sectional samples and does not show individual change.

This image was created by the author of this study from the same participant-level data using Matplotlib version 3.10.8 (Matplotlib Development Team) for Python.

pp: percentage points

Item-level performance

Item-level performance is reported descriptively in Table 1 and Figure 2; no inferential testing was performed at item level. With four options per item, 25% of answers would be expected to be correct by chance. At baseline, performance was weakest on four CT items, each answered correctly by five of 18 respondents (27.8%), and strongest for the fatal malignancy risk of a chest radiograph (12 of 18, 66.7%). Grouped by imaging modality, using the classification applied in the original audit analysis, correct responses rose in all four groups (Table 1). CT items showed the greatest change and are among the highest-dose examinations assessed.

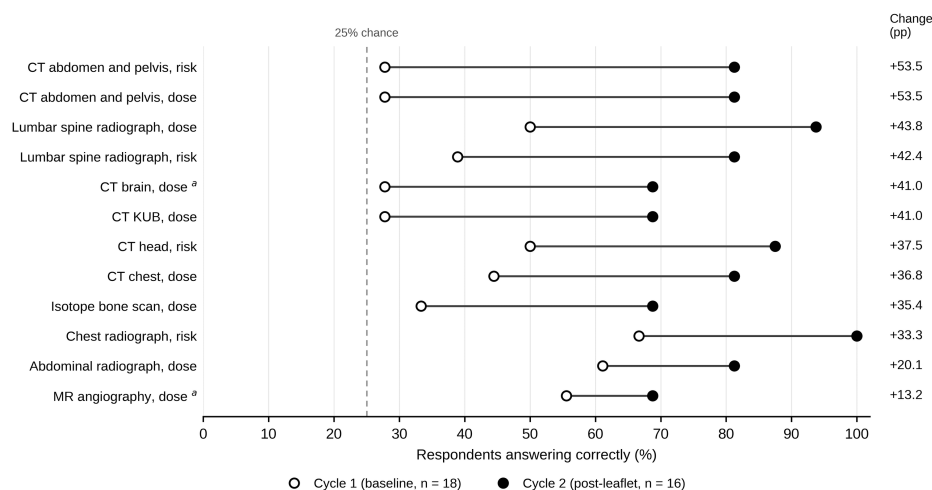


FIGURE 2: Item-level correct-response rates across cycles.

^aAmbiguously keyed items. Item-level data are descriptive and were not tested inferentially.

Percentage of respondents answering each of the 12 assessment items correctly at baseline (open circles, n=18) and following leaflet distribution (filled circles, n=16), ordered by the size of the change. The dashed line marks the 25% expected from random selection. Values at the right give the change in percentage points. The two items rising by 53.5 percentage points, both concerning computed tomography of the abdomen and pelvis, are the two the leaflet addressed most directly. The design cannot establish that the leaflet produced that pattern. Correct responses were defined by the historical scoring key; missing responses were counted as incorrect. Connecting lines join the two cycle-level percentages and do not represent individual change.

This image was created by the author of this study from the same participant-level data using Matplotlib version 3.10.8 (Matplotlib Development Team) for Python.

KUB: kidneys, ureters, and bladder; MR: magnetic resonance; pp: percentage points

Every item was answered correctly by a higher proportion of respondents in cycle 2 than at baseline. The largest changes were in CT abdomen and pelvis dose and in its fatal malignancy risk, both rising by 53.5 percentage points to 13 of 16 respondents (81.3%). All 16 cycle 2 respondents selected the historical keyed response for the chest radiograph risk item (1:100,000), the lowest risk offered by the assessment. Deficits persisted: only 11 of 16 respondents answered four items correctly (68.8%). MR angiography dose showed the smallest change, rising by 13.2 percentage points and remaining jointly lowest.

Other outcomes

Because the audit template specifies no pass mark, no formal judgment of attainment against the standard was made. No unintended consequences, complaints, or adverse effects were reported by participants or identified during either cycle.

Discussion

Principal findings

Radiation-risk assessment scores were substantially higher in the cycle following leaflet distribution, with a mean score difference of +37.6 percentage points (95% CI: +24.4 to +50.9 percentage points). The finding was stable across all seven robustness analyses performed (Table 3). The two items most directly addressed by the leaflet, CT abdomen and pelvis dose and its associated fatal malignancy risk, showed the largest changes, each rising by 53.5 percentage points. By contrast, MR angiography dose, addressed only in passing, showed the smallest increase, at 13.2 percentage points, and remained among the weakest items afterward. This content-response gradient is hypothesis-generating; it is consistent with, but does not establish, a content-specific leaflet contribution because item-level comparisons were descriptive and cycles were unlinked cross-sectional samples. Items less directly addressed also rose substantially.

Baseline performance was poor in absolute terms, with a mean of 42.6% against the 25% expected to be correct by chance. Fewer than a third of respondents correctly identified the dose or fatal malignancy risk for four computed tomography items, all of which were among the highest-dose examinations assessed. Deficits persisted after the intervention, with four items still answered correctly by only 68.8% of respondents.

Comparison with existing evidence

The baseline mean score of 42.6% is consistent with the knowledge gaps reported by Shiralkar et al. and Mellis et al. [4,5]. A relevant international comparison is Keijzers and Britton's study, in which 96 emergency doctors achieved a mean knowledge score of 40% (95% CI: 38%-43%); 76% reported no formal training in radiation risk. Their assessment also included chest radiograph equivalents and knowledge of cancer risk. However, differences in assessment content, scoring, and clinical population preclude treating the two percentage scores as equivalent measures [15].

The present findings also sit alongside studies of brief educational interventions. Young et al. reported improved awareness of CT-associated cancer risk after including an educational message in CT reports for one year [16]. This provides a relevant comparison for education delivered through routine clinical communication. However, repeated exposure through radiology reports over a year differs substantially from leaflet distribution followed by reassessment two to five days later [16].

Yamauchi et al. evaluated a 20-min radiation-safety lecture among 95 senior medical students and reported improvements in self-assessed knowledge and radiation-exposure management immediately afterward [17]. Their outcomes reflected participants' perceptions rather than objectively tested knowledge or observed clinical skills. Together, these studies illustrate the range of outcomes used to evaluate radiation education and the importance of distinguishing self-assessment, assessment performance, and clinical practice [17].

Merchant et al.'s foundation-doctor quality improvement project provides a closer population comparison [18]. After a 1-h lecture, radiation-dose knowledge increased from 38.7% to 61.6%. At six months, the score was 46.6% and did not differ significantly from baseline ($p=0.15$). These percentages describe the dose-knowledge outcome, whereas the present overall score combines dose and fatal malignancy-risk items. The magnitudes of change are therefore not directly comparable, but the delayed findings reinforce the need to assess retention beyond the immediate intervention period [18].

Strengths and limitations

The study used a standardized RCR AuditLive instrument rather than a locally devised assessment, allowing comparison with other users of the template. All 34 responses were included without exclusions. Paper-response grade was independently verified, and the intervention is fully specified and reproducible without a dedicated budget or additional staffing.

The design was not randomized and included no control group, so the observed difference cannot be attributed to the leaflet. Responses could not be linked, leaving respondent overlap unknown; the cycles are therefore neither demonstrably paired nor composed of different individuals. Independent-samples methods were used. Unrecorded respondent overlap could induce dependence between cycles, which the reported standard errors and confidence intervals do not account for.

Response rates were low at 37.5% and 33.3% of planned posts, with self-selection present in both cycles. Grade composition differed substantially between cycles, and paper responses fell from seven to one (Table 2). Adjustment for grade and response mode only slightly attenuated the estimate, but these models are fragile and exploratory given the small sample, grade imbalance, and single paper response in cycle 2.

Nothing is known about the roughly two-thirds of the eligible cohort who did not respond. Cycle 2 measured prompted, open-book performance rather than unaided recall. No marking scheme, individual result, or aggregate feedback was released before cycle 2 closed. However, answer reconstruction from the leaflet or other sources, discussion between respondents, and any contribution from prior testing could not be assessed. Consultation of the leaflet during completion cannot be distinguished from recall of it.

Leaflet receipt, uptake, and engagement were unmeasured, so exposure is unknown. Printed copies were distributed during weekly teaching and were therefore not wholly independent of existing teaching time; paper assessments in both cycles were completed immediately after scheduled teaching. Instrument validity and internal consistency were not assessed. Two of the three keying issues were tested in sensitivity analyses, with omission analyses indicating that the conclusion depends on neither. The chest-radiograph risk item retained the lowest available risk option and was not included in the reported item-omission analyses. Its constrained response options limit interpretation of performance in both cycles. Reassessment followed the leaflet by two to five days, precluding inference about retention. Named inferential tests, effect size estimators, regression models, and sensitivity analyses were selected after data collection, although participant-level scoring and comparison of overall cycle scores were planned prospectively. Multiple secondary analyses are reported without multiplicity adjustment; they examine the robustness of a single hypothesis rather than independent hypotheses and should not be read as independent confirmations. Finally, the study was conducted in a single foundation program at one trust over one academic year, limiting generalizability beyond that setting.

Implications

This study provides an implementation account rather than an efficacy estimate as follows: a low-resource leaflet distributed through routine electronic and print channels without a scheduled lecture; participant-

level analysis appropriate to anonymous, unlinked cycles; sensitivity analyses showing that the overall result depends on neither ambiguously keyed AuditLive dose item; and descriptive alignment between leaflet emphasis and item-level change that is hypothesis-generating rather than confirmatory. Within these constraints, the intervention required no dedicated teaching session, additional staffing, or funding, which may be useful to programs facing similar gaps without available curricular time.

The observed difference in assessment performance does not establish improved imaging-requesting practice. In a survey of 213 clinicians, Borgen et al. found that greater emphasis on radiation dose when referring was associated with fewer self-reported referrals considered unlikely to affect treatment, whereas detailed radiation knowledge was not associated with the reported frequency of such referrals. Although those behavioral measures were self-reported, the findings support assessing knowledge and referral practice as distinct outcomes [19]. The present study measured neither requesting behavior nor the quality of justification and cannot establish regulatory compliance or patient benefit. Further evaluation should include delayed, unaided reassessment at three to six months, measurement of leaflet receipt and engagement, and participant linkage using confidential study identifiers. Assessment of requesting practice would require additional data, such as documented clinical indications and adherence to relevant imaging pathways; changes in request volume alone would not establish improved appropriateness. Future assessments should also offer a zero- or no-ionizing-radiation option, use clearly specified contemporary dose sources, and prespecify scoring rules. These changes would address the principal uncertainties concerning exposure to the intervention, retention, clinical relevance, and measurement.

Conclusions

Radiation-dose and malignancy-risk knowledge among foundation doctors at this trust was poor at baseline and weakest for CT examinations, which are among the highest-dose investigations assessed. Assessment performance was substantially higher in the cycle following distribution of a low-cost educational leaflet, and the difference was stable across all robustness analyses. Deficits persisted, with four items still answered correctly by only 68.8% of respondents.

The observed score difference should be interpreted as an immediate association rather than a causal effect. Reassessment was announced, conducted open-book, and completed two to five days after leaflet distribution; response rates were low, and respondent overlap was unknown. Retention, imaging-requesting behavior, regulatory compliance, and patient outcomes were not assessed. The study nevertheless shows that a short, locally written leaflet can be distributed through existing channels without a dedicated budget, additional staffing, or a scheduled teaching session. Longer-term evaluation across a broader group of staff performing delegated practitioner functions is warranted.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Daniel J. Myers

Acquisition, analysis, or interpretation of data: Daniel J. Myers

Drafting of the manuscript: Daniel J. Myers

Critical review of the manuscript for important intellectual content: Daniel J. Myers

Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. East Cheshire NHS Trust Clinical Effectiveness Team issued approval Exempt. The project was registered with East Cheshire NHS Trust under Audit ID 3883 following clinical governance review. The study was deemed exempt from IRB review. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Acknowledgements

The author thanks Catherine Rimmer, Foundation and Specialist/Associate Specialist Doctors Administrator

at East Cheshire NHS Trust, for circulating the assessment and educational leaflet, facilitating and recording paper-based responses, and independently verifying respondents' grades. The author also thanks Jack Perrin, BSc (Hons) in Mathematics, for independently rechecking the analysis workbook. The author acknowledges the Royal College of Radiologists for providing the AuditLive template and accompanying assessment used in this project. The Royal College of Radiologists had no role in the conduct, analysis, or reporting of the project. Anonymized respondent-level data will be made available by the corresponding author upon reasonable request, subject to approval under East Cheshire NHS Trust's information governance procedures. OpenAI GPT-6 Astra (San Francisco, CA: OpenAI) was used to assist with manuscript drafting and formatting by adhering to the journal's guidelines. The author reviewed all AI-generated output, verified the reported data against the source records, and accepts full responsibility for the final manuscript.

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