Pulmonary nodules and CT screening: the past, present and future

M Ruparel, S L Quaife, N Navani, J Wardle, S M Janes, D R Baldwin

ABSTRACT
Lung cancer screening has come a long way since the early studies with chest X-ray. Advancing technology and progress in the processing of images have enabled low-dose CT to be tried and tested, and evidence suggests its use can result in a significant mortality benefit. There are several issues that need refining in order to successfully implement screening in the UK and elsewhere. Some countries have started patchy implementation of screening and there is increased recognition that the appropriate management of pulmonary nodules is crucial to optimise benefits of early detection, while reducing harm caused by inappropriate medical intervention. This review summarises and differentiates the many recent guidelines on pulmonary nodule management, discusses screening activity in other countries and exposes the present barriers to implementation in the UK.

INTRODUCTION
Individuals diagnosed with lung cancer generally have a poor prognosis, largely attributable to delayed diagnosis due to the absence of discriminating symptoms at the early stages of the disease. In the UK, it was recently estimated for the period 2010–2012 that the net 5-year survival rate of lung cancer patients was 12.7%—a reflection on the 67.6% of lung cancers that are diagnosed at stage III or IV. One-year survival ranges from 14% for patients who present with stage IV disease to 71% for patients with stage I disease. Early detection has the potential to transform lung cancer outcomes and the case for screening with low-dose CT (LDCT) has recently gained significant momentum. However, there is a need to ensure cost-effectiveness and minimisation of harms are considered in the face of a considerable healthcare burden that has arisen from these LDCT studies; namely the management of the pulmonary nodule. In this review, we briefly discuss the pedestrian history of lung cancer screening through to the rapid evolution of the present, and highlight potential important differences in the management of the pulmonary nodule between recent guidelines.

THE HISTORY OF LUNG CANCER SCREENING
Studies in screening for asymptomatic lung cancer began in the 1950s using photofluorographs. As early as 1959, it was clear that the lung cancer detection rate varied depending on whether medical risk was used to select the population to be screened.

Early studies using chest X-ray
Unfortunately, the trials for chest X-ray (CXR) screening for lung cancer failed spectacularly. Four large randomised controlled trials in the 1970s–1980s failed to detect a significant mortality benefit from CXR screening. Sadly, none of these studies used a true, null screening control group and rather compared screening with different modalities or at different frequencies. The Mayo clinic and Czechoslovakian studies compared CXR and sputum cytology at lower and higher frequencies. Both the John Hopkins and Memorial Sloan Kettering projects compared CXR with or without sputum cytology. Likely due to the trial designs and the short period of follow-up, no statistically significant differences in lung cancer-specific mortality were detected. However, an increase in early detection and a threefold increase in long-term survival were reported in both arms of the Memorial and Hopkins studies, when compared with the National Cancer Institutes’ Surveillance, Epidemiology and End Results for unscreened cancers data. At the time, this was attributed to lead time bias (ie, the apparent increase in survival observed due to ‘preponing’ the diagnosis rather than the prolonging of life). Of particular note however, was an unequivocal difference in 5-year survival of early-stage detected cancers between those who had surgical resection (70%) and those who did not (10%) due to either refusal or medical contraindication, suggesting a successful early diagnosis strategy should save lives.

Despite the overall negativity following these early trials, more robust studies were carried out including the Prostate, Lung, Colorectal and Ovarian (PLCO) study which started in 1993. 155 000 smokers and non-smokers aged 55–74 were randomised to have either annual CXR for 4 years or no screening. Disappointingly, the authors reported no effect on lung cancer diagnosis, stage, histology or mortality after 13 years of follow-up. A subanalysis of the efficacy of yearly CXR screening in those at high risk also demonstrated no effect on lung cancer incidence or mortality.

Computed tomography
The Mayo Lung Project, a North American single-arm, LDCT screening pilot carried out in 1999, detected pulmonary nodules in 74% and lung cancer in 4% of those screened. The authors concluded that LDCT could detect early-stage lung cancers but had no significant effect on mortality when compared with subjects screened by CXR in the earlier Mayo Clinic Study. They suggested that LDCT screening had led to overdiagnosis of...
indolent early-stage cancers and that due to the high false positive rate, the risk of complications and expense incurred in the work-up of false positive lesions, the evidence to support LDCT screening was inconclusive.\textsuperscript{11, 12}

Therefore, the concept of LDCT screening for lung cancer was largely rejected until the Early Lung Cancer Action Project.\textsuperscript{13-14} This study increased the threshold for nodule positivity to a diameter of 5mm and consequently only 13% of participants had baseline scans positive for pulmonary nodules. The prevalence lung cancer detection rate was 1.2% of all those screened and 9.7% of positive baseline scans. The majority (85%) of detected lung cancers were stage I, and these patients had an estimated 10-year survival rate of 88%. Only 8% of biopsies revealed benign lesions. These findings dramatically transformed prospects for lung cancer screening and it became apparent that deriving benefit may be possible, but further evidence from well-powered randomised studies was required. Furthermore, this study emphasised the importance of optimising protocols to manage positive screens.

This leads us to the pivotal North American, National Lung Screening Trial (NLST). This was the first well-powered randomised study that compared LDCT screening with CXR in smokers and former smokers aged 55–74. A 20% and 6.7% relative reduction in lung cancer-specific and all-cause mortality, respectively, was observed across the two groups; with a number needed to screen of 320 to save one life from lung cancer after three annual screens and seven years of follow-up.\textsuperscript{15} The use of CXR as a control has provoked controversy, as some argue the lack of mortality benefit observed by screening smokers and former smokers in the PLCO trial justifies CXR as equivalent to null screening, while others have argued otherwise.\textsuperscript{16} Another limitation of this study is that the majority of NLST participants were younger, white, well-educated and affluent, while higher risk individuals were under-represented. This brings us to two important observations. First, the failure to engage those most at risk of lung cancer in screening in the NLST study may have led to an underestimation of the potential benefit of screening. But second, this study importantly highlights the difficulties faced in undertaking a cost-effective screening approach across society.

NLST radically changed prospects for LDCT screening, but can these data be extrapolated to the UK and Europe? One of the aims of the UK Lung Cancer Screening Trial (UKLS) was to address this and to evaluate costs within the UK National Health Service (NHS).\textsuperscript{17} Several other trials in Europe have also recruited, but those that reported on mortality were substantially underpowered and failed to detect a benefit.\textsuperscript{18–23} Combining the populations within these studies together with the Dutch-Belgian lung cancer screening trial (NELSON), the Danish Lung Cancer Screening Trial and UKLS will amount to a total of approximately 36,000 participants; although, with varying nodule management algorithms and criteria for eligibility. The pooled results are eagerly awaited by physicians and health providers alike, and should mature in 2016.\textsuperscript{24}

LDCT: MANAGEMENT OF PULMONARY NODULES

The studies discussed have clarified the CT features of nodules and growth rates that support benign or malignant diagnoses.\textsuperscript{25–30} Several predictive models taking into account clinical and demographic factors, as well as CT and positron emission tomography (PET) features of nodules have been proposed and validated, enabling quantification of risk of malignancy for a given nodule.\textsuperscript{31–33} As a result, we can adopt a more conservative approach to certain nodules by employing CT surveillance, reserving the more invasive procedures for higher risk nodules.

In 2005, in response to the growing problem of small CT-detected nodules, the Fleischner Society published a management algorithm.\textsuperscript{34} The strategy adopted was a conservative one that mandated that all small nodules should be followed-up in high-risk people (essentially smokers or former smokers). More recent guidelines, published by the American College of Chest Physicians (ACCP),\textsuperscript{35} generally mirror the Fleischner guidelines with little change to follow-up recommendations (Table 1). The Fleischner Society have recently responded to the problem of the subsolid nodule by publishing a further statement on their management.\textsuperscript{36} For those who are at high risk as per the US Preventative Services Task Force (USPSTF) criteria, the Lung CT Screening Reporting and Data System (Lung-RADS) has been specifically created.\textsuperscript{37} However, there is emerging evidence that implementation of the ACCP guidelines in the US has been suboptimal and that performance of Lung-RADS may not be as accurate as an approach using the Brock University nodule risk prediction model.\textsuperscript{38} Tables 1–3 show the comparison between these various nodule management strategies, which vary considerably.

The British Thoracic Society (BTS) published new guidelines on the investigation and management of pulmonary nodules in July 2015 following a comprehensive review of the evidence, with a third of the references cited from 2012 or later.\textsuperscript{39} Importantly, recommendations differ substantially from the earlier guidelines, especially for very small nodules, and recommend higher nodule follow-up thresholds, the use of risk prediction calculators and automated volumetric assessment to clarify follow-up requirements and growth rates (Table 4). The inclusion of volumetric measurement will be challenging to implement across the UK but this will be offset by a substantial reduction in follow-up scans compared with previous guidelines. The Brock University risk prediction tool, which was developed from the Pan-Canadian screening cohort\textsuperscript{32} and the Herder model, where PET-CT results are available, are recommended to more accurately define risk of malignancy. The role of further imaging, minimally invasive investigations and therapy is reviewed and recommendations made. This guideline also includes a service delivery model.

CURRENT CT SCREENING ACTIVITY INSIDE AND OUTSIDE THE UK

Lung cancer screening by CXR was advocated by the American Cancer Society in the 1970s, however this recommendation was withdrawn following evidence from the trials in the 1980s. Following the publication of the NLST results, the USPSTF recommended screening with LDCT of individuals aged 55–80 who have accrued at least a 30 pack-year smoking history and are current or former smokers who have given up for 15 years. The ACCP/American Thoracic Society, American College of Radiology (ACR) and National Comprehensive Cancer Network have all also released statements or guidelines for screening.\textsuperscript{40–42}

In February 2015, the US insurers, the Center for Medicare and Medicaid Services agreed to fund screening of asymptomatic insured individuals aged 55–77 who meet the USPSTF smoking criteria.\textsuperscript{43} The newly instated ‘Obamacare’ enables some 30% of the uninsured population to access LDCT screening; however, once a nodule is detected it is classified as surveillance rather than screening, and perversely funds are insufficient to cover this crucial aspect of the screening process. Furthermore, a significant proportion of the US population do not qualify for screening at all through lack of insurance coverage. What is really required, therefore, is a national screening programme that is accessible to individuals from all communities such as the US National Breast...
and Cervical Cancer Early Detection Program. Nonetheless, LDCT screening for insured individuals is now underway in the US. The ACR runs an accreditation programme outlining basic standards for performing and evaluating screening scans using the above-mentioned Lung-RADS. At the time of writing, there were 1220 accredited centres for LDCT screening in the US, 43 of which had been awarded accredited status by the ACR.42

In the meantime, several centres around the UK have initiated early diagnosis campaigns or pilot screening projects and these will contribute to record outcomes from screening and the first feedback was expected in autumn 2015.45

In China, several lung cancer screening programmes have been initiated, particularly in areas with high lung cancer incidence, funded by central or local government.47

The UK National Screening Committee (NSC) is due to make a decision on lung cancer LDCT screening in the UK pending the results of the pooled European data.48 In the meantime, a number of optimising benefits and harms.49 In order to aid the appropriate selection of conditions for which the benefits of screening outweighed the harms, they outlined 10 screening principles for appraising the viability, effectiveness and appropriateness of a screening programme,46 which form the basis for the criteria outlined by the UK NSC. Table 5 lists these 10 principles, and

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**Table 1** Comparison of Fleischner, Lung-RADS and ACCP guideline management of SN detected within or outside of screening

<table>
<thead>
<tr>
<th>Feature</th>
<th>Fleischner</th>
<th>ACCP</th>
<th>Lung-RADS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline scan</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No nodules or nodules with benign features</td>
<td>No follow-up</td>
<td>Optional follow-up</td>
<td>Category 1 (negative): return to annual screening at 12 months</td>
</tr>
<tr>
<td>&lt;4 mm</td>
<td>Interval CT at 12 months</td>
<td>Optional follow-up</td>
<td>Category 2 (benign): return to annual screening at 12 months</td>
</tr>
<tr>
<td>4–6 mm</td>
<td>Interval CT at 6–12 months and 18–24 months</td>
<td>Interval CT at 12 months then discharge if stable</td>
<td>Category 3 (probably benign): interval CT at 6 months</td>
</tr>
<tr>
<td>6–8 mm</td>
<td>Interval CT at 6–12 and 18–24 months</td>
<td>Interval CT at 6–12 and 18–24 months and discharge at 24 months if stable</td>
<td>Category 4A (suspicious): PET-CT: interval CT at 3 months</td>
</tr>
<tr>
<td>8–15 mm</td>
<td>Interval CT at 3, 9, 24 months, dynamic CT chest, PET-CT±histology</td>
<td>Risk&lt;5%: perform CT surveillance at 3–6, 9–12 and 18–24 months</td>
<td>Category 4B (suspicous): perform standard CT with or without contrast; PET-CT; histology</td>
</tr>
<tr>
<td>&gt;15 mm</td>
<td>Interval CT at 18 months</td>
<td>Risk &gt;65%: perform PET and consider biopsy/resection</td>
<td>Category 5 (likely malignant): PET-CT: interval CT at 3 months</td>
</tr>
<tr>
<td><strong>Interval scan</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;4 mm (new)</td>
<td>Discharge if resolved or at 12 months if no growth</td>
<td>If there is clear evidence of growth (VDT&lt;600 days is suggestive of malignancy), favour surgical resection</td>
<td>Category 2 (benign): return to annual screening at 12 months</td>
</tr>
<tr>
<td>4–6 mm (new)</td>
<td>Discharge if resolved or at 18–24 months if no growth</td>
<td>If no growth or decrease in size, follow-up for 2 years or until nodule disappears</td>
<td>Category 3 (probably benign): interval CT at 6 months</td>
</tr>
<tr>
<td>&lt;8 mm (new/growing)</td>
<td>Discharge if resolved or at 24 months if no growth</td>
<td>Discharge if resolved or at 24 months if no growth</td>
<td>Category 4A (suspicious): interval CT at 3 months</td>
</tr>
<tr>
<td>&gt;8 mm (new/growing)</td>
<td>Perform PET-CT±histology</td>
<td>Discharge if resolved or at 24 months if no growth</td>
<td>Category 4B (suspicous): perform standard CT with or without contrast; PET-CT; histology</td>
</tr>
</tbody>
</table>

N.B. Lung-RADS is for CT screening scans only.
ACCP, American College of Chest Physicians; PET, positron emission tomography; RADS, Reporting and Data System; SN, solid nodules.
### Table 2  Comparison of Fleischner, Lung-RADS and ACCP guideline management of PSN detected at baseline screening or incidental scans

<table>
<thead>
<tr>
<th>Baseline scan</th>
<th>Fleischner</th>
<th>ACCP</th>
<th>Lung-RADS</th>
</tr>
</thead>
<tbody>
<tr>
<td>No nodules or nodules with benign features</td>
<td>If &lt;8 mm: interval CT at 3 and 12 months and then annually for 3–5 years if multiple, consider each nodule separately</td>
<td>Category 1 (negative): interval CT at 12 months</td>
<td>Category 2 (benign): interval CT at 12 months</td>
</tr>
<tr>
<td>&lt;6 mm</td>
<td>Interval CT at 3 months + PET if solid component &gt;8 mm</td>
<td>Category 3 (probably benign): interval CT at 3 months; PET-CT if solid component &gt;8 mm</td>
<td></td>
</tr>
<tr>
<td>≥6 mm with solid component &lt;6 mm</td>
<td>Interval CT at 3 months+PET if solid component &gt;8 mm</td>
<td>Category 4A (suspicious): interval CT at 3 months; PET-CT if solid component &gt;8 mm</td>
<td></td>
</tr>
<tr>
<td>≥6 mm with solid component 6–8 mm</td>
<td>N.B. If &gt;15 mm, consider PET+biopsy/resection at baseline</td>
<td>Category 4B (suspicious): standard CT with or without contrast; PET-CT if solid component &gt;8 mm; histology</td>
<td></td>
</tr>
<tr>
<td>≥6 mm with solid component ≥8 mm</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

### Table 3  Comparison of Fleischner, Lung-RADS and ACCP guideline management of pGGN detected at baseline screening or incidental scans

<table>
<thead>
<tr>
<th>Baseline scan</th>
<th>Fleischner</th>
<th>ACCP</th>
<th>Lung-RADS</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5 mm</td>
<td>No follow-up if solitary, but if multiple, perform interval CT at 2 and 4 years</td>
<td>No follow-up</td>
<td>See below</td>
</tr>
<tr>
<td>&gt;5 mm</td>
<td>Interval CT at 3 months, then annual for minimum 3 years (for solitary and multiple nodules)</td>
<td>Annual CT surveillance for minimum 3 years (follow-up at 3 months if &gt;10 mm)</td>
<td>Category 2 (benign): interval CT at 12 months</td>
</tr>
<tr>
<td>&lt;20 mm</td>
<td>As above</td>
<td></td>
<td>Category 3 (probably benign): interval CT at 6 months</td>
</tr>
<tr>
<td>≥20 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Interval scan

<table>
<thead>
<tr>
<th>New nodule</th>
<th>Fleischner</th>
<th>ACCP</th>
<th>Lung-RADS</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20 mm</td>
<td>As for baseline scan</td>
<td>If &gt;10 mm and persistent or growing favour resection</td>
<td>Category 2 (benign): interval CT at 12 months</td>
</tr>
<tr>
<td>≥20 mm and stable or slow growth</td>
<td></td>
<td></td>
<td>Category 3 (probably benign): interval CT at 6 months</td>
</tr>
<tr>
<td>Persistent nodule</td>
<td>Annual CT surveillance for a minimum of 3 years Favour excision if nodule &gt;10 mm or multiple pGGN with a persistent dominant nodule Biopsy noted to have low yield</td>
<td></td>
<td>Category 2 (benign): interval CT at 12 months</td>
</tr>
</tbody>
</table>

N.B. Lung-RADS is for CT screening scans only.

ACCP, American College of Chest Physicians; PET, positron emission tomography; PSN, part-solid nodules; RADS, Reporting and Data System.

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N.B. Lung-RADS is for CT screening scans only.

ACCP, American College of Chest Physicians; pGGN, pure ground glass nodules; RADS, Reporting and Data System.

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proposes key factors that need to be addressed for successful implementation of a lung cancer screening programme. These factors are discussed below.

**Radiation risk**
Advances in CT scanning technology have improved nodule detection and characterisation while reducing radiation dose. Techniques such as iterative reconstruction (which reduces the extent of noise and artefact associated with images at lower radiation doses), altering tube voltage, current and gantry rotation speed are valuable in reducing effective radiation doses. Further reduction to overall radiation exposure over time will follow implementation of the more conservative approaches to managing positive findings, suggested in the more recent guidelines.\(^5\) Nevertheless, radiation risk will remain a problem and always needs to be considered when balancing risks and benefits.

**Overdiagnosis and false positives**
Overdiagnosis is the detection and characterisation of disease that would not otherwise cause harm. It may be minimised in LDCT screening by taking into account morphological features that denote more indolent cancers that may be managed with a more conservative approach less likely to cause harm. False positives are benign lesions that undergo investigation and may therefore result in harm, both physical and psychological. Pure ground glass nodules\(^8\) and solid and subsolid nodules with longer volume doubling times are more likely to be indolent or benign. The recent BTS guidelines support a more conservative management of volumetrically assessed, potentially indolent or benign lesions, thus reducing the rate of overdiagnosis and benign histological diagnoses.

**Optimal eligibility criteria for screening**
It is clear that overdiagnosis rates, false positive rates, the number needed to be screened to save one life from lung cancer and cost of screening can all be reduced by selecting the higher risk population.\(^5\) However, what the appropriate threshold for risk is, and how this interacts with entry and exit age, competing mortality and fitness are complex. Randomised trials of LDCT screening have adopted a number of different approaches in determining who to invite to screening. The UKLS sent out questionnaires which enabled determination of the Liverpool Lung Project lung cancer risk prediction algorithm and had a relatively high lung cancer detection rate (2.1%),\(^5\) while the NLST used just age and smoking status. Which risk assessment tool most appropriately balances simplicity and predictive accuracy still needs to be determined. Furthermore, based on the results from the NELSON study, screening interval may also need to be varied by risk. They showed that interval cancers occur at a low rate (1%) and this occurrence was associated with age but not smoking status.\(^5\) Further research into other factors predictive of interval cancers is needed. With ongoing research into potential biomarkers, LDCT screening may one day be offered to a wider demographic and include non-smokers with a positive biomarker test.

**Balance of psychological impact**
The psychological burden of screening remains to be determined, and for the individual, may in large part depend on the severity

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**Table 4** Summary of BTS guidelines for management of pulmonary nodules detected at baseline screening or incidental scans

<table>
<thead>
<tr>
<th>Baseline scan</th>
<th>Solid nodules</th>
<th>Part solid nodules</th>
<th>Pure ground glass nodules</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5 mm or &lt;80 mm(^3)</td>
<td>Discharge</td>
<td>Discharge</td>
<td></td>
</tr>
<tr>
<td>5–6 mm</td>
<td>CT at 12 months</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥6 to &lt;8 mm or 80 to &lt;300 mm(^3)</td>
<td>Interval CT at 3 and 12 months</td>
<td></td>
<td>Interval CT at 3 months</td>
</tr>
<tr>
<td>&gt;8 mm or &gt;300 mm(^3)</td>
<td>1. PET-CT 2. Assess Herder risk 3. If &lt;10%: do CT at 3 and 12 months 4. If &gt;10%: consider biopsy or resection or CT surveillance on individual basis 5. If &gt;70% favour resection</td>
<td></td>
<td></td>
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BTS, British Thoracic Society; PET, positron emission tomography; 2D, two-dimensional; 3D, three-dimensional.

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**Review**
of the screening result and psychosocial characteristics. To date, most studies of trial participants undergoing lung screening have shown that the anxiety and distress associated with false positive screens are minimal and short-lived. Clinically, meaningful changes in health-related quality of life were observed one month after the detection of an indeterminate pulmonary nodule, but returned to prescreening levels after two years, suggesting no long-lasting effects. However, this is yet to be studied in the community context and there is evidence from other screening programmes for long-term psychological distress. Furthermore, given a significant proportion of screening participants will at one time receive a false positive or indeterminate result, further research is needed to monitor the psychological impact of the surveillance process, examine individual differences in response and develop strategies which minimise harm. Qualitative evidence suggests effective communication about indeterminate nodules by health professionals could be one such strategy, and evidence suggests effective communication about indeterminate nodules by health professionals could be one such strategy, and evidence suggests effective communication about indeterminate nodules by health professionals could be one such strategy, and evidence suggests effective communication about indeterminate nodules by health professionals could be one such strategy, and evidence suggests effective communication about indeterminate nodules by health professionals could be one such strategy, and evidence suggests effective communication about indeterminate nodules by health professionals could be one such strategy, and evidence suggests effective communication about indeterminate nodules by health professionals could be one such strategy, and evidence suggests effective communication about indeterminate nodules by health professionals could be one 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adjusted life year (QALY) gained, ranging from US$28 000 to over US$100 000.79–81 The cost of lung cancer screening in the UK is not known, but has been estimated to be around £9000 per QALY gained;85 well below the threshold of £30 000 deemed acceptable by the National Institute for Health and Care Excellence. If NLST eligibility criteria were to be implemented, an estimated 8.7 million people in the US may be eligible for screening.86 The size of the UK lung cancer screening eligible population is unclear, however, even assuming uptake levels may be low (in the region of 50%), numbers are likely to be significant. This has considerable resource implications in terms of carrying out the baseline and interval CT scans required for nodule follow-up.

Most hospitals now have the technology to perform LDCT scans and take advantage of many of the other CT advances such as Maximum Intensity Projections (which allow enhanced visualisation of high attenuating structures such as nodules) and Multi-Planar Reconstruction (where images are reconstructed in customised planes). Automated estimation of the volume of nodules, calculated by mapping the CT attenuation values, is also possible with modern volumetric nodule assessment packages. These packages also autocalculate volume doubling times, which can more accurately quantify growth of a nodule than conventional two-dimensional measurements.83 However, exactly what proportion of UK hospitals currently has access to the technical, radiological and clinical know-how to implement volumetric assessment needs to be determined.

Various strategies as outlined above including appropriate selection criteria for screening and improved management of pulmonary nodules will help reduce the cost of screening. The cost of various methodologies that can be used in the screening process, such as the use of mobile CT scanners versus dedicated screening centres, also needs to be evaluated. Scan reading time is also a factor, and research is needed to explore whether there are feasible options that will relieve some of the work from radiologists.

**Equitable access, uptake and adherence to screening across the population**

Participation in national screening programmes for breast and colorectal cancer is around 70% and 60%, respectively,84–87 but there is evidence to suggest this will be lower in future lung cancer screening programmes. In the NELSON trial, 32% of the approached persons (aged 50–75 years) in the general population responded to an initial questionnaire on general health, lifestyle and smoking history (which did not mention the NELSON trial88), similar to the response rate for the UKLS pilot randomised control trial.85 In NELSON, 19% (6% overall) of these were at high risk and half gave informed consent and were recruited. In UKLS, only 11.5% met the risk threshold for trial entry (higher than for NELSON) and a similar proportion were recruited. Although participation in a trial might be less than in a screening programme, in both of these well-conducted studies the participation rate of higher risk people was low enough to be of concern for implementation.

UKLS also showed that current smoking and low socioeconomic status (SES) were associated with lower uptake, a problem observed across European and US trials89–91 and for other cancer screening programmes more widely.92 Lung cancer prevalence is higher in lower SES communities, where lifelong smokers are both over-represented92 and more tobacco-dependent.93 Indeed, over 40% of the lung cancers detected in UKLS were in people from the most deprived quintile. Reported barriers to participation among smokers include concern about risk of lung cancer, a lower perceived benefit of early detection, perceived blame and stigma and fearful, fatalistic and nihilistic beliefs around lung cancer outcomes.94–97 In addition, methods of recruitment, which demand significant correspondence from potential participants (as required by most trials), are likely to increase attrition among lower SES groups. A UK study has begun recruitment to a trial examining a tailored invitation method designed to overcome these barriers and reduce inequalities in participation (Quaife et al manuscript in preparation).

Factors affecting screening adherence may be similar to those affecting uptake, with the added complexity of psychological responses to positive and negative results received in previous screening rounds.98 Given that the ratio of screening benefit to risk increases with lung cancer risk, promoting engagement of the higher risk and hard-to-reach groups aims to reduce lung cancer inequalities and improve the cost-effectiveness and efficacy of screening.

**Regulating CT screening**

Any screening programme needs to have stringent audit and quality control to ensure compliance with best practice. Availability of adequate resources to successfully implement and deliver such a programme to a high standard is vital. Controls also need to be in place to ensure uniformly low radiation doses are used, scans are read to an adequate level of accuracy and that nodules and other findings are appropriately managed. A database to record outcomes is crucial to enable measurement of screening outcomes and further develop and improve the protocols used for all aspects of screening.

**CONCLUSION**

LDCT screening is undoubtedly a promising method to improve lung cancer outcomes. If lung cancer screening is to be initiated in the UK, adequate provision of resources is essential, with employment of stringent screening protocols and regulatory processes to ensure benefits outweigh harms and costs are minimised. Although it is acknowledged that the UK NHS is under considerable resource pressure, lung cancer is a condition that has not seen the improved outcomes observed in other cancers. With an overall 5-year survival for lung cancer in the UK <13%99 and the limited efficacy of available treatments for late-stage disease, there seems to be no alternative but to proceed with screening to improve rates of early detection and curative treatment.

**Author note** We are sad to announce that Professor Jane Wardle passed away whilst this paper was in preparation. Jane had a phenomenal wealth of experience, knowledge and understanding of cancer screening and as an academic she was an inspiration to all who knew her. She is deeply missed by all of her co-authors and colleagues.

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M Ruparel, S L Quaife, N Navani, J Wardle, S M Janes and D R Baldwin

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