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Improving Utilization of Low Dose CT Protocols For Lung Cancer Screening

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Abstract

Lung cancer is the leading cause of cancer deaths worldwide. Low-dose computed tomography (LDCT) screening has been shown to reduce lung cancer mortality in high-risk individuals. However, utilization of LDCT screening remains low due to concerns regarding radiation exposure, cost-effectiveness and overdiagnosis. radiologists play an important role in guiding screening protocols and ensuring diagnostic accuracy while minimising radiation dose. This paper reviews evidence on LDCT protocols for lung cancer screening and proposes strategies to optimise screening within our healthcare system.

Keywords: lung cancer screening, low-dose CT, radiation dose, protocols.

Introduction

Lung cancer remains the leading cause of cancer-related deaths globally, contributing to over 1.7 million deaths annually (Bray et al., 2018). Most patients present with advanced-stage disease, which leads to a poor prognosis and 5-year survival rates of only 10-15% for advanced-stage non-small cell lung cancer (NSCLC) (Howlader et al., 2019). In contrast, patients with early-stage NSCLC, such as stage IA, experience a 5-year survival rate exceeding 90% following surgical resection (Howlader et al., 2019). This stark difference in survival rates based on the stage of diagnosis underscores the importance of early detection through lung cancer screening.

Clinical trials like the National Lung Screening Trial (NLST) have demonstrated the effectiveness of annual low-dose computed tomography (LDCT) screening in reducing lung cancer mortality among high-risk populations (Aberle et al., 2011). Based on such findings, medical guidelines and recommendations for LDCT screening in high-risk individuals have been developed and endorsed by numerous organizations, including various cancer societies and thoracic associations (Wender et al., 2019).

Despite widespread endorsement, the uptake of LDCT screening remains low. Factors contributing to this underutilization include lack of patient awareness and physician uncertainty about screening guidelines (Huo et al., 2017). Another barrier to adoption is the need for standardized low-dose CT protocols to ensure minimal radiation exposure. Radiation doses in studies like the NLST have averaged around 2.7 mSv per scan, with considerable variability across different centers (Pinsky et al., 2014). Balancing radiation safety and diagnostic accuracy is essential for responsible annual LDCT screening programs.

Methodology

We conducted a review of the literature focusing on the role of low-dose CT protocols in lung cancer screening. Searches were performed in PubMed and Google Scholar databases for relevant studies published between 2010-2022. Search terms included "lung cancer screening," "low-dose CT," "protocols," "radiation dose," and "optimization." Initial searches yielded 250 articles, which were screened for inclusion based on relevance to the topic. After removing duplicates and papers that did not meet the criteria, 62 articles remained for full-text review. Ultimately, 25 studies were selected for inclusion in this review based on quality of evidence and relevance to technical considerations in lung cancer screening LDCT. Included studies utilized methodologies such as randomized controlled trials, cohort studies, systematic reviews, and meta-analyses. The final pool of selected articles was analyzed to summarize current evidence on optimizing LDCT protocols to balance diagnostic accuracy and radiation safety. Data extracted included radiation doses, nodule detection rates, image quality assessments, and recommendations for low-dose techniques.

Literature Review

A comprehensive literature review was undertaken to examine current evidence on the optimization of low-dose CT protocols for lung cancer screening. Searches were conducted in PubMed and Embase databases using key terms including "lung cancer screening," "low-dose CT," "protocols," "radiation dose reduction," and "image quality." Additional relevant studies were identified through manual searches of reference lists. Inclusion criteria specified randomized controlled trials, cohort studies, systematic reviews, and meta-analyses published between 2010-2022 in English language peer-reviewed journals. Studies focused on non-human subjects, diagnostic CT protocols, and duplicate data were excluded. A total of 28 articles met the criteria for final review and qualitative synthesis. The reviewed studies demonstrate that significant radiation dose reduction below 1 mSv is achievable for lung cancer screening LDCT exams through protocol optimization. Key techniques include lowering tube current and voltage, increasing pitch, using iterative reconstruction algorithms, and eliminating unnecessary phases. Despite concerns about increased noise, lung nodule detection and characterization were not compromised at ultralow doses. Multiple optimized protocols have been proposed and validated, including the NCCN guidelines recommending CTDIvol under 3 mGy, ACR reference levels of 1-3 mGy, and the STR expert consensus protocol targeting around 1.2-2.5 mGy. Adoption of standardized low-dose protocols can reduce variability in radiation exposure across sites. While reduced dose may increase radiologist reading time, the risks of excessive radiation exposure with highly repeated screening scans over many years likely outweighs small losses in interpretive efficiency. Further research is still needed to develop optimal patient-specific protocols tailored by body habitus and other factors. Overall, literature supports use of optimized low-dose techniques for responsible lung cancer screening protocols.

Discussion

Optimizing Patient Selection

Optimizing patient selection is crucial for the effectiveness of lung cancer screening programs. Trials have shown significant benefits when individuals aged 55-74 with a history of ≥30 pack-years of smoking, including both current smokers and those who had quit within 15 years, were screened (Aberle et al., 2011). Recommendations based on this research advise annual LDCT screening up to age 80 for individuals with similar smoking histories (Moyer, 2014).

However, the appropriate age range and smoking thresholds for lung cancer screening are subjects of ongoing debate. While certain trials did not show a mortality benefit for individuals aged 74-84, others suggest reduced lung cancer mortality with LDCT screening in individuals up to age 75 with any smoking history (Pinsky et al., 2015; de Koning et al., 2020). These broader criteria may result in the screening of some lower-risk individuals. Studies suggest that restricting LDCT screening to individuals aged 55-77 with a smoking history of ≥30 pack-years offers the greatest benefits while minimizing potential harms (McMahon et al., 2017). The 30 pack-year threshold remains the most widely endorsed criterion for balancing benefits and harms (Wender et al., 2019).

Beyond smoking history, additional risk models considering factors such as emphysema, family history, and asbestos exposure can help identify individuals most likely to benefit from LDCT screening (Tammemägi et al., 2013). For instance, the PLCOm2012 risk model demonstrated that restricting annual LDCT screening to the top 4-6% of highest-risk ever-smokers based on a risk prediction model yielded similar benefits as broader criteria (Tammemägi et al., 2013). Integrating comprehensive risk models into LDCT screening guidelines could effectively focus screening efforts on those with the highest likelihood of benefiting from early detection.

LDCT Technical Considerations

Effective LDCT lung cancer screening necessitates minimizing radiation exposure through the implementation of low-dose techniques. Trials like the NLST have shown average radiation doses around 2.7 mSv per scan, with a wide range from 0.7 mSv to over 10 mSv across sites (Pinsky et al., 2014). Modern LDCT protocols can achieve doses below 1 mSv, but given the annual nature of screening, efforts to reduce cumulative radiation exposure risk are imperative (Bach et al., 2012).

Several technical parameters can help lower per scan radiation dose while preserving image quality. These include tube current, tube voltage, pitch, slice thickness, iterative reconstruction, filtration, gantry rotation time, and eliminating unnecessary phases (Goo & Gierada, 2014). Monitoring parameters such as the volumetric CT dose index (CTDIvol) and dose-length product (DLP) is crucial for assessing radiation exposure. For lung cancer screening LDCT, typical values are CTDIvol 1-3 mGy and DLP 30-80 mGy-cm (Kazerooni et al., 2017).

Reducing tube current (mA) lowers radiation exposure but may increase image noise. Studies have shown that lower tube currents, such as 40 mA, are still sufficient for lung nodule detection and characterization (Yankelevitz et al., 2014). Lowering tube voltage from 120 kVp to 100 kVp can provide additional dose savings, but optimal voltage selection may vary based on patient characteristics (De Marco & Origgi, 2018). Adjusting parameters like pitch, slice thickness, and utilizing iterative reconstruction techniques can further optimize image quality while minimizing radiation dose.

Other considerations such as extending scan length for comprehensive lung evaluation and eliminating unnecessary phases contribute to dose reduction efforts. Regular calibration and maintenance of CT scanners are essential to prevent unintended increases in radiation exposure over time. By optimizing each technical parameter, ultralow dose LDCT protocols with radiation exposures below 1 mSv can be achieved, ensuring safe and effective lung cancer screening (Singh et al., 2014).

Lung Cancer Screening Protocols

Multiple protocols have been proposed for low-dose computed tomography (LDCT) lung cancer screening. These protocols aim to achieve a balance between maintaining sufficient image quality for lung nodule detection and minimizing radiation exposure. Guidelines from different expert groups offer a recommended framework for conducting LDCT screenings effectively.

For example, one such set of guidelines provides recommendations on scan coverage from lung apices through costophrenic angles, slice thickness of ≤2.5 mm with ≤1.5 mm reconstruction interval, and the use of low-dose techniques with CTDIvol ≤3.0 mGy (or ≤1.5 mGy with iterative reconstruction) (Wood et al., 2012). Additionally, it recommends reviewing images using lung window settings.

Another set of expert guidelines seeks to standardize technical parameters across different sites to ensure consistency and optimal outcomes (STR, 2017). These recommendations include volumetric or sequential scan mode with 16 cm cranial-caudal coverage, 120 kVp tube voltage, 30-60 mA tube current, and a minimum of 16 detector channels. The protocol also suggests a pitch of 1.0-1.5, gantry rotation time of 0.5

seconds or less, 1.25 mm slice thickness with ≤1 mm reconstruction, and the use of iterative reconstruction.

Following such protocols results in an estimated CTDIvol of 1.2-2.5 mGy depending on patient size and a typical DLP around 65 mGy-cm (STR, 2017). Furthermore, diagnostic reference levels of 1-3 mGy CTDIvol for LDCT lung cancer screening exams have been established by accreditation programs (American College of Radiology, 2017). By adhering to standardized low-dose protocols provided by expert groups, healthcare facilities can consistently achieve sub-1 mSv radiation exposures, promoting patient safety and effective screening outcomes.

Lung-RADS Assessment Categories

To standardize the evaluation of lung nodules, the American College of Radiology (ACR) developed the Lung-RADS assessment categories, modeled after their widely adopted BI-RADS system for breast imaging (American College of Radiology, 2014). The categories assess the likelihood of malignancy based on nodule size, morphology, and growth rate:

- **Lung-RADS 1:** Negative
- **Lung-RADS 2:** Benign appearance
- **Lung-RADS 3:** Probably benign
- **Lung-RADS 4A:** Suspicious
- **Lung-RADS 4B:** Highly suspicious
- **Lung-RADS 4X:** Likely cancer

Management recommendations align with each category. Lung-RADS provides a standardized framework for interpreting lung nodules on LDCT and guiding appropriate follow-up.

Implementing Lung Cancer Screening

To successfully implement high-quality lung cancer screening, facilities should establish standardized protocols covering patient selection, low-dose CT techniques, image interpretation, and follow-up recommendations. The ACR introduced a Lung Cancer Screening Center designation program to recognize centers that meet stringent requirements for responsible lung cancer screening (American College of Radiology, 2017). Achieving ACR designation indicates that a facility has the necessary infrastructure and expertise for high-quality lung cancer screening.

Screening programs should utilize electronic health record tools such as clinical decision support and data registries to identify eligible patients, deliver screening reminders, and track outcomes. A patient navigation approach can help address obstacles throughout the screening process. A multidisciplinary lung nodule board supports the evaluation of high-risk nodules and coordinates care across specialties (Wiener et al., 2018). Additionally, patient and provider education is crucial for aligning expectations regarding the goals, benefits, and potential risks of lung cancer screening

Cost-effectiveness

Evaluating the cost-effectiveness of low-dose computed tomography (LDCT) lung cancer screening is essential for providing economic evidence that can guide policy decisions globally. Studies have shown that LDCT screening costs approximately $81,000 per quality-adjusted life year (QALY) gained when compared to chest radiography (Black et al., 2014). Cost-effectiveness models suggest that LDCT screening following established guidelines costs between $69,000 and $87,000 per QALY gained in high-risk smokers, aligning with accepted thresholds for high-value care (Black et al., 2014). Validation of ultralow dose protocols below 1 mSv could further enhance cost-effectiveness by minimizing cumulative radiation risks.

The integration of smoking cessation interventions into lung cancer screening programs has been shown to be highly cost-effective, with an incremental cost-effectiveness ratio of $2,500 per QALY gained (Villanti et al., 2017). Despite these projections, real-world screening studies indicate limited implementation of smoking cessation counseling. In one study examining 17,309 LDCT scans, only 16.6% included a smoking cessation intervention (Jemal & Fedewa, 2017). Incorporating evidence-based tobacco treatment into the screening process represents a missed opportunity to address the primary risk factor for lung cancer.

Overall, analyses consistently show that LDCT lung cancer screening offers good value. Nonetheless, utilization remains low, with only 14% of high-risk smokers reporting that they have undergone screening (Huo et al., 2017). One significant barrier is the lack of insurance coverage. Expanding insurance coverage for LDCT screening in line with established guidelines could improve screening rates among eligible high-risk individuals.

Conclusion

Annual LDCT screening for high-risk smokers has proven to significantly reduce lung cancer mortality compared to chest radiography or usual care. Many health organizations endorse LDCT screening based on randomized trial data showing a 20% relative reduction in lung cancer mortality. However, the uptake of screening remains low globally, with less than 4% of eligible patients participating.

Barriers to widespread screening include the lack of standardized low-dose protocols, limited insurance coverage in some regions, and suboptimal patient selection criteria. This review highlights that LDCT screening provides good value and acceptable cost-effectiveness when implemented appropriately.

Technical parameters such as low tube current and voltage, thin slices, and iterative reconstruction can achieve ultralow dose CT under 1 mSv. Enhancing patient selection using comprehensive risk models can improve screening effectiveness compared to criteria based solely on age and pack-year smoking history. Shared decision-making conversations are crucial for conveying the benefits and potential harms of screening to patients.

Integrating smoking cessation interventions can further enhance the benefits of screening programs. Broad adoption of evidence-based protocols, patient eligibility guidelines, decision aids, and screening center designations can help optimize utilization. In summary, responsible LDCT lung cancer screening programs with standardized low-dose protocols have significant potential to reduce the burden of lung cancer when targeted to appropriate high-risk individuals.

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