# ACR-STR PRACTICE PARAMETER FOR THE PERFORMANCE AND REPORTING OF LUNG CANCER SCREENING THORACIC COMPUTED TOMOGRAPHY (CT)

The American College of Radiology, with more than 40,000 members, is the principal organization of radiologists, radiation oncologists, and clinical medical physicists in the United States. The College is a nonprofit professional society whose primary purposes are to advance the science of radiology, improve radiologic services to the patient, study the socioeconomic aspects of the practice of radiology, and encourage continuing education for radiologists, radiation oncologists, medical physicists, and persons practicing in allied professional fields.

The American College of Radiology will periodically define new practice parameters and technical standards for radiologic practice to help advance the science of radiology and to improve the quality of service to patients throughout the United States. Existing practice parameters and technical standards will be reviewed for revision or renewal, as appropriate, on their fifth anniversary or sooner, if indicated.

Each practice parameter and technical standard, representing a policy statement by the College, has undergone a thorough consensus process in which it has been subjected to extensive review and approval. The practice parameters and technical standards recognize that the safe and effective use of diagnostic and therapeutic radiology requires specific training, skills, and techniques, as described in each document. Reproduction or modification of the published practice parameter and technical standard by those entities not providing these services is not authorized.

This document is an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. Practice Parameters and Technical Standards are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care  $\frac{1}{2}$ . For these reasons and those set forth below, the American College of Radiology and our collaborating medical specialty societies caution against the use of these documents in litigation in which the clinical decisions of a practitioner are called into question.

The ultimate judgment regarding the propriety of any specific procedure or course of action must be made by the practitioner considering all the circumstances presented. Thus, an approach that differs from the guidance in this document, standing alone, does not necessarily imply that the approach was below the standard of care. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in this document when, in the reasonable judgment of the practitioner, such course of action is indicated by variables such as the condition of the patient, limitations of available resources, or advances in knowledge or technology after publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document may consider documenting in the patient record information sufficient to explain the approach taken.

The practice of medicine involves the science, and the art of dealing with the prevention, diagnosis, alleviation, and treatment of disease. The variety and complexity of human conditions make it impossible to always reach the most appropriate diagnosis or to predict with certainty a particular response to treatment. Therefore, it should be recognized that adherence to the guidance in this document will not assure an accurate diagnosis or a successful outcome. All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The purpose of this document is to assist practitioners in achieving this objective.

## I. INTRODUCTION

**<sup>1</sup>** Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing, 831 N.W.2d 826 (Iowa 2013) Iowa Supreme Court refuses to find that the "ACR Technical Standard for Management of the Use of Radiation in Fluoroscopic Procedures (Revised 2008)" sets a national standard for who may perform fluoroscopic procedures in light of the standard's stated purpose that ACR standards are educational tools and not intended to establish a legal standard of care. See also, <u>Stanley v. McCarver</u>, 63 P.3d 1076 (Ariz. App. 2003) where in a concurring opinion the Court stated that "published standards or guidelines of specialty medical organizations are useful in determining the duty owed or the standard of care applicable in a given situation" even though ACR standards themselves do not establish the standard of care.

This practice parameter has been revised collaboratively by the American College of Radiology (ACR) and the Society of Thoracic Radiology (STR).

Thoracic CT is the only test that has been demonstrated to reduce mortality from lung cancer in high-risk current and former cigarette smokers [1,2]. Screening with CT may have additional health benefits when associated with smoking cessation [3-7]. The optimal performance of low-dose chest CT for lung cancer screening requires knowledge of normal anatomy, anatomic variants, pathophysiology, and the risks associated with lung cancer screening. In addition, attention to CT technical parameters to achieve lower radiation exposure levels than is characteristic of standard adult thoracic CT examinations is important, particularly because a positive CT screening examination may result in subsequent follow-up examinations that expose screen-positive individuals to additional ionizing radiation, and screening CT may be repeated annually for several decades, depending on when an individual begins screening. This practice parameter outlines the principles for performing high-quality thoracic CT in adults at high risk for lung cancer.

Lung cancer screening is to be considered in asymptomatic patients 50-80 years old who are at risk of lung cancer based on their smoking history and are potential candidates for curative treatment. Before participating in screening, individuals should consult with a healthcare provider about the risks and benefits of lung cancer screening and discuss shared decision making. It is recommended that radiology practices performing lung cancer screening participate in a multidisciplinary approach that includes the specialties of radiology, pulmonary medicine, pathology, thoracic surgery, medical and radiation oncology, and other related health care disciplines.

For current smokers, there should be a mechanism for referral to smoking cessation programs. Educational messaging and materials promoting smoking cessation may be included in program-related patient correspondence.

The primary goal of lung cancer screening CT is to detect abnormalities that may represent lung cancer and may require further diagnostic evaluation. In addition, examinations should be reviewed for other abnormalities in accordance with the <u>ACR–SABI–SPR Practice Parameter for the Performance of Thoracic Computed Tomography</u> (CT) [8].

## **II. INDICATIONS AND RISK FACTORS**

Lung cancer screening CT is indicated for asymptomatic individuals between 50 and 80 years with a at least a 20 pack year smoking history [9]. Currently additional risk factors do not qualify subjects for screening. For at risk individuals based on other factors listed below, a diagnostic CT scan may be considered.

An individual's risk for lung cancer is primarily determined by:

Smoking history and age [10-16]

Additional risk factors which include the following [17-45]:

- 1. Emphysema and chronic obstructive pulmonary disease
- 2. Interstitial lung disease, such as pulmonary fibrosis
- 3. Occupational and environmental exposures, such as asbestos, arsenic, beryllium, cadmium, chromium, coal smoke, diesel fumes, nickel, silica, and soot
- 4. High levels of radon exposure
- 5. History of cancer, including lung cancer, head and neck cancer, and other smoking-related cancers
- 6. Family history of lung cancer, and genetic mutations such as Li-Fraumeni syndrome, P53, BRCA1 etc.
- 7. Extensive secondhand smoke exposure
- 8. Prior thoracic radiation therapy, as may occur for breast cancer and lymphoma.

For other thoracic CT techniques beyond the scope of this practice parameter, please refer to the <u>ACR–SABI–SPR</u> <u>Practice Parameter for the Performance of Thoracic Computed Tomography (CT)</u> [8] and the <u>ACR–STR Practice</u> <u>Parameter for the Performance of High-Resolution Computed Tomography (HRCT) of the Lungs in Adults</u> [46].

There are no absolute contraindications to screening thoracic CT. As with all procedures, the relative benefits and risks of the procedure should be evaluated prior to the performance of thoracic CT. Appropriate precautions should be taken to minimize patient risks, including radiation exposure. Subjects with prior history of malignancy should not have active malignancy at risk of metastatic disease at the time of screening to ensure optimal management.

Self-referred individuals are defined as those individuals with no health care provider, who decline having a health care provider, or for whom the health care provider declines responsibility. It is at the discretion of the facility's medical director whether or not to offer screening to the self-referred individual. However, screening facilities that elect to accept self-referred individuals must have procedures for referring them to a qualified health care provider if abnormal findings are present.

For the pregnant or potentially pregnant patient, see the <u>ACR–SPR Practice Parameter for Imaging Pregnant or</u> <u>Potentially Pregnant Patients with Ionizing Radiation [47]</u>.

## **III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL**

See the <u>ACR–SPR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [48]</u>

## **IV. SPECIFICATIONS OF THE EXAMINATION**

### A. Prior to the Examination

The written or electronic request for a lung cancer screening CT should provide sufficient information to demonstrate the medical appropriateness of the examination and allow for its proper performance and interpretation. This should include the patient's age, smoking history in pack-years, and should identify the patient as a current smoker or as a former smoker with a quit date. History of electronic cigarettes and other devices used for smoking or inhalation related history may also be collected.

#### B. Examination

A typical lung cancer screening CT of the thorax must be performed with multidetector helical (spiral) technique in a single breath-hold. The study must include axial images from the lung apices to the costophrenic sulci acquired and viewed at 2.5-mm slice thickness or smaller (preferably at 1.0-mm slice thickness or smaller), with reconstruction intervals equal to or less than the slice thickness [53]. Maximum intensity projection (MIP) reconstruction is a technique that may be useful to increase the sensitivity for lung nodule detection [54-58]. Multiplanar reconstruction (MPR) may be useful to further characterize nodules, particularly nodules located along the pleural surfaces (also known as juxtapleural nodules) [59-61].

Scans should be obtained in a suspended state of full inspiration. Scans must be obtained through the entire lungs, from apices to bases, and the field of view must be optimized for each patient to include the entire transverse and anteroposterior diameter of the lungs.

The examination is conducted without the use of intravenous contrast medium.

Although many of the operations of a CT scanner are automated, a number of technical parameters remain operator dependent and may significantly affect the diagnostic quality of the CT examination. Wherever possible, scanning protocols should be preprogrammed and saved on the CT scanner console to reduce the operator input required. It is necessary for the supervising physician to acquire familiarity with the following:

- 1. Radiation exposure factors (including milliamperes, peak kilovoltage, gantry rotation time)
- 2. Detector configuration (including detector rows, width of each detector row, configurations allowed, etc)

- 3. Slice thickness and interval
- 4. Field of view and matrix size (eg, 512 x 512)
- 5. Window and level settings
- 6. Reconstruction algorithms
- 7. Reformatted images (MPR, curvilinear, MaxIP, and MinIP)
- 8. Dose reduction techniques such as automatic exposure control and iterative reconstruction methods, if available

Optimization of the CT examination requires communication between the supervising physician, medical physicist, and radiologic technologist to develop and monitor appropriate CT protocols based on the clinical indications and associated risks. The technique should be set to yield a dose index volume (CTDI<sub>vol</sub>) of 3 mGy or less for a standard-sized patient. It should be reduced for smaller-sized patients and increased for larger-sized patients [<u>49-51,62-70</u>].

The protocol should be developed with attention to the organ system of interest, in this case primarily the lungs, for the specific purpose of lung cancer screening. Techniques should result in diagnostic quality images with the lowest possible patient radiation exposure. For each study, the protocol should specify:

- 1. Use of volumetric acquisition
- 2. Collimation, table increment, and pitch as appropriate
- 3. Peak kilovoltage and milliamperes appropriate to body habitus
- 4. Superior and inferior extent of the area of interest to be imaged
- 5. Reconstructed image thickness and spacing (interval)
- 6. Reconstruction algorithm and level and window settings
- 7. Field of view and matrix size
- 8. Image reformatting

Examples of lung cancer screening protocols for several specific CT scanner manufacturers and models are available [71]. They should not be used for other manufacturers or models without careful review and adjustment with the assistance of a qualified medical physicist. The lung cancer screening protocol should be reviewed at regular intervals or with a change in screening equipment.

#### **V. INTERPRETATION AND REPORTING**

The interpretation and reporting of lung cancer screening CT should adhere to classification and management recommendations provided by the ACR Lung-RADS<sup>®</sup> system, currently v2022 [72].

Anatomically appropriate window and level settings should be used to view all of the anatomy within the obtained CT coverage, including the lung parenchyma, mediastinum, chest wall, bones, lower neck, and upper abdomen within the scanned field of view.

Lung nodules and focal lung lesions should be reported with respect to anatomic location (lung lobe, segment) and series/image number to facilitate comparison to both prior and subsequent thoracic CT examinations. Nodules should be described with respect to size, attenuation (soft tissue, type of calcification, fat), opacity (solid, ground glass [also known as nonsolid], and part-solid, containing both solid and ground-glass components), and margins (eg, smooth, lobulated, spiculated) [73-79]. Comparison with prior imaging studies is an important part of nodule evaluation. Specific reference should be made to change, or lack thereof, from prior examinations, are needed to determine the significance of positive findings, an attempt should be made to obtain and compare with the images directly and not rely on prior reports alone. When comparing changes in nodule size, opacity, and contour, efforts should be made to compare the oldest scans available in addition to the most recent prior scan to assess for changes over time, including subtle changes. Volumetric analysis or volume measurement of nodules may be incorporated into the report [80].

The use of computer-assisted nodule detection and volumetric assessment of nodule size and growth by

computer workstation analysis can be adjuncts to the evaluation. Risk assessment calculators can be used to assist with clinical decision making for specific Lung-RADS categories [81-87].

For the management of screen-detected lung nodules, standard guidelines should be followed within a practice or screening program [88-91] and should be included in the radiology report. Although a guideline about interpretation and follow-up may be useful as an attachment to the report, the interpreting radiologist should make recommendations for the appropriate management and follow-up specific to the individual patient whose CT is under review [92-96].

Screening results should be reported using a structured reporting system for lesion assessment, imaging-pathologic correlation, quality improvement, and medical outcomes auditing. Reporting and management recommendations of incidental findings are also important for lung cancer screening [97-100].

Review of the entire examination for other potentially significant findings should be performed and reported in accordance with the <u>ACR–SABI–SPR Practice Parameter for the Performance of Thoracic Computed Tomography</u> (<u>CT</u>) [8]. In addition, the report should include the presence or absence of coronary artery calcification and, if present, the degree of coronary artery calcification (eg, mild, moderate, severe) [101-103]. Additional significant findings requiring further diagnostic workup or referral should also be incorporated into the report with the appropriate Lung-RADS classification [87].

## VI. DOCUMENTATION AND COMMUNICATION OF RESULTS

Reporting should be in accordance with the <u>ACR Practice Parameter for Communication of Diagnostic Imaging</u> <u>Findings</u> [104].

A structured reporting system facilitates data management, patient care, and quality assurance activities. Such a system should include the adherence of radiologist recommendations to screening guidelines, patient tracking and storage of findings in a structured database, automatic generation of results-specific findings, triage of risk categories within the screened population, and appropriate referral of the small number of patients with suspicious findings who require multidisciplinary team management [100,105,106].

Imaging providers may wish to establish infrastructure in the form of a relational database application that facilitates and helps manage patient intake, scheduling, and follow-up. Software and data management systems can be used based on the size of the program.

Lung Cancer Screening Registry:

Studies performed for lung cancer screening under the Medicare program should also be reported to a CMS (Centers for Medicare and Medicaid Services) registry. Data from the quarterly reports of the facility can be used for improving the lung cancer screening program. <u>https://www.acr.org/Practice-Management-Quality-Informatics/Registries/Lung-Cancer-Screening-Registry</u>.

Communication of results to subjects and referring physicians should include the pertinent incidental findings and Lung-RADS category and recommendations for follow up. For categories Lung-RADS 3 and 4 a closed loop communication strategy based on the program can be implemented to ensure optimal management and triage.

#### **VII. EQUIPMENT SPECIFICATIONS**

Equipment performance monitoring should be in accordance with the <u>ACR–AAPM Technical Standard for</u> <u>Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment [107]</u>.

To achieve acceptable clinical CT scans of the thorax for lung cancer screening, a CT scanner should meet the current <u>ACR–SABI–SPR Practice Parameter for the Performance of Thoracic Computed Tomography (CT)</u> [8] and meet or exceed the following capabilities:

- 1. Gantry rotation times: 0.75 seconds or less
- 2. Slice thickness: 2.5 mm or less (1.0 mm or less is preferred)
- 3. Detector rows: 16 or more detector rows are preferred

The CT scanner and/or the viewing platform should be capable of generating MIP and MPR images.

## **VIII. RADIATION SAFETY IN IMAGING**

Radiologists, medical physicists, non-physician radiology providers, radiologic technologists, and all supervising physicians have a responsibility for safety in the workplace by keeping radiation exposure to staff, and to society as a whole, "as low as reasonably achievable" (ALARA) and to assure that radiation doses to individual patients are appropriate, taking into account the possible risk from radiation exposure and the diagnostic image quality necessary to achieve the clinical objective. All personnel who work with ionizing radiation must understand the key principles of occupational and public radiation protection (justification, optimization of protection, application of dose constraints and limits) and the principles of proper management of radiation dose to patients (justification, optimization including the use of dose reference levels). <a href="https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1775\_web.pdf">https://www-publications/PDF/PUB1775\_web.pdf</a>

Nationally developed guidelines, such as the <u>ACR's Appropriateness Criteria</u><sup>®</sup>, should be used to help choose the most appropriate imaging procedures to prevent unnecessary radiation exposure.

Facilities should have and adhere to policies and procedures that require ionizing radiation examination protocols (radiography, fluoroscopy, interventional radiology, CT) to vary according to diagnostic requirements and patient body habitus to optimize the relationship between appropriate radiation dose and adequate image quality. Automated dose reduction technologies available on imaging equipment should be used, except when inappropriate for a specific exam. If such technology is not available, appropriate manual techniques should be used.

Additional information regarding patient radiation safety in imaging is available from the following websites – Image Gently<sup>®</sup> for children (<u>www.imagegently.org</u>) and Image Wisely<sup>®</sup> for adults (<u>www.imagewisely.org</u>). These advocacy and awareness campaigns provide free educational materials for all stakeholders involved in imaging (patients, technologists, referring providers, medical physicists, and radiologists).

Radiation exposures or other dose indices should be periodically measured by a Qualified Medical Physicist in accordance with the applicable ACR Technical Standards. Monitoring or regular review of dose indices from patient imaging should be performed by comparing the facility's dose information with national benchmarks, such as the ACR Dose Index Registry and relevant publications relying on its data, applicable ACR Practice Parameters, NCRP Report No. 172, Reference Levels and Achievable Doses in Medical and Dental Imaging: Recommendations for the United States or the Conference of Radiation Control Program Director's National Evaluation of X-ray Trends; 2006, 2009, amended 2013, revised 2023 (Res. 2d).

A medical physicist and radiologist together should verify that any dose reduction devices or utilities maintain acceptable image quality while actually reducing radiation dose.

## IX. QUALITY CONTROL AND IMPROVEMENT, SAFETY, INFECTION CONTROL, AND PATIENT EDUCATION

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control, and Patient Education appearing under the heading *Position Statement on QC & Improvement, Safety, Infection Control, and Patient Education* on the ACR website (<u>https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement</u>).

#### **QUALITY ASSURANCE**

#### A. Auditing and Outcomes Monitoring

A rigorous quality assurance and medical outcomes audit program should be established at screening sites to document that performance and interpretation is of the highest possible quality. This is central to patient safety

because of the potential morbidity and mortality associated with false-positive workups and biopsies. Methodology should be in place to evaluate the appropriateness of screening referrals.

It is recommended that a lung cancer CT screening program have a documented policy for collecting outcomes data, such as positive and negative screen rates, the rate of clinically significant incidental extrapulmonary findings, and false-positive finding rates.

### **QUALITY ASSURANCE**

#### **B. EQUIPMENT QUALITY CONTROL**

The quality control program for CT equipment should be designed to minimize patient, personnel, and public radiation risks and to optimize the diagnostic quality of the examination. The program should be supervised by a medical physicist and follow the <u>ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance</u> <u>Monitoring of Computed Tomography (CT) Equipment [107]</u>.

### **QUALITY ASSURANCE**

### C. Quality Control

For specific issues regarding CT quality control, see the <u>ACR–SPR Practice Parameter for Performing and</u> <u>Interpreting Diagnostic Computed Tomography (CT)</u> [48].

### ACKNOWLEDGEMENTS

This practice parameter was revised according to the process described under the heading *The Process for Developing ACR Practice Parameters and Technical Standards* on the ACR website (<u>https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards</u>) by the Committee on Thoracic Radiology of the ACR Commissions on Body Imaging and the Committee on Practice Parameters – General, Small, Emergency, and/or Rural Practice of the ACR Commission on General, Small, Emergency, and/or Rural Practice in collaboration with the STR.

Writing Committee – members represent their societies in the initial and final revision of this practice parameter

ACR
Gill, Ritu MPH, MBBS, Chair
Chiles, Caroline MD
Hammer, Mark MD
Johnstone, Candice MD
Lynch, David A ChB, MB

<u>STR</u> Christensen, Jared D MBA, MD Cronin, Paul Patrick Healey, Terrance MD Litmanovich, Diana MD

<u>Committee on Thoracic Imaging – Body Imaging</u> (ACR Committee responsible for sponsoring the draft through the process)

Ko, Jane P MD, Chair	Gill, Ritu MPH, MBBS
Hammer, Mark MD	Koo, Chi Wan MD
Lau, Charles MD	Lynch, David A ChB, MB
Price, Melissa C MD	Thomas, Kerry L MD
Vlahos, Ionnis MBBS	

Larson, David B MBA, MD, Chair, Commission on Quality and Safety Rosenkrantz, Andrew MD, Chair, Commission on Body Imaging

**Comments Reconciliation Committee** 

Gerson, Rachel MD - CSC, Chair	Gupta, Yasha - CSC, Co-Chair
Chiles, Caroline MD	Christensen, Jared D MBA, MD
Cronin, Paul Patrick	Crummy, Timothy MD, MHA - CSC
Gill, Ritu MPH, MBBS	Hammer, Mark MD
Healey, Terrance MD	Johnstone, Candice MD
Ko, Jane P MD	Larson, David B MBA, MD
Litmanovich, Diana MD	Lynch, David A ChB, MB
Rosenkrantz, Andrew MD	Schoppe, Kurt MD - CSC

#### REFERENCES

- 1. Aberle DR, Adams AM, Berg CD, et al. Reduced lung-cancer mortality with low-dose computed tomographic screening. The New England journal of medicine 2011;365:395-409.
- 2. Henschke CI, Boffetta P, Gorlova O, Yip R, Delancey JO, Foy M. Assessment of lung-cancer mortality reduction from CT Screening. Lung Cancer 2011;71:328-32.
- 3. Ashraf H, Tonnesen P, Holst Pedersen J, Dirksen A, Thorsen H, Dossing M. Effect of CT screening on smoking habits at 1-year follow-up in the Danish Lung Cancer Screening Trial (DLCST). Thorax 2009;64:388-92.
- 4. Taylor KL, Cox LS, Zincke N, Mehta L, McGuire C, Gelmann E. Lung cancer screening as a teachable moment for smoking cessation. Lung Cancer 2007;56:125-34.
- 5. Townsend CO, Clark MM, Jett JR, et al. Relation between smoking cessation and receiving results from three annual spiral chest computed tomography scans for lung carcinoma screening. Cancer 2005;103:2154-62.
- 6. van den Bergh KA, Essink-Bot ML, Borsboom GJ, Scholten ET, van Klaveren RJ, de Koning HJ. Long-term effects of lung cancer computed tomography screening on health-related quality of life: the NELSON trial. The European respiratory journal : official journal of the European Society for Clinical Respiratory Physiology 2011;38:154-61.
- 7. van den Bergh KA, Essink-Bot ML, Borsboom GJ, et al. Short-term health-related quality of life consequences in a lung cancer CT screening trial (NELSON). British journal of cancer 2010;102:27-34.
- American College of Radiology. ACR–SABI–SPR Practice Parameters for the Performance of Thoracic Computed Tomography (CT). Available at: <u>https://www.acr.org/-/media/ACR/Files/Practice-Parameters/CT-Thoracic.pdf</u>. Accessed January 13, 2023.
- American College of Physicians. Screening for lung cancer: U.S. Preventive Services Task Force Recommendation Statement. Available at: <u>http://annals.org/article.aspx?articleid=1809422</u> Accessed January 13, 2023.
- 10. Garfinkel L. Time trends in lung cancer mortality among nonsmokers and a note on passive smoking. Journal of the National Cancer Institute 1981;66:1061-6.
- 11. Hackshaw AK, Law MR, Wald NJ. The accumulated evidence on lung cancer and environmental tobacco smoke. BMJ 1997;315:980-8.
- 12. Jemal A, Bray F, Center MM, Ferlay J, Ward E, Forman D. Global cancer statistics. CA: a cancer journal for clinicians 2011;61:69-90.
- 13. Peto R, Darby S, Deo H, Silcocks P, Whitley E, Doll R. Smoking, smoking cessation, and lung cancer in the UK since 1950: combination of national statistics with two case-control studies. BMJ 2000;321:323-9.
- 14. Thun MJ, Henley SJ, Burns D, Jemal A, Shanks TG, Calle EE. Lung cancer death rates in lifelong nonsmokers. Journal of the National Cancer Institute 2006;98:691-9.
- US Department of Health and Human Service. The health consequences of involuntary exposure to tobacco smoke: a report of the surgeon general. Available at: <u>https://www.ncbi.nlm.nih.gov/books/NBK179276</u>. Accessed January 13, 2023.
- 16. US Department of Health and Human Service. The health consequences of smoking: a report of the surgeon general. Available at: <u>https://www.ncbi.nlm.nih.gov/books/NBK44324/</u>. Accessed January 13, 2023.
- 17. Alavanja MC, Brownson RC, Boice JD, Jr., Hock E. Preexisting lung disease and lung cancer among nonsmoking women. American journal of epidemiology 1992;136:623-32.
- 18. Atabek U, Mohit-Tabatabai MA, Raina S, Rush BF, Jr., Dasmahapatra KS. Lung cancer in patients with head and neck cancer. Incidence and long-term survival. American journal of surgery 1987;154:434-8.

- 19. Darby S, Hill D, Auvinen A, et al. Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies. BMJ 2005;330:223.
- 20. Driscoll T, Nelson DI, Steenland K, et al. The global burden of disease due to occupational carcinogens. American journal of industrial medicine 2005;48:419-31.
- 21. El Ghissassi F, Baan R, Straif K, et al. A review of human carcinogens--part D: radiation. The lancet oncology 2009;10:751-2.
- 22. Fletcher O, Easton D, Anderson K, Gilham C, Jay M, Peto J. Lifetime risks of common cancers among retinoblastoma survivors. Journal of the National Cancer Institute 2004;96:357-63.
- 23. Hubbard R, Venn A, Lewis S, Britton J. Lung cancer and cryptogenic fibrosing alveolitis. A population-based cohort study. American journal of respiratory and critical care medicine 2000;161:5-8.
- 24. Hughes JM, Weill H. Asbestosis as a precursor of asbestos related lung cancer: results of a prospective mortality study. British journal of industrial medicine 1991;48:229-33.
- 25. Jones AS, Morar P, Phillips DE, Field JK, Husband D, Helliwell TR. Second primary tumors in patients with head and neck squamous cell carcinoma. Cancer 1995;75:1343-53.
- 26. Jonsson S, Thorsteinsdottir U, Gudbjartsson DF, et al. Familial risk of lung carcinoma in the Icelandic population. JAMA : the journal of the American Medical Association 2004;292:2977-83.
- 27. Koshiol J, Rotunno M, Consonni D, et al. Chronic obstructive pulmonary disease and altered risk of lung cancer in a population-based case-control study. PloS one 2009;4:e7380.
- 28. Leuraud K, Schnelzer M, Tomasek L, et al. Radon, smoking and lung cancer risk: results of a joint analysis of three European case-control studies among uranium miners. Radiation research 2011;176:375-87.
- 29. Li X, Hemminki K. Familial multiple primary lung cancers: a population-based analysis from Sweden. Lung Cancer 2005;47:301-7.
- 30. Lubin JH, Boice JD, Jr. Lung cancer risk from residential radon: meta-analysis of eight epidemiologic studies. Journal of the National Cancer Institute 1997;89:49-57.
- 31. Matakidou A, Eisen T, Houlston RS. Systematic review of the relationship between family history and lung cancer risk. British journal of cancer 2005;93:825-33.
- 32. Mayne ST, Buenconsejo J, Janerich DT. Previous lung disease and risk of lung cancer among men and women nonsmokers. American journal of epidemiology 1999;149:13-20.
- 33. Reid A, de Klerk NH, Ambrosini GL, Berry G, Musk AW. The risk of lung cancer with increasing time since ceasing exposure to asbestos and quitting smoking. Occupational and environmental medicine 2006;63:509-12.
- 34. Samet JM, Humble CG, Pathak DR. Personal and family history of respiratory disease and lung cancer risk. The American review of respiratory disease 1986;134:466-70.
- 35. Skillrud DM, Offord KP, Miller RD. Higher risk of lung cancer in chronic obstructive pulmonary disease. A prospective, matched, controlled study. Annals of internal medicine 1986;105:503-7.
- 36. Steenland K, Loomis D, Shy C, Simonsen N. Review of occupational lung carcinogens. American journal of industrial medicine 1996;29:474-90.
- 37. Travis LB, Gospodarowicz M, Curtis RE, et al. Lung cancer following chemotherapy and radiotherapy for Hodgkin's disease. Journal of the National Cancer Institute 2002;94:182-92.
- 38. Tucker MA, Murray N, Shaw EG, et al. Second primary cancers related to smoking and treatment of smallcell lung cancer. Lung Cancer Working Cadre. Journal of the National Cancer Institute 1997;89:1782-8.
- 39. Turner MC, Chen Y, Krewski D, Calle EE, Thun MJ. Chronic obstructive pulmonary disease is associated with lung cancer mortality in a prospective study of never smokers. American journal of respiratory and critical care medicine 2007;176:285-90.
- 40. Turner-Warwick M, Lebowitz M, Burrows B, Johnson A. Cryptogenic fibrosing alveolitis and lung cancer. Thorax 1980;35:496-9.
- 41. Wu-Williams AH, Dai XD, Blot W, et al. Lung cancer among women in north-east China. British journal of cancer 1990;62:982-7.
- 42. Yang P, Sun Z, Krowka MJ, et al. Alpha1-antitrypsin deficiency carriers, tobacco smoke, chronic obstructive pulmonary disease, and lung cancer risk. Archives of internal medicine 2008;168:1097-103.
- 43. Kato K, Gemba K, Ashizawa K, et al. Low-dose chest computed tomography screening of subjects exposed to asbestos. European journal of radiology 2018;101:124-28.
- 44. Benusiglio PR, Fallet V, Sanchis-Borja M, Coulet F, Cadranel J. Lung cancer is also a hereditary disease. Eur Respir Rev 2021;30.

- 45. Coco S, Boccardo S, Mora M, et al. Radiation-Related Deregulation of TUBB3 and BRCA1/2 and Risk of Secondary Lung Cancer in Women With Breast Cancer. Clin Breast Cancer 2021;21:218-30.e6.
- 46. American College of Radiology. ACR–STR Practice Parameter for the Performance of High-Resolution Computed Tomography (HRCT) of the Lungs in Adults. Available at: <u>https://www.acr.org/-/media/ACR/Files/Practice-Parameters/HRCT-Lungs.pdf</u>. Accessed January 13, 2023
- 47. American College of Radiology. ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation. Available at: <u>https://www.acr.org/-</u> /media/ACR/Files/Practice-Parameters/Pregnant-Pts.pdf. Accessed January 13, 2023.
- 48. American College of Radiology. ACR-SPR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT). Available at: <u>https://www.acr.org/-/media/ACR/Files/Practice-Parameters/CT-Perf-Interpret.pdf</u>. Accessed January 13, 2023.
- 49. Lopes Pegna A, Picozzi G, Mascalchi M, et al. Design, recruitment and baseline results of the ITALUNG trial for lung cancer screening with low-dose CT. Lung Cancer 2009;64:34-40.
- 50. Menezes RJ, Roberts HC, Paul NS, et al. Lung cancer screening using low-dose computed tomography in atrisk individuals: the Toronto experience. Lung Cancer 2010;67:177-83.
- 51. Pedersen JH, Ashraf H, Dirksen A, et al. The Danish randomized lung cancer CT screening trial--overall design and results of the prevalence round. Journal of thoracic oncology : official publication of the International Association for the Study of Lung Cancer 2009;4:608-14.
- 52. Aberle DR, Berg CD, Black WC, et al. The National Lung Screening Trial: overview and study design. Radiology 2011;258:243-53.
- 53. Fischbach F, Knollmann F, Griesshaber V, Freund T, Akkol E, Felix R. Detection of pulmonary nodules by multislice computed tomography: improved detection rate with reduced slice thickness. European radiology 2003;13:2378-83.
- 54. Jankowski A, Martinelli T, Timsit JF, et al. Pulmonary nodule detection on MDCT images: evaluation of diagnostic performance using thin axial images, maximum intensity projections, and computer-assisted detection. European radiology 2007;17:3148-56.
- 55. Kawel N, Seifert B, Luetolf M, Boehm T. Effect of slab thickness on the CT detection of pulmonary nodules: use of sliding thin-slab maximum intensity projection and volume rendering. AJR. American journal of roentgenology 2009;192:1324-9.
- 56. Park EA, Goo JM, Lee JW, et al. Efficacy of computer-aided detection system and thin-slab maximum intensity projection technique in the detection of pulmonary nodules in patients with resected metastases. Investigative radiology 2009;44:105-13.
- 57. Peloschek P, Sailer J, Weber M, Herold CJ, Prokop M, Schaefer-Prokop C. Pulmonary nodules: sensitivity of maximum intensity projection versus that of volume rendering of 3D multidetector CT data. Radiology 2007;243:561-9.
- 58. Valencia R, Denecke T, Lehmkuhl L, Fischbach F, Felix R, Knollmann F. Value of axial and coronal maximum intensity projection (MIP) images in the detection of pulmonary nodules by multislice spiral CT: comparison with axial 1-mm and 5-mm slices. European radiology 2006;16:325-32.
- 59. Ahn MI, Gleeson TG, Chan IH, et al. Perifissural nodules seen at CT screening for lung cancer. Radiology 2010;254:949-56.
- 60. Hanaoka T, Sone S, Takayama F, Hayano T, Yamaguchi S, Okada M. Presence of local pleural adhesion in CT screening-detected small nodule in the lung periphery suggests noncancerous, inflammatory nature of the lesion. Clinical imaging 2007;31:385-9.
- 61. Xu DM, van der Zaag-Loonen HJ, Oudkerk M, et al. Smooth or attached solid indeterminate nodules detected at baseline CT screening in the NELSON study: cancer risk during 1 year of follow-up. Radiology 2009;250:264-72.
- 62. Bankier AA, Tack D. Dose reduction strategies for thoracic multidetector computed tomography: background, current issues, and recommendations. Journal of thoracic imaging 2010;25:278-88.
- 63. Brenner DJ. Radiation risks potentially associated with low-dose CT screening of adult smokers for lung cancer. Radiology 2004;231:440-5.
- 64. Henschke CI, McCauley DI, Yankelevitz DF, et al. Early Lung Cancer Action Project: overall design and findings from baseline screening. Lancet 1999;354:99-105.
- 65. Kubo T, Lin PJ, Stiller W, et al. Radiation dose reduction in chest CT: a review. AJR. American journal of roentgenology 2008;190:335-43.

- 66. Mascalchi M, Belli G, Zappa M, et al. Risk-benefit analysis of X-ray exposure associated with lung cancer screening in the Italung-CT trial. AJR. American journal of roentgenology 2006;187:421-9.
- 67. Pontana F, Duhamel A, Pagniez J, et al. Chest computed tomography using iterative reconstruction vs filtered back projection (Part 2): image quality of low-dose CT examinations in 80 patients. European radiology 2011;21:636-43.
- 68. Pontana F, Pagniez J, Flohr T, et al. Chest computed tomography using iterative reconstruction vs filtered back projection (Part 1): Evaluation of image noise reduction in 32 patients. European radiology 2011;21:627-35.
- 69. Cody DD, Kim HJ, Cagnon CH, et al. Normalized CT dose index of the CT scanners used in the National Lung Screening Trial. AJR. American journal of roentgenology 2010;194:1539-46.
- 70. Larke FJ, Kruger RL, Cagnon CH, et al. Estimated radiation dose associated with low-dose chest CT of average-size participants in the National Lung Screening Trial. AJR. American journal of roentgenology 2011;197:1165-9.
- 71. Cagnon CH, Cody DD, McNitt-Gray MF, Seibert JA, Judy PF, Aberle DR. Description and implementation of a quality control program in an imaging-based clinical trial. Academic radiology 2006;13:1431-41.
- 72. American College of Radiology. Lung-RADS v2022. Available at: <u>https://www.acr.org/\_/media/ACR/Files/RADS/Lung-RADS/Lung-RADS-2022.pdf</u>. Accessed May 16, 2023.
- 73. Carter D, Vazquez M, Flieder DB, et al. Comparison of pathologic findings of baseline and annual repeat cancers diagnosed on CT screening. Lung Cancer 2007;56:193-9.
- 74. Henschke CI, Yankelevitz DF, Naidich DP, et al. CT screening for lung cancer: suspiciousness of nodules according to size on baseline scans. Radiology 2004;231:164-8.
- 75. Henschke CI, Yip R, Yankelevitz DF, Miettinen OS. Computed tomography screening for lung cancer: prospects of surviving competing causes of death. Clinical lung cancer 2006;7:323-5.
- 76. Kim HY, Shim YM, Lee KS, Han J, Yi CA, Kim YK. Persistent pulmonary nodular ground-glass opacity at thinsection CT: histopathologic comparisons. Radiology 2007;245:267-75.
- 77. Li F, Sone S, Abe H, Macmahon H, Doi K. Malignant versus benign nodules at CT screening for lung cancer: comparison of thin-section CT findings. Radiology 2004;233:793-8.
- 78. Travis WD, Brambilla E, Noguchi M, et al. International association for the study of lung cancer/american thoracic society/european respiratory society international multidisciplinary classification of lung adenocarcinoma. Journal of thoracic oncology : official publication of the International Association for the Study of Lung Cancer 2011;6:244-85.
- 79. Funama Y, Awai K, Liu D, et al. Detection of nodules showing ground-glass opacity in the lungs at low-dose multidetector computed tomography: phantom and clinical study. Journal of computer assisted tomography 2009;33:49-53.
- 80. Ohno Y, Aoyagi K, Chen Q, et al. Comparison of computer-aided detection (CADe) capability for pulmonary nodules among standard-, reduced- and ultra-low-dose CTs with and without hybrid type iterative reconstruction technique. European journal of radiology 2018;100:49-57.
- 81. Yamada Y, Shiomi E, Hashimoto M, et al. Value of a Computer-aided Detection System Based on Chest Tomosynthesis Imaging for the Detection of Pulmonary Nodules. Radiology 2018;287:333-39.
- 82. Røe OD, Markaki M, Tsamardinos I, et al. 'Reduced' HUNT model outperforms NLST and NELSON study criteria in predicting lung cancer in the Danish screening trial. BMJ Open Respir Res 2019;6:e000512.
- 83. Winter A, Aberle DR, Hsu W. External validation and recalibration of the Brock model to predict probability of cancer in pulmonary nodules using NLST data. Thorax 2019;74:551-63.
- 84. White CS, Dharaiya E, Dalal S, Chen R, Haramati LB. Vancouver Risk Calculator Compared with ACR Lung-RADS in Predicting Malignancy: Analysis of the National Lung Screening Trial. Radiology 2019;291:205-11.
- 85. Li Y, Hu H, Wu Z, et al. Evaluation of models for predicting the probability of malignancy in patients with pulmonary nodules. Biosci Rep 2020;40.
- 86. Kessler A, Peng R, Mardakhaev E, Haramati LB, White CS. Performance of the Vancouver Risk Calculator Compared with Lung-RADS in an Urban, Diverse Clinical Lung Cancer Screening Cohort. Radiol Imaging Cancer 2020;2:e190021.
- 87. Stemmer A, Shadmi R, Bregman-Amitai O, et al. Using machine learning algorithms to review computed tomography scans and assess risk for cardiovascular disease: Retrospective analysis from the National Lung Screening Trial (NLST). PloS one 2020;15:e0236021.
- 88. Naidich DP, Bankier AA, MacMahon H, et al. Recommendations for the management of subsolid pulmonary

nodules detected at CT: a statement from the Fleischner Society. Radiology 2013;266:304-17.

- 89. Godoy MC, Naidich DP. Subsolid pulmonary nodules and the spectrum of peripheral adenocarcinomas of the lung: recommended interim guidelines for assessment and management. Radiology 2009;253:606-22.
- 90. MacMahon H, Austin JH, Gamsu G, et al. Guidelines for management of small pulmonary nodules detected on CT scans: a statement from the Fleischner Society. Radiology 2005;237:395-400.
- 91. National Comprehensive Cancer Network. NCCN Guidelines for Patients. Available at: https://www.nccn.org/guidelines/guidelines-detail?category=patients&id=18. Accessed January 13, 2023.
- 92. Chelala L, Hossain R, Kazerooni EA, Christensen JD, Dyer DS, White CS. Lung-RADS Version 1.1: Challenges and a Look Ahead, From the AJR Special Series on Radiology Reporting and Data Systems. AJR. American journal of roentgenology 2021;216:1411-22.
- 93. Jonas DE, Reuland DS, Reddy SM, et al. Screening for Lung Cancer With Low-Dose Computed Tomography: Updated Evidence Report and Systematic Review for the US Preventive Services Task Force. JAMA : the journal of the American Medical Association 2021;325:971-87.
- 94. Wood DE KE, et al,. NCCN Clinical Practices Guidelines in Oncology (NCCN Guidelines) for lung cancer screening *Version 1. 2021* [Available at: <u>https://www.nccn.org/</u>.
- 95. Force UPST. Screening for Lung Cancer: US Preventive Services Task Force Recommendation Statement. JAMA : the journal of the American Medical Association 2021;325:962-70.
- 96. Wood DE, Kazerooni EA, Aberle D, et al. NCCN Guidelines<sup>®</sup> Insights: Lung Cancer Screening, Version 1.2022. J Natl Compr Canc Netw 2022;20:754-64.
- 97. Tsai EB, Chiles C, Carter BW, et al. Incidental Findings on Lung Cancer Screening: Significance and Management. Semin Ultrasound CT MR 2018;39:273-81.
- 98. Tanoue LT, Sather P, Cortopassi I, et al. Standardizing the Reporting of Incidental, Non-Lung Cancer (Category S) Findings Identified on Lung Cancer Screening Low-Dose CT Imaging. Chest 2022;161:1697-706.
- 99. Cubillos L, Brenner AT, Birchard K, et al. Multidisciplinary quality improvement initiative to standardize reporting of lung cancer screening. Transl Lung Cancer Res 2018;7:S297-s301.
- 100. Carter BW, Lichtenberger JP, 3rd, Wu CC, Munden RF. Screening for Lung Cancer: Lexicon for Communicating With Health Care Providers. AJR. American journal of roentgenology 2018;210:473-79.
- 101. Fan L, Fan K. Lung cancer screening CT-based coronary artery calcification in predicting cardiovascular events: A systematic review and meta-analysis. Medicine (Baltimore) 2018;97:e10461-e61.
- 102. Lu MT, Onuma OK, Massaro JM, D'Agostino RB, Sr., O'Donnell CJ, Hoffmann U. Lung Cancer Screening Eligibility in the Community: Cardiovascular Risk Factors, Coronary Artery Calcification, and Cardiovascular Events. Circulation 2016;134:897-99.
- 103. Digumarthy SR, De Man R, Canellas R, Otrakji A, Wang G, Kalra MK. Multifactorial Analysis of Mortality in Screening Detected Lung Cancer. J Oncol 2018;2018:1296246-46.
- 104. American College of Radiology. ACR Practice Parameter for Communication of Diagnostic Imaging Findings. Available at: <u>https://www.acr.org/-/media/ACR/Files/Practice-Parameters/CommunicationDiag.pdf</u>. Accessed January 13, 2023.
- 105. Rennert L, Zhang L, Lumsden B, et al. Factors influencing lung cancer screening completion following participation in shared decision-making: A retrospective study in a U.S. academic health system. Cancer Treat Res Commun 2020;24:100198.
- 106. Lancaster HL, Heuvelmans MA, Oudkerk M. Low-dose computed tomography lung cancer screening: Clinical evidence and implementation research. J Intern Med 2022;292:68-80.
- 107. American College of Radiology. ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment. Available at: <u>https://www.acr.org/-</u> /media/ACR/Files/Technical-Standards/MonitorCTEquipment.pdf?la=en</u>. Accessed January 13, 2023.

\*Practice parameters and standards are published annually with an effective date of October 1 in the year in which amended, revised or approved by the ACR Council. For practice parameters and standards published before 1999, the effective date was January 1 following the year in which the practice parameter or standard was amended, revised, or approved by the ACR Council.

Development Chronology for this Practice Parameter

2014 (Resolution 4)

Revised 2029 (Resolution 47)

Revised 2024 (Resolution 27)