2019 (Resolution 4)*

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

PREAMBLE

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[1]. 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 in light of 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 the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document is advised to document in the patient record information sufficient to explain the approach taken.

The practice of medicine involves not only the science, but also 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 sole purpose of this document is to assist practitioners in achieving this objective.

[1] Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing, ___ N.W.2d ___ (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, Stanley v. McCarver, 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.

I. INTRODUCTION

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 thoracic 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.

Before participating in screening, individuals should consult with a health care provider about the risks and benefits of lung cancer screening. 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 ACR–SCBT-MR–SPR Practice Parameter for the Performance of Thoracic Computed Tomography (CT) [8].

II. INDICATIONS AND CONTRAINDICATIONS

Screening thoracic CT is appropriate for asymptomatic individuals at high risk for lung cancer [9]. An individual's risk for lung cancer is primarily determined by:

- Smoking history and age [10-16].

Additional risk factors include the following [17-42]:

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 smoking-related cancers
6. Family history of lung cancer
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 ACR–SCBT-MR–SPR Practice Parameter for the Performance of Thoracic Computed Tomography (CT) [8] and the ACR Practice Parameter for the Performance of High-Resolution Computed Tomography (HRCT) of the Lungs in Adults [43].

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.

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 ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation [44].

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [45]

IV. SPECIFICATIONS OF THE EXAMINATION [46-49]

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 quit date.

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, with reconstruction intervals equal to or less than the slice thickness. The examination may be acquired and reconstructed at 1.0-mm slice thickness or smaller, and reconstruction intervals to allow for better characterization of small lung nodules [50]. Maximum intensity projection (MIP) reconstruction is a technique that may be useful to increase the sensitivity for lung nodule detection [51-55]. Multiplanar reconstruction (MPR) may be useful to further characterize nodules, particularly nodules located along the pleural surfaces (also known as perifissural nodules) [56-58].

Scans should be obtained in a suspended state of full inspiration whenever possible. 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)
5. Window and level settings
6. Reconstruction algorithms
7. Reformatted images (MPR, curvilinear, MaxIP, and MinIP)
8. Advanced 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 ($CTDI_{vol}$)of 3 mGy or less for a standard-sized patient. It should be reduced for smaller-sized patients and increased for larger-sized patients [46-48,59-67].

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 [68]. 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

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) [69-75]. 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 when serial examinations are reviewed. If previous imaging studies, particularly thoracic CT 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.

The use of computer-assisted nodule detection and volumetric assessment of nodule size and growth by computer workstation analysis can be valuable adjuncts to the evaluation.

For the management of screen-detected lung nodules, standard guidelines should be followed within a practice or screening program [76-79] 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.

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 [80].

Review of the entire examination for other potentially significant findings should be performed and reported in accordance with the ACR–SCBT-MR–SPR Practice Parameter for the Performance of Thoracic Computed Tomography (CT) [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) [81-83].

VI. DOCUMENTATION AND COMMUNICATION OF RESULTS

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [84].

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.

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.

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 to meet quality reporting requirements. Data from the quarterly reports of the facility can be used for improving the lung cancer screening program. https://www.acr.org/Practice-Management-Quality-Informatics/Registries/Lung-Cancer-Screening-Registry.

VII. EQUIPMENT SPECIFICATIONS

To achieve acceptable clinical CT scans of the thorax for lung cancer screening, a CT scanner should meet the current ACR–SCBT-MR–SPR Practice Parameter for the Performance of Thoracic Computed Tomography (CT) [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. 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 ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment [85].

IX. RADIATION SAFETY IN IMAGING

Radiologists, medical physicists, registered radiologist assistants, 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 and application

of dose limits) and the principles of proper management of radiation dose to patients (justification, optimization and the use of dose reference levels). http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1578_web-57265295.pdf.

Nationally developed guidelines, such as the ACR's Appropriateness Criteria®, should be used to help choose the most appropriate imaging procedures to prevent unwarranted radiation exposure.

Facilities should have and adhere to policies and procedures that require varying ionizing radiation examination protocols (plain radiography, fluoroscopy, interventional radiology, CT) to take into account patient body habitus (such as patient dimensions, weight, or body mass index) to optimize the relationship between minimal radiation dose and adequate image quality. Automated dose reduction technologies available on imaging equipment should be used whenever appropriate. If such technology is not available, appropriate manual techniques should be used.

Additional information regarding patient radiation safety in imaging is available at the Image Gently® for children (www.imagegently.org) and Image Wisely® for adults (www.imagewisely.org) websites. 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 measured and patient radiation dose estimated for representative examinations and types of patients by a Qualified Medical Physicist in accordance with the applicable ACR technical standards. Regular auditing of patient dose indices should be performed by comparing the facility's dose information with national benchmarks, such as the ACR Dose Index Registry, the 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. (ACR Resolution 17 adopted in 2006 – revised in 2009, 2013, Resolution 52).

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

X. QUALITY CONTROL AND IMPROVEMENT, SAFETY, INFECTION CONTROL, AND PATIENT EDUCATION

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.

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 (https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement).

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.

For specific issues regarding CT quality control, see the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [45].

Equipment performance monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment [85].

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 (https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards) 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.

Collaborative Committee
Members represent their societies in the initial and final revision of this practice parameter.

ACR
Reginald F. Munden MD, DMD, MBA, FACR, Chair
Subba R. Digumarthy, MD
Carolyn A. Haerr, MD
Terrance T. Healey, MD
Ann N. Leung, MD
Tammam Nehme, MD

STR
Paul Cronin, MB, BCh, BAO, FACR

Committee on Body Imaging (Thoracic)
(ACR Committee responsible for sponsoring the draft through the process)

Lynn Broderick, MD, FACR, Chair
William C. Black, MD
Daniel W. Brown, MD
Stuart L. Cohen, MD
Andetta R. Hunsaker, MD
Negar Knowles, MD
Elizabeth Lee, MD
Ann N. Leung, MD
Cristopher A. Meyer, MD, FACR
Reginald F. Munden, MD, DMD, MBA, FACR
Shawn D. Teague, MD, FACR
Charles S. White, MD, FACR

Committee on Practice Parameters – General, Small, Emergency and/or Rural Practices
(ACR Committee responsible for sponsoring the draft through the process)

Sayed Ali, MD, Chair
Marco A. Amendola, MD, FACR
Lynn Broderick, MD, FACR
Resmi A. Charalel, MD
Brian D. Gale, MD, MBA
Carolyn A. Haerr, MD
Charles E. Johnson, MD
Candice Johnstone, MD
Padmaja A. Jonnalagadda, MD
Steven E. Liston, MD, MBA, FACR
Tammam Nehme, MD
Samir S. Shah, MD
Jennifer L. Tomich, MD

Lincoln L. Berland, MD, FACR, Chair, Commission on Body Imaging
Robert S. Pyatt, Jr., MD, FACR, Chair, Commission on General, Small, Emergency and/or Rural Practice
Jacqueline Anne Bello, MD, FACR, Chair, Commission on Quality and Safety
Matthew S. Pollack, MD, FACR, Chair, Committee on Practice Parameters and Technical Standards
Mary S. Newell, MD, FACR, Vice Chair, Committee on Practice Parameters and Technical Standards

Comments Reconciliation Committee
Eric Rubin, MD, Chair
Catherine Everett, MD, MBA, FACR, Co-Chair
Sayed Ali, MD
Jacqueline A. Bello, MD, FACR
Lincoln L. Berland, MD, FACR
Lynn Broderick, MD, FACR
Terrance T. Healey, MD
Ann N. Leung, MD
Cristopher A. Meyer, MD, FACR
Reginald F. Munden MD, DMD, MBA, FACR
Mary S. Newell, MD, FACR
Tammam Nehme, MD

Comments Reconciliation Committee

Paul Cronin, MB, BCh, BAO, FACR
Subba R. Digumarthy, MD
Richard Duszak, Jr., MD, FACR
Carolyn A. Haerr, MD
Matthew S. Pollack, MD, FACR
Robert S. Pyatt, Jr, MD, FACR
Timothy L. Swan, MD, FACR
Shawn D Teague, MD, FACR

REFERENCES

1. Aberle DR, Adams AM, Berg CD, et al. Reduced lung-cancer mortality with low-dose computed tomographic screening. *N Engl J Med.* 2011;365(5):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(3):328-332.
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(5):388-392.
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(1):125-134.
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(10):2154-2162.
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. *Eur Respir J.* 2011;38(1):154-161.
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). *Br J Cancer.* 2010;102(1):27-34.
8. American College of Radiology. ACR–SCBT-MR–SPR Practice Parameters for the Performance of Thoracic Computed Tomography (CT). 2013; Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/CT-Thoracic.pdf. Accessed January 8, 2018.
9. American College of Physicians. Screening for lung cancer: U.S. Preventive Services Task Force Recommendation Statement. 2014; Available at: http://annals.org/article.aspx?articleid=1809422 Accessed October 1, 2018.
10. Garfinkel L. Time trends in lung cancer mortality among nonsmokers and a note on passive smoking. *J Natl Cancer Inst.* 1981;66(6):1061-1066.
11. Hackshaw AK, Law MR, Wald NJ. The accumulated evidence on lung cancer and environmental tobacco smoke. *BMJ.* 1997;315(7114):980-988.
12. Jemal A, Bray F, Center MM, Ferlay J, Ward E, Forman D. Global cancer statistics. *CA Cancer J Clin.* 2011;61(2):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(7257):323-329.
14. Thun MJ, Henley SJ, Burns D, Jemal A, Shanks TG, Calle EE. Lung cancer death rates in lifelong nonsmokers. *J Natl Cancer Inst.* 2006;98(10):691-699.
15. US Department of Health and Human Service. The health consequences of involuntary exposure to tobacco smoke: a report of the surgeon general. 2006; Available at: http://www.surgeongeneral.gov/library/reports/secondhandsmoke/fullreport.pdf. Accessed October 1, 2018.
16. US Department of Health and Human Service. The health consequences of smoking: a report of the surgeon general. 2014; Available at: https://www.surgeongeneral.gov/library/reports/50-years-of-progress/index.html. Accessed October 1, 2018.

17. Alavanja MC, Brownson RC, Boice JD, Jr., Hock E. Preexisting lung disease and lung cancer among nonsmoking women. *Am J Epidemiol.* 1992;136(6):623-632.
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. *Am J Surg.* 1987;154(4):434-438.
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(7485):223.
20. Driscoll T, Nelson DI, Steenland K, et al. The global burden of disease due to occupational carcinogens. *Am J Ind Med.* 2005;48(6):419-431.
21. El Ghissassi F, Baan R, Straif K, et al. A review of human carcinogens--part D: radiation. *Lancet Oncol.* 2009;10(8):751-752.
22. Fletcher O, Easton D, Anderson K, Gilham C, Jay M, Peto J. Lifetime risks of common cancers among retinoblastoma survivors. *J Natl Cancer Inst.* 2004;96(5):357-363.
23. Hubbard R, Venn A, Lewis S, Britton J. Lung cancer and cryptogenic fibrosing alveolitis. A population-based cohort study. *Am J Respir Crit Care Med.* 2000;161(1):5-8.
24. Hughes JM, Weill H. Asbestosis as a precursor of asbestos related lung cancer: results of a prospective mortality study. *Br J Ind Med.* 1991;48(4):229-233.
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(6):1343-1353.
26. Jonsson S, Thorsteinsdottir U, Gudbjartsson DF, et al. Familial risk of lung carcinoma in the Icelandic population. *JAMA.* 2004;292(24):2977-2983.
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(10):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. *Radiat Res.* 2011;176(3):375-387.
29. Li X, Hemminki K. Familial multiple primary lung cancers: a population-based analysis from Sweden. *Lung Cancer.* 2005;47(3):301-307.
30. Lubin JH, Boice JD, Jr. Lung cancer risk from residential radon: meta-analysis of eight epidemiologic studies. *J Natl Cancer Inst.* 1997;89(1):49-57.
31. Matakidou A, Eisen T, Houlston RS. Systematic review of the relationship between family history and lung cancer risk. *Br J Cancer.* 2005;93(7):825-833.
32. Mayne ST, Buenconsejo J, Janerich DT. Previous lung disease and risk of lung cancer among men and women nonsmokers. *Am J Epidemiol.* 1999;149(1):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. *Occup Environ Med.* 2006;63(8):509-512.
34. Samet JM, Humble CG, Pathak DR. Personal and family history of respiratory disease and lung cancer risk. *Am Rev Respir Dis.* 1986;134(3):466-470.
35. Skillrud DM, Offord KP, Miller RD. Higher risk of lung cancer in chronic obstructive pulmonary disease. A prospective, matched, controlled study. *Ann Intern Med.* 1986;105(4):503-507.
36. Steenland K, Loomis D, Shy C, Simonsen N. Review of occupational lung carcinogens. *Am J Ind Med.* 1996;29(5):474-490.
37. Travis LB, Gospodarowicz M, Curtis RE, et al. Lung cancer following chemotherapy and radiotherapy for Hodgkin's disease. *J Natl Cancer Inst.* 2002;94(3):182-192.
38. Tucker MA, Murray N, Shaw EG, et al. Second primary cancers related to smoking and treatment of small-cell lung cancer. Lung Cancer Working Cadre. *J Natl Cancer Inst.* 1997;89(23):1782-1788.
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. *Am J Respir Crit Care Med.* 2007;176(3):285-290.

40. Turner-Warwick M, Lebowitz M, Burrows B, Johnson A. Cryptogenic fibrosing alveolitis and lung cancer. *Thorax.* 1980;35(7):496-499.
41. Wu-Williams AH, Dai XD, Blot W, et al. Lung cancer among women in north-east China. *Br J Cancer.* 1990;62(6):982-987.
42. Yang P, Sun Z, Krowka MJ, et al. Alpha1-antitrypsin deficiency carriers, tobacco smoke, chronic obstructive pulmonary disease, and lung cancer risk. *Arch Intern Med.* 2008;168(10):1097-1103.
43. American College of Radiology. ACR–STR Practice Parameter for the Performance of High-Resolution Computed Tomography (HRCT) of the Lungs in Adults. 2015; Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/HRCT-Lungs.pdf. Accessed January 8, 2018
44. American College of Radiology. ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation. 2013; Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/Pregnant-Pts.pdf. Accessed January 8, 2018.
45. American College of Radiology. ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT). 2017; Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/CT-Perf-Interpret.pdf. Accessed January 8, 2018.
46. 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(1):34-40.
47. Menezes RJ, Roberts HC, Paul NS, et al. Lung cancer screening using low-dose computed tomography in at-risk individuals: the Toronto experience. *Lung Cancer.* 2010;67(2):177-183.
48. Pedersen JH, Ashraf H, Dirksen A, et al. The Danish randomized lung cancer CT screening trial--overall design and results of the prevalence round. *J Thorac Oncol.* 2009;4(5):608-614.
49. Aberle DR, Berg CD, Black WC, et al. The National Lung Screening Trial: overview and study design. *Radiology.* 2011;258(1):243-253.
50. 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. *Eur Radiol.* 2003;13(10):2378-2383.
51. 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. *Eur Radiol.* 2007;17(12):3148-3156.
52. 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 Am J Roentgenol.* 2009;192(5):1324-1329.
53. 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. *Invest Radiol.* 2009;44(2):105-113.
54. 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(2):561-569.
55. 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. *Eur Radiol.* 2006;16(2):325-332.
56. Ahn MI, Gleeson TG, Chan IH, et al. Perifissural nodules seen at CT screening for lung cancer. *Radiology.* 2010;254(3):949-956.
57. 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. *Clin Imaging.* 2007;31(6):385-389.

58. 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(1):264-272.
59. Bankier AA, Tack D. Dose reduction strategies for thoracic multidetector computed tomography: background, current issues, and recommendations. *J Thorac Imaging.* 2010;25(4):278-288.
60. Brenner DJ. Radiation risks potentially associated with low-dose CT screening of adult smokers for lung cancer. *Radiology.* 2004;231(2):440-445.
61. Henschke CI, McCauley DI, Yankelevitz DF, et al. Early Lung Cancer Action Project: overall design and findings from baseline screening. *Lancet.* 1999;354(9173):99-105.
62. Kubo T, Lin PJ, Stiller W, et al. Radiation dose reduction in chest CT: a review. *AJR Am J Roentgenol.* 2008;190(2):335-343.
63. 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 Am J Roentgenol.* 2006;187(2):421-429.
64. 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. *Eur Radiol.* 2011;21(3):636-643.
65. 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. *Eur Radiol.* 2011;21(3):627-635.
66. Cody DD, Kim HJ, Cagnon CH, et al. Normalized CT dose index of the CT scanners used in the National Lung Screening Trial. *AJR Am J Roentgenol.* 2010;194(6):1539-1546.
67. 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 Am J Roentgenol.* 2011;197(5):1165-1169.
68. 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. *Acad Radiol.* 2006;13(11):1431-1441.
69. 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(2):193-199.
70. 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(1):164-168.
71. Henschke CI, Yip R, Yankelevitz DF, Miettinen OS. Computed tomography screening for lung cancer: prospects of surviving competing causes of death. *Clin Lung Cancer.* 2006;7(5):323-325.
72. Kim HY, Shim YM, Lee KS, Han J, Yi CA, Kim YK. Persistent pulmonary nodular ground-glass opacity at thin-section CT: histopathologic comparisons. *Radiology.* 2007;245(1):267-275.
73. 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(3):793-798.
74. 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. *J Thorac Oncol.* 2011;6(2):244-285.
75. 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. *J Comput Assist Tomogr.* 2009;33(1):49-53.
76. 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(1):304-317.
77. 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(3):606-622.

78. 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(2):395-400.
79. National Comprehensive Cancer Network. NCCN Guidelines for Patients. 2017; Available at: http://www.nccn.org/patients/guidelines/lung_screening/index.html. Accessed October 1, 2018.
80. Tsai EB, Chiles C, Carter BW, et al. Incidental Findings on Lung Cancer Screening: Significance and Management. *Semin Ultrasound CT MR.* 2018;39(3):273-281.
81. Fan L, Fan K. Lung cancer screening CT-based coronary artery calcification in predicting cardiovascular events: A systematic review and meta-analysis. *Medicine.* 2018;97(20):e10461-e10461.
82. 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(12):897-899.
83. Digumarthy SR, De Man R, Canellas R, Otrakji A, Wang G, Kalra MK. Multifactorial Analysis of Mortality in Screening Detected Lung Cancer. *Journal of oncology.* 2018;2018:1296246-1296246.
84. American College of Radiology. ACR Practice Parameter for Communication of Diagnostic Imaging Findings. 2014; Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/CommunicationDiag.pdf. Accessed January 8, 2018.
85. American College of Radiology. ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment. 2017; Available at: https://www.acr.org/-/media/ACR/Files/Technical-Standards/MonitorCTEquipment.pdf?la=en. Accessed January 8, 2018.

---

*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 (Resolution 4)