JBR–BTR, 2013, 96: 160-162.

DOSIMETRY: WHICH DOSE FOR SCREENING, DIAGNOSIS AND FOLLOW-UP?*

D. Tack[1], H. Salame[1]

The question of which dose for screening, diagnosing ad follow-up of pulmonary nodules is a permanent issue for radiologists and radiotherapists. The proposed dose values for 2013 reflect the possibilities of the latest CT generations, from 2010 or later and include all technical novelties such as iterative reconstructions, automatic tube potential selection, and latest detectors. As the technology is constantly evolving, these parameters are susceptible to lower every year.

Key-words: Lung neoplasms, therapeutic radiology – Lung neoplasms, diagnosis – Dosimetry.

Approximately 570.000 Americans will die from cancer in 2013, corresponding to more than 1500 deaths per day (1). Lung carcinoma is the first cause of death in both genders, surpassing prostate and colorectal cancer in men, and breast and colorectal cancer in women. There is a strong relationship between tumour size at time of diagnosis and the survival rate. The discussion of whether and how to screen for lung cancer is decades old and chest radiographs associated to sputum failed to prove providing a reduction in lung cancer specific mortality (2). The introduction of spiral CT made it technically possible to obtain volumetric data with a lower radiation dose than normally used for diagnostic purposes. In the July issue of the 2011 NEJM, the results of the multicenter North-American National Lung cancer Screening Trial (NLST) were published. This trial had been designed to have a more than 90% power to find a 20% decrease of mortality rate (3, 4). Before being answered, the question proposed as title of this overview requires to address two aspects of the radiation dose, the risk of CT scanning and the way to express the dose used for imaging.

Risks of CT scanning

Apart from the risks associated with the workup or treatment of false-positive or of indeterminate findings at CT screening, the risk from radiation-induced cancer has been discussed controversially in the literature. Brenner, in particular, has calculated risk estimates for various screening applications of CT, such as lung cancer, colon cancer and full-body CT screening (5-7). For lung cancer, for example, the life-time risk of a cancer that is induced by the CT screening exam has been calculated to amount up to 0.85% under unfavorable conditions with an upper 95% confidence interval of as much as 5.5% (5). These numbers have to be weighed against the incidence of screening detected cancers and – more importantly – the actual decrease of cancer-related mortality due to screening.

This estimation of the risks related to CT screening and CT diagnosis is controversial because it is based on a linear no threshold dose-response relationship that is a matter of huge debate since years (8). However for the first time ever, one recent article based on epidemiological data demonstrated a direct increase in incidence of cancer after CT scanning (9). This research was conducted on children and young adults undergoing CT examinations of the brain and showed that within a delay of 10 year, a 3.18 fold brain cancer and leukemia risk could be observed after one CT examination obtained at a dose higher than 30 mGy. This risk (about 1/10000) has been considered as not far from the one estimated by the National Council on Radiation Protection (10, 11). Even if not negligible, it is from far much lower than the benefit from CT scanning for diagnosis and for screening, provided that these examinations are indicated. These recent data reinforce the ALARA principle to be applied on any CT technique and in particular for screening, diagnosing and for follow-up of nodules in smokers.

The response to the addressed question to define which dose should be deliver for screening, diagnosis and follow-up could thus be very simple: a "low-dose" should be applied in screening and follow-up and "standard dose" for diagnosis. However, these terms deserve further discussion.

Nomenclature for describing the dose from CT scanning

In the literature and in the daily practice, the term low-dose CT is often used but rarely well defined. No quantitative definition exists to indicate how low the dose in low-dose CT must be. A given CT examination can, thus, be "low dose" only as compared with an examination with a higher dose, commonly referred to as standard-dose CT. Likewise, however, no precise definition of the term standard dose exists. Any definition of low dose is, therefore, substantially limited by its relativistic foundation (12). In addition, the term low dose suffers from several other important drawbacks. First, the term low dose is subject to considerable variation over time because the technique is rapidly evolving and the general awareness of dose is increasing. Thanks to these positive trends in managing the dose, CT examination protocols that were considered low dose in 2000 are now used as default standard ones. Therefore, at any given point in time, the term low dose is accurate only in the short run (12). In screening, the first studies published on low-dose CT delivered around 1.5 mSv per individual screening examination (13, 14). In 2011, an up to date CT "standard" helical CT protocol delivered 77.7 mGy.cm (around 1.2 mSv) in a western population (15). In comparison, the NLST CT protocols used from 2002 to 2005 were quite heterogeneous and delivered 1.5 to 3.5 mSv in the US (3). Up to date CT technique used for follow-up of CT scanning can be done at an effective dose lower than 1 mSv (16).

A second drawback of using the term low-dose is that its meaning is

*Meeting "Lung Cancer Imaging in 2012: Updates and innovations", Tervuren, 10.11.2012.

1. Epicura Hospital, Clinique Louis Caty, Baudour, Belgium.

Table I. — Dose values proposed in 2013.

	CTDIvol in mGy	DLP in mGy.cm	Effective Diameter in cm	SSDE in mGy
Screening	0.5	20	29	0.6
Diagnosis	2.6	90	29	3.2
Follow-up	< 1	< 35	29	< 1,2

CTDIvol, DLP, effective diameters and SSDE proposed for screening, diagnosis and follow-up of pulmonary nodules.

subject to considerable variation geographically and individually due to variable awareness and to variable average body size around the world. The first screening on lung cancer was conducted on a Japanese population (12) and delivered the same tube output as that conducted by Henschke et al. in a US population with an average weight of 25 to 30% higher that the Japanese one. Thus, both the image quality and the individual risk were not the same in these two publications. Inter-individual variations also reflect the technological possibilities of CT scanners in these years, that where not equipped with automatic exposure control (AEC) devices. Without AEC, there are considerable image quality differences between individuals who are small and or large. On the other hand, using the same tube output in individuals of various body sizes, the risk of each individual is also very different, being higher in small ones and lower in larger ones.

Another drawback of using the term low-dose more extensively in the literature is that this term has lost its implicit significance. Thus, new terms appear such as "extremely low dose" and "ultralow dose" CT, and why not emerging newer terms such as "super-extra-nano-low-dose" (12)?

Radiology Editors have thus elaborated a statement for describing the CT dose as follows. First, avoidance of the terms low-dose, and standard-dose. Second, avoidance of the use of effective dose. The concept of effective dose is not suited for individual risk calculations and the conversion factors elaborated by the International Commission on Radiological Protection (ICRP) are periodically reassessed and have been changing three times since their introduction (17-23). In particular for chest examinations, the weighting risk factor of the breast has been changes from 5% to 12% between 1990 and 2007. Third, to use of the CT dose descriptors available on the CT console and the CT dose reports: the volume computed tomography dose index (CTDIvol), and the dose-length product (DLP). These two descriptors describe the tube output respectively in a slice and in the entire scanned region. Fourth, use the effective diameter for description of the patient population. The American Association of Physicists in Medicine Task Group 204 report (24) defines the effective diameter as the square root of the antero-posterior diameter times the transverse diameter. These diameters can be measured on the scout views and or on axial slices. Fifth, to introduce the size-specific dose estimate (SSDE), a new dose descriptor proposed by the AAPM 204 report, aiming to describe the absorbed dose while taking into account the patient's individual size as follows: SSDE = f(size) × CTDIvol.

To warrant a comprehensive description of their results, authors submitting to scientific Journals are thus proposed to report the above mentioned four parameters: CTDIvol, DLP, effective diameter, and SSDE. CTDIvol and DLP will provide information about scanner radiation output. The effective diameter will provide information about the dimensional characteristics of the study population. SSDE will provide an approximation of the dose absorbed by the individual patient.

Which dose for screening, diagnosis and follow-up?

Now that the justification of minimizing dose, and the parameters to describe the dose have been clarified, it appears easier to answer the addressed question on which dose for screening, diagnosing ad follow-up of pulmonary nodules. The actual 2013 dose values proposed are listed in Table I (25). They reflect the possibilities of the latest CT generations, from 2010 or later and include all technical novelties such as iterative reconstructions, automatic tube potential selection, and latest detectors. As the technology is constantly evolving, these parameters are susceptible to lower every year.

References

1. http://www.cancer.gov/statistics
2. Detterbeck F.C., Boffa D.J., Tanoue L.T.: The new lung cancer staging system. *Chest*, 2009, 136: 260-271.
3. National Lung Screening Trial Research Team. The national lung screening trial: overview and study design. *Radiology*, 2011, 258: 243-253.
4. Reduced lung-cancer mortality with low-dose computed tomographic screening. The National Lung Screening Trial research team. *NEJM*, 2011, 365: 395-409.
5. Brenner D.J.: Radiation risks potentially associated with low-dose ct screening of adult smokers for lung cancer. *Radiology*, 2004, 231: 440-444.
6. Brenner D.J., Georgsson M.A.: Mass screening with CT colonography: should the radiation exposure be of concern? *Gastroenterology*, 2005, 129: 328-337.
7. Brenner D.J., Elliston C.D.: Estimated radiation risks potentially associated with full-body CT screening. *Radiology*, 2004, 232: 735-738.
8. Pearce M.S., Salotti J.A., Little M.P., McHugh K., Lee C., Kim K.P., Howe N.L., Ronckers C.M., Rajaraman P., Sir Craft A.W., Parker L., Berrington de González A.: Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. *Lancet*, 2012, 380 (9840): 499-505.
9. Hendee W.R., O'Connor M.K.: Radiation risks of medical imaging: separating fact from fantasy. *Radiology*, 2012, 264: 312-321.
10. *National Council on Radiation Protection and Measurements. Ionizing radiation exposure of the population of the United States. NCRP Report No. 160. Bethesda, Md: National Council on Radiation Protection and Measurements, 2009.*
11. Brenner D.J., Hall E.J.: Cancer Risks from CT Scans: Now We Have Data, What Next? *Radiology*, 2012, 265: 330-331.
12. Bankier A.A., Kressel H.Y.: Through the Looking Glass Revisited: The

Need for More Meaning and Less Drama in the Reporting of Dose and Dose Reduction in CT. *Radiology*, 2012, 265: 4-8.
13. Sone S., Takashima S., Li F., Yang Z., Honda T., Maruyama Y., Hasegawa M., Yamanda T., Kubo K., Hanamura K., Asakura K.: Mass screening for lung cancer with mobile spiral computed tomography scanner. *Lancet*, 1998, 351: 1242-1245.
14. Henschke C.I., McCauley D.I., Yankelevitz D.F., Naidich D.P., McGuinness G., Miettinen O.S., Libby D.M., Pasmantier M.W., Koizumi J., Altorki N.K., Smith J.P.: Early Lung Cancer Action Project: overall design and findings from baseline screening. *Lancet*, 1999, 354 (9173): 99-105.
15. Bendaoud S., Remy-Jardin M., Wallaert B., Deken V., Duhamel A., Faivre J.B., Remy J.: Sequential versus volumetric computed tomography in the follow-up of chronic bronchopulmonary diseases: comparison of diagnostic information and radiation dose in 63 adults. *J Thorac Imaging*, 2011, 26: 190-195.
16. Bankier A.A., Tack D.: Dose reduction strategies for thoracic multidetector computed tomography: background, current issues, and recommendations. *J Thorac Imaging*, 2010, 25: 278-288.
17. Mettler F.A. Jr., Huda W., Yoshizumi T.T., Mahesh M.: Effective doses in radiology and diagnostic nuclear medicine: a catalog. *Radiology*, 2008, 248 (1): 254-263.
18. Martin C.J.: Effective dose: how should it be applied to medical exposures? *Br J Radiol*, 2007, 80: 639-647.
19. McCollough C.H., Christner J.A., Kofler J.M.: How effective is effective dose as a predictor of radiation risk? *AJR*, 2010, 194: 890-896.
20. McCollough C.H., Schueler B.A.: Calculation of effective dose. *Med Phys*, 2000, 27: 828-837.
21. International Commission on Radiological Protection. Recommendations of the ICRP. ICRP Publication 26. *Ann ICRP*, 1977, 1 (3): 1990
22. Recommendations of the International Commission on Radiological Protection. *Ann ICRP*, 1991, 21: 1-201.
23. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. *Ann ICRP*, 2007, 37(2-4): 1-332.
24. American Association of Physicists in Medicine. Size-Specific dose estimates (SSDE) in pediatric and adult body CT examinations. Task Group 204. College Park, Md: American Association of Physicists in Medicine, 2011.
25. Gevenois P.A., Tack D.: Dose Reduction and Optimization in Computed Tomography of the Chest. In Radiation Dose from Multidetector CT. Springer 2012. ISBN: 978-3-642-24534-3 (Print) 978-3-642-24535-0.