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Original article

Pulmonary nodules: detection with low-dose vs conventional-dose spiral CT

M. Gartenschläger[1], F. Schweden[1], K. Gast[1], T. Westermeier[2], H.-U. Kauczor[1], H. von Zitzewitz[1], M. Thelen[1]

[1] Department of Diagnostic Radiology, J. Gutenberg University, University Hospital, Langenbeckstrasse 1, D-55131 Mainz, Germany
[2] Medical Statistics and Documentation, J. Gutenberg University, University Hospital, Langenbeckstrasse 1, D-55131 Mainz, Germany

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Abstract. The purpose of the study was the evaluation of low-dose spiral CT in the detection and assessment of contours of pulmonary nodules. In a prospective investigation 71 consecutive chest CT examinations were acquired both at 30 and 200 mA. Films were interpreted independently by two radiologists. According to the size, nodules were divided into four categories: ≤ 3, 4–5, 6–10, and > 10 mm; nodule shape was registered. With both protocols, 240 nodules were detected. The correlation coefficient for both methods was 0.89. Discrepancies were found most frequently in nodules near to pulmonary vessels. Nodule size estimation did not differ more than one size category. Eight spiculated nodules were identified by both techniques. Low-dose spiral CT of the chest has a high sensitivity in the detection of pulmonary nodules. If clinical circumstances require dose minimization, low-dose spiral CT may be advocated as an alternative screening method to conventional dose spiral CT.

Key words: Lung – Nodule – CT – Technology

Introduction

Computed tomography is the most sensitive imaging technique for the detection of pulmonary nodules. It is widely used as a screening method for lung metastases in patients with extrathoracic malignancy where detection of metastases would influence treatment, as well as for the detection of primary lung cancer. Spiral CT allows rapid acquisition of a large volume of data during the period of a single breathhold, which minimizes section misregistration and respiration artifact. It is now accepted that spiral CT is superior to conventional CT in the detection of pulmonary nodules [1, 2]. Modern spiral scanners have the ability to reduce the radiation dose in a wide range. With respect to radiation protection, the imperative to obtain radiological diagnoses with the lowest dose that is reasonably achievable ("ALARA" principle) constitutes a permanent challenge [3, 4]. In CT, dose reduction increases image noise; however, the increase in image noise may be accepted in clinical settings in which the inherent tissue contrast is high, such as thoracic CT [5]. For single-slice chest CT, several studies concerning the possibility of dose reduction have been published [11–13, 15]. Dose reduction by decreasing the tube current from 140–400 mAs to 20–140 mAs were advocated. The purpose of this prospective study was to compare spiral CT examinations of the chest obtained at standard tube current with those obtained at reduced tube current in the detection of pulmonary nodules in patients with known or suspected pulmonary nodules. The following questions were asked:

1. Is low-dose spiral chest CT equivalent or inferior compared with conventional-dose spiral chest CT in the detection of pulmonary nodules?
a) How closely does the number of nodules detected with low-dose spiral chest CT match the number seen with conventional-dose spiral chest CT?
b) Does dose reduction lead to failure in the detection of small pulmonary nodules?
c) If so, what kind of nodules are missed with low-dose spiral chest CT?
2. Are particular nodule shapes reproduced in the same way by low-dose and conventional-dose spiral chest CT?

Materials and methods

Patient population

Over a period of 8 months, 71 consecutive patients, referred to thoracic CT for suspected or known pulmonary nodules, entered the study. Patient referral was

Correspondence to: M. Gartenschläger

Table 1. Diagnoses at time of CT examination ($n = 69$)

Disease	No. of patients	%
Cancer of colon or rectum	11	16
Lung cancer	8	12
Cancer of esophagus	7	10
Cancer of oral cavity or pharynx	6	9
Malignant melanoma	5	7
Renal cell carcinoma	5	7
Malignant lymphoma	3	4
Myosarcoma	2	3
Other tumors	13	19
Suspected nodule in chest radiography	7	10
Benign diseases	2	3

from the departments of surgery, dermatology, and otolaryngology of our institution. Two patients underwent thoracic CT twice during different disease stages and entered the study both of the times, so that a total of 69 individuals were examined. Informed consent was obtained before inclusion of a patient into the study. Age ranged from 17–82 years (median age 60.7 ± 11.5 years). Underlying diseases are listed in Table 1.

Examination technique

Patients underwent non-enhanced spiral CT of the chest acquired with a reduced tube current of 30 mA, immediately followed by contrast-enhanced spiral CT with a standard tube current of 200 mA. All scans were obtained during suspended full inspiration with the patient in the supine position. The remaining scan parameters were kept constant for both spiral scans: Tube current was 120 kV, spiral pitch 1.5, section thickness 8 mm, reconstruction interval 8 mm, scan time 1 s/rotation. The standard examination protocol followed the recommendations of the scanner manufacturer, except for the section thickness which was recommended to be 10 mm. The field that was covered by any spiral as well as the field of view was defined on the scout view of the individual patient. All spiral scans were calculated both with a "sharp" algorithm and spiral interpolator at a window width and window center setting of 1500/–500 HU and with a "standard" algorithm and spiral interpolator at a window/center setting of 300/60 HU. One hundred milliliters of non-ionic contrast agent with a concentration of 300 mg Iodine/mL (Iomeprol, Bracco Byk Gulden, Konstanz, Germany) were administered with a CT 9000 power injector (Liebel-Flarsheim, Cincinnati, Ohio) into a cubital vein at a rate of 2 mL/s and 40-s delay before the start of the conventional-dose spiral scan. For technical reasons, in two patients scans were obtained not consecutively, but with an interval of 1 day between both spirals. All studies were performed on a PQ 5000 scanner (Picker International, Highland Hights, Ohio). In selected cases a second set of images with a reconstruction interval of 4 mm was obtained. These small reconstruction interval images were not included in the initial image interpretation.

Image interpretation

In accordance with Remy-Jardin et al., any focal, rounded, or ovoid lesion that was identified within the lung parenchyma on CT sections viewed at lung window settings was considered as pulmonary nodule [1]. This led to the inclusion of some areas of nodular pleural thickening which were not distinguishable from parenchymal nodules. Two blinded observers (M. G., F. S.) read all standard-dose and reduced-dose scans independently and in a random order. Low-dose and conventional-dose films were not interpreted consecutively. Presence, number, size, and shape of nodules were assessed. In cases of discrepancies between the observers, final interpretation was obtained by consensus in a second session. To establish the size of the detected foci, nodules were assigned to one of four size groups: (a) up to 3 mm; (b) 4–5 mm; (c) 6–10 mm; and (d) more than 10 mm in diameter on a simple viewing base. For comparison purposes, pulmonary nodules were recorded in their segmental location in the right and in the left lung, and each nodule was assigned an identification number.

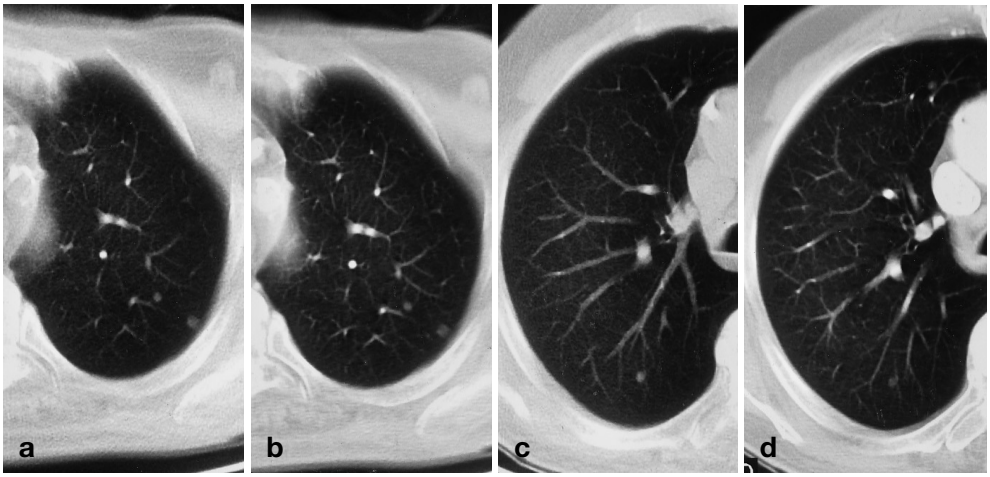

Fig. 1. **a** A 63-year-old male patient with cancer of the oropharynx. Low-dose spiral chest CT demonstrates two pulmonary nodules 4–5 mm in size. **b** Image obtained with conventional dose at the same location as **a**. **c** A 60-year-old male patient with cancer of the colon. Low dose spiral chest CT demonstrates two pulmonary nodules 4–5 mm in size. **d** Image obtained with conventional dose at the same location as **c**

Data analysis

For the quantification of agreement between conventional-dose spiral chest CT and low-dose spiral chest CT, Spearman correlation coefficient and the mean value of differences in number of nodules per patient were calculated. A logarithmic plot of the number of nodules detected with conventional-dose spiral chest CT against the number detected with low-dose spiral chest CT was constructed. Sensitivity and positive predictive value of low-dose spiral chest CT as compared with conventional-dose spiral chest CT were calculated. Specificity was estimated on the basis of a separate evaluation of each patient's right and left lung. A true-negative finding was defined as lack of nodule in a right or a left lung, respectively, in both conventional- and low-dose spiral chest CT. A nodule-by-nodule analysis was carried out by both observers in consensus. As part of the nodule-by-nodule analysis for any lesion positive in low-dose and negative in conventional-dose spiral CT images, additional images from the conventional-dose examination reconstructed at 4-mm intervals were sought and searched for the depiction of the discrepant nodule.

If the nodule-by-nodule analysis revealed, that milliamperage could not be held responsible for the discrepancy, a correction was made for that nodule, and a second calculation of correlation coefficient, sensitivity, positive predictive value, and specificity was carried out. The following discrepancies were considered unrelated to dose: nodules located in the costophrenic angles and masked in one of the examinations by poorer level of inspiration, nodules overlooked in one examination for the presence of motion artifacts, proven partial volume effects, and lesions presenting identically in the nodule-by-nodule analysis and thus indicating vigilance impairment during film reading.

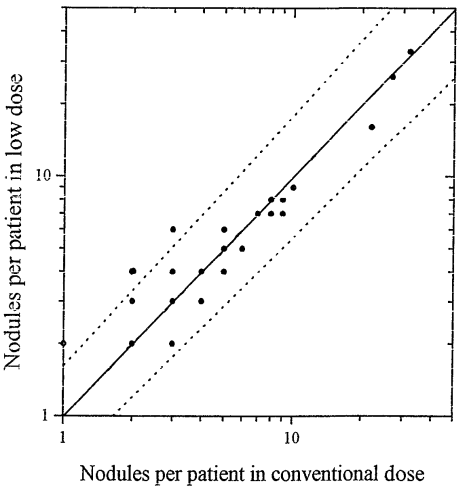

Fig. 2. Logarithmic plot showing the relationship between numbers of pulmonary nodules detected with conventional-dose spiral chest CT and low-dose spiral chest CT. *Solid line* complete agreement; dotted line 50% difference in numbers of nodules between the two techniques

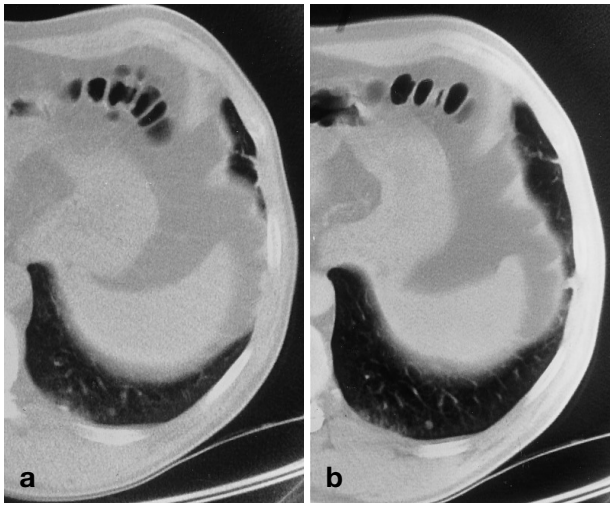

Fig. 3a, b. A 65-year-old male patient with metastases from a primary tumor of unknown origin. **a** At low-dose spiral CT a pulmonary nodule in the left posterior basal segment was missed. Note the increased image blurring compared to **b**. **b** Nodule 4–5 mm in size in conventional-dose spiral CT

Results

Both techniques detected 240 pulmonary nodules. Examples of small pulmonary nodules visualized similarly with both methods are shown in Fig. 1. The mean number of nodules/patient was 3.4 ± 5.3 for conventional-dose and 3.4 ± 5.6 for low-dose spiral CT, ranging from 0–33 in conventional and from 0–32 in low-dose spiral CT. The Spearman correlation coefficient for the number of nodules per patient found with the two techniques was 0.89 ($p > 000.1$). The sensitivity of low-dose related to conventional-dose spiral CT was 85% (confidence interval 81–90%), and the positive predictive value was 85% (81–90%). The specificity of low-dose compared with conventional-dose spiral CT was estimated 93% (86–100%). The number of nodules detected with conventional-dose spiral chest CT is plotted against the number detected with low-dose spiral chest CT in Fig. 2. The mean value of differences in number of nodules per patient was 0.01. In 17 instances, low dose detected more nodules than did conventional-dose spiral CT, and in 17 instances conventional-dose detected more nodules than did low-dose spiral CT. Examples for missed nodules are given in Figs. 3 and 4. A description of the characteristics of discrepant nodules is given in Table 2. In 10 cases of nodules missing in conventional-dose spiral CT , a second reconstruction of conventional-dose spiral examination data obtained with a reconstruction interval of 4 mm was available. During nodule-by-nodule analysis, in 5 of those patients the conventional-dose images reconstructed at 4-mm intervals clearly showed six of the discrepant nodules and thus proved partial volume effect to be responsible for misregistration. After correction for dose-unrelated discrepancies, Spearman correlation coefficient was 0.94 ($p > 000.1$), sensitivity 89% (confidence interval

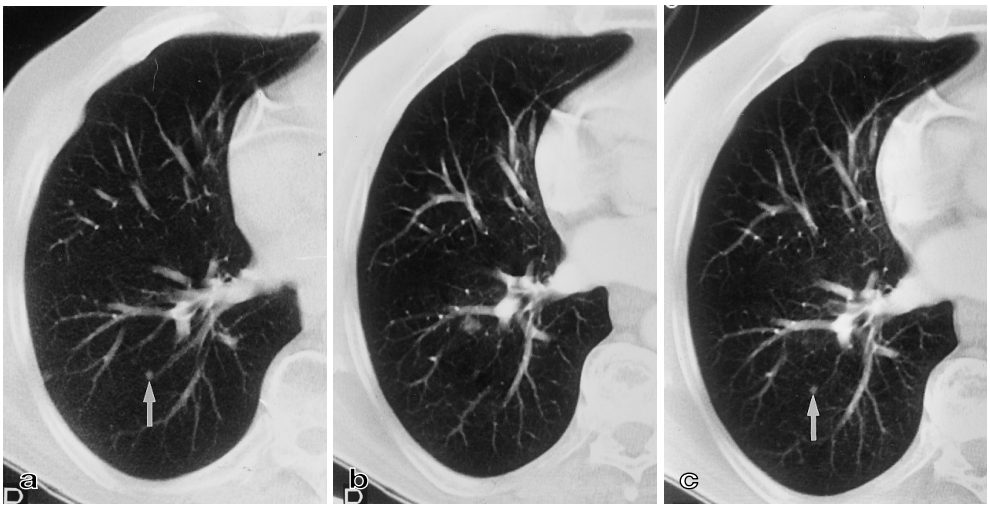

Fig. 4. **a** A 69-year-old male patient with cancer of the colon. Image obtained with low-dose spiral CT shows a small nodule *(arrow)*. **b** At conventional dose, the nodule is missed. **c** The same examination as in **b** reconstructed at 4 mm intervals shows the nodule *(arrow)*. Another pulmonary nodule 6–10 mm in size is seen in **b** dorsally to the vessels of the lateral lower lobe segment. This lesion was detected by low-dose technique with the same size estimation on an adjacent image (not shown)

Table 2. Characteristics of discrepant nodules ($n = 35$)

Nodule characteristics	Low dose negative	Low dose positive
Adjacent to vessel	15	6
Same characteristics[a]	3	8
Differential diagnosis scar	5	4
Alternative scan poor visibility	3	11[b]
Adjacent to infiltrate	3	3
Partial volume[a]	0	6
Adjacent to edema	2	2
Location in costophrenic angle[a]	2	1
Motion artifact[a]	2	0

[a] Dose-unrelated discrepancy
[b] Six of these lesions were clearly visualized in images reconstructed at 4-mm reconstruction interval from the conventional-dose spiral examination and are therefore dose-unrelated discrepancies

Table 3. Distribution of nodule size according to CT-technique

CT dose	Nodule diameter (mm)			
	≤ 3	4–5	6–10	> 10
Conventional	86	81	43	30
Low	83	80	48	29

84–93 %), positive predictive value 92 % (89–95 %), and specificity 100 %.

Differences in size estimation never exceeded one size category. The assignment of nodules to one of the four size categories is reported in Table 3. Morphological details, namely spiculated shape, were recognized in 8 pulmonary nodules by both of the CT techniques (see Fig. 5). Calcifications within a pulmonary nodule were seen in six cases in low-dose spiral chest CT. Five of these lesions appeared to be calcified in the conventional-dose spiral chest CT. The sixth lesion was only retrospectively found in the conventional-dose image set obtained with 4-mm reconstruction interval and its appearance was compatible with calcification, too (density > 350 HU at retrospective measurement).

Discussion

As in previous studies evaluating different CT techniques in their capability to detect pulmonary nodules [1, 2], nodule size in our series tended to be ≤ 5 mm in diameter. This is of importance since a smaller pulmonary lesion is more likely to be missed with a modified CT technique, thus providing an opportunity to demonstrate quality differences between the alternative CT techniques.

In clinical routine, at our institution contrast-enhanced chest CT is preceded by non-enhanced scanning whenever possible. In order to avoid either increased radiation and application of an increased contrast dose to patients included in the presented study, we performed low-dose scanning without and conventional-dose scanning with intravenous contrast. It may be criticized that not only the CT tube current, but also the application of intravenous contrast material, varied between the two examinations. We feel, however, that the high intrinsic contrast between normal lung and pulmonary nodules exceeds by far that of a possible nodule enhancement after intravenous contrast administration, which therefore should not influence the nodule detectibility. Moreover, as the contrast agent was given with conventional-dose and not with low-dose spiral CT, a bias in favor of the low-dose protocol may be excluded. A direct comparison of nodule calcification, however, is impossible: Calcified lesions can be excluded by conventional-dose CT, but a confirmation of the calcification is not possible.

With a reconstruction interval of 8 mm, as chosen in this study, small pulmonary nodules may be missed: A recent study compared reconstructions at 8- or 10-mm intervals with reconstructions at 4- or 5-mm intervals for the detection of pulmonary nodules [7]. The smaller reconstruction interval yielded 4.75 % more true-positive nodules as compared with the wider reconstruction interval. In our series, we found that six nodules missed in conventional-dose CT because of partial volume effect were visible on images obtained at a reconstruction interval of 4 mm. The impact of small overlapping re-

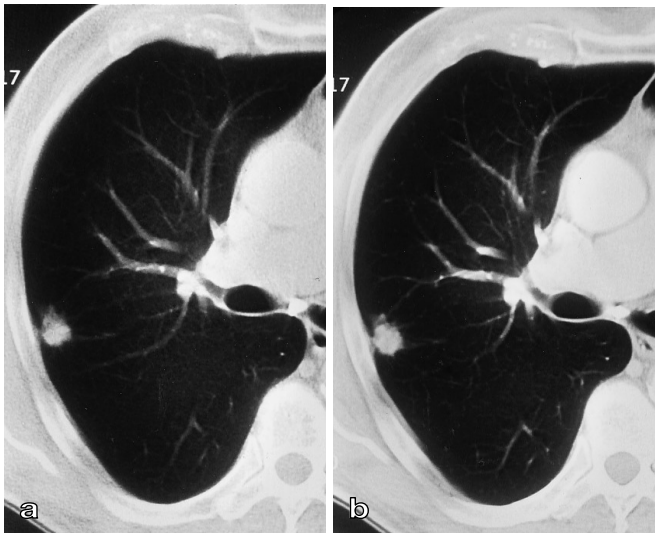

Fig. 5 a, b. A 67-year-old male patient. Spiculated pulmonary nodule, bronchial carcinoma, histologically verified. **a** Low-dose spiral CT; **b** conventional-dose spiral CT

construction on nodule detectability was not the purpose of this paper. However, this incidental observation illustrates that a reconstruction interval of 8 mm may lead to decreased nodule detection which is independent of the chosen radiation dose, and that a smaller reconstruction interval may constitute a valuable alternative [8].

The deviation of numbers of pulmonary nodules in Fig. 2 is symmetrical, indicating that there is no tendency toward under- or overcounting in low-dose spiral chest CT. This is also expressed by the low mean value of differences. In a comparison of the number of pulmonary nodules detected by spiral CT at different pitch values, very close correlations ranging from 0.977 to 0.989 were found [6]. The correlation between our conventional- and low-dose spiral protocol, after correction for dose-unrelated discrepancies, shows a slightly inferior correlation indicating that the impact of dose reduction might be slightly superior to that of increased pitch with respect to nodule detection. One reason for failed nodule detection in low-dose spiral chest CT is likely the poor visibility caused by increased image noise. An example is shown in Fig. 3. Image noise in spiral CT may also be increased due to elevated pitch, which results in decreased local radiation dose. Elevated pitch was recently found to be a reason for failure to detect small pulmonary nodules [6]. Some authors advocate the replacement of plain chest X-ray with spiral CT for lung-cancer screening [9, 10, 11]. The reduction of radiation dose of chest CT would be an important precondition to its introduction into screening protocols. For conventional single-slice chest CT with 10-mm collimation, various recommendations concerning the minimal tube current required to provide good image quality have been given: Based on image-quality criteria, which included not only pulmonary parenchymal disease but also mediastinal adenopathy and pleural pathology, 140 mA were found to be the minimal tube current to provide good image quality [12]. A comparative study of conventional single-slice CT with a milliamperage of 140 vs 10 mA assessing only pulmonary parenchymal disease concluded that in no case was a structure identified on conventional-dose scans missed on scans with reduced milliamperage [11]. Another study compared 10-mm CT sections acquired with a milliamperage of 140 and of 20 mA and found an accuracy between 74.8 and 73.3 %. The authors saw no detrimental impact on lung-nodule detection at the lower milliamperage [13]. Ohomatsu et al. tested spiral chest CT with a tube current of 50 mA against conventional CT obtained with 10-mm-thick sections at 10-mm intervals and found that the results of low-dose spiral chest CT are good enough to recommend it as a chest screening tool [10].

Dose reduction in chest CT is of particular interest for pediatric patients. In a feasibility study, high resolution (HR) low-dose single-slice chest CT was evaluated in children with a mean age of 5.5 years [14]. Scans were obtained at 20, 40, 80, 140, and 200 mA. No loss in image quality was observed at 80 mA as compared with 140- and 200-mA scans, whereas the 40-mA scans were reported as being relatively noisy and the 20-mA scans as being too noisy for reliable interpretation. In another study with adult patients with lung diseases, 20-mA HR CT led to equivalent findings except for the detection of subtle ground-glass densities, mild peripheral bronchiectasis, and mild emphysema [15]. Considering the pitch factor 1.5 proposed in the present study, the milliamperage in the low-dose spiral chest CT protocol is 20 mAs per 8-mm section.

In a recent study by Seltzer et al. [8], which primarily compared film based and cine-based CT viewing, the sensitivity in diagnosing small pulmonary nodules was determined. Nodules were superimposed electronically on conventional-dose spiral chest CT scans of healthy persons. Sensitivity of film based diagnosis was 72.5 %. The sensitivity of low-dose compared with conventional-dose spiral chest CT as determined in the present study is not inferior to the above-quoted sensitivity.

The presented data suggest low-dose scanning to be equivalent in the detection of pulmonary nodules. For a complete evaluation of the capabilities of low-dose chest CT, indications apart from pulmonary nodules, however, need investigation.

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Book review

European Radiology

Gillespie, J.E., Gholkar, A.: Magnetic Resonance Imaging and Computed Tomography of the Head and Neck. London: Chapman & Hall Medical, 1994, 233 pp., 8 line illustrations, 442 halftone illustrations, (ISBN 0-412-45200-6), £ 75.00.

This book on head and neck imaging was written for radiologists in training and general radiologists undertaking occasional CT or MRI studies in this area. The aim of the authors was to fill the gap between exhaustive reference works and standard radiology textbooks that give only limited coverage of this field. Succesful imaging of this area depends on meticulous technique, a good knowledge of the normal radiological anatomy and spectrum of variants, and an understanding of the disease processes occurring in this region; it represented a major challenge to provide sufficient information on successful CT and MRI of the head and neck in the limited space available in this book.

In the opening chapter on imaging principles, MRI is said to have replaced CT as the investigation of choice in many head and neck lesions. The book does not provide many examples to corroborate this statement. The indications where MRI is indeed the method of choice are rather superficially discussed, such as imaging of the temporomandibular joint (rather lost in the chapter on facial trauma) or imaging of the inner ear and retrocochlear structures. In other cases where MRI provides additional information to CT, no MR images are illustrated (for example the cholesterol granuloma in fig. 3.39 indistinguishable from congenital cholesteatoma on CT). On the other hand, I did like the discussion on the relative role of CT and MRI in the chapter on the nasopharynx, oropharynx and oral cavity. The discussion on the role of CT and MRI in the evaluation of the larynx is somewhat outdated, but the authors cannot be blamed for this as the book was published in 1994.

This book includes chapters on facial trauma, skull base, orbital imaging, paranasal sinuses, nasopharynx, oropharynx and oral cavity, and larynx and hypopharynx. An overview of the most common pathologies is given. The illustrations are usually of good quality; some are in my opinion displayed at a suboptimal window/level setting, and the field of view is also not always optimally coned on the region of interest.

Not enough attention is paid to the description of tumor extension pathways. Knowledge of these pathways is necessary for accurate interpretation of CT or MRI examinations of tumoral lesions in this region, where subtle extensions with clinical relevance may otherwise be missed. In this regard I do not agree with the statement on p. 197 that larger (laryngeal) lesions can be examined with sections at 10-mm intervals. The use of such large section intervals is risky in neck CT (at my institution, 5 mm contiguous cuts are used routinely for the neck and 2–3 mm contiguous cuts for all laryngeal lesions). No size criteria are found in this work for deciding on the normality or abnormality of neck lymph nodes.

This book provides an overview of head and neck pathology but only limited attention is paid to temporal bone pathology. The quality of some chapters is good but the standard is not consistent throughout the work. I did not like the technical quality of some of the images displayed. Furthermore, I think more attention should have been paid to describing the natural evolution of certain disorders, such as extension patterns in squamous cell carcinoma. More complete and more recent introductory books on head and neck imaging are available for a similar price.

R. Hermans, Leuven