LOW-DOSE CHEST CT WITH MILLIMETRIC THIN SLICES: MYTH OR REALITY?

O Corneloup (1), O Delval (1), F Laurent (2), M Morin (1) and P Vandermarcq (1)

INTRODUCTION

In spite of new available technologies including MRI, CT often remains necessary in the work-up of chest pathology. In Europe (1), while CT comprises only 4% of all performed radiological procedures, it gives rise to approximately 40% of the population dose from medical exposure. In order to study the possibility of dose reduction during high resolution CT (HRCT) imaging of the chest, we have performed a prospective study comparing standard dose HRCT with low-dose (80 mA) HRCT.

MATERIALS AND METHODS

This study evaluated HRCT of the chest (1 mm thick axial images at 10 mm intervals), a technique typically used to assess interstitial lung diseases. This prospective study included 41 patients (11 females, 30 males) aged from 21 to 83 years (mean: 60 years). These unselected patients were referred for HRCT imaging of the chest. After informed consent was obtained, all patients underwent a dual acquisition: a standard HRCT using 170 mA (manufacturer protocol) and a low-dose HRCT (80 mA). 2 experienced chest radiologists reviewed all examinations independently. Both reviewers were blinded to clinical and technical data. All examinations were reviewed in separate settings. A single examination per patient was presented per setting to exclude possible bias.

The reading sheet (table I) included 16 imaging findings classified into 5 main categories: nodular opacities, linear opacities, increased attenuation, cystic lesions, and bronchi. A sixth category was used for normal examinations. For
each acquisition, the main and secondary imaging findings were recorded. Statistical analysis was limited to the main imaging findings.

Patient exposure was evaluated using the dose-length product (DLP), as calculated by the CT console. In spite of limitations, the DLP remains the better of the calculated indices of patient exposure from CT (1, 2) since it considers irradiated length, slice thickness, number of slices, as well as skin and organ exposures using a weighting factor: 2/3 for superficial and 1/3 for deeper organs.

Dose calculation was performed using the CT-Dose® calculation freeware. This program uses a Monte Carlo phantom simulation routine to estimate dose distribution and consequently organ doses, effective dose and DLP from the acquisition parameters. This freeware was developed by the National Institute of Radiation Hygiene, Denmark (internet site: http://www.mta.au.dk/dk/projekter/ctdose/index.htm).

### Table I:
**Reading form.**

<table>
<thead>
<tr>
<th>Reading form</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT N°: ..........</td>
</tr>
<tr>
<td>Series N°: ......</td>
</tr>
<tr>
<td>Patient: ...............</td>
</tr>
<tr>
<td>— Normal examination</td>
</tr>
<tr>
<td>— Nodular opacities:</td>
</tr>
<tr>
<td>□ Mass (≥3cm)</td>
</tr>
<tr>
<td>□ Macronodule</td>
</tr>
<tr>
<td>□ Micronodule</td>
</tr>
<tr>
<td>□ Mediastinal node</td>
</tr>
<tr>
<td>— Linear opacities:</td>
</tr>
<tr>
<td>□ septal thickening, reticular density</td>
</tr>
<tr>
<td>□ pleural thickening</td>
</tr>
<tr>
<td>— Increased attenuation:</td>
</tr>
<tr>
<td>□ alveolar opacities</td>
</tr>
<tr>
<td>□ ground glass</td>
</tr>
<tr>
<td>□ mosaic</td>
</tr>
<tr>
<td>— Cystic lesions:</td>
</tr>
<tr>
<td>□ Bulla</td>
</tr>
<tr>
<td>□ Cyst</td>
</tr>
<tr>
<td>□ Cavity lesion</td>
</tr>
<tr>
<td>□ Fibrosis</td>
</tr>
<tr>
<td>— Image bronchique:</td>
</tr>
<tr>
<td>□ bronchial thickening</td>
</tr>
<tr>
<td>□ bronchiectasis</td>
</tr>
<tr>
<td>□ Atelectasis</td>
</tr>
</tbody>
</table>

### Table II:
**Inter-observer comparison for normal dose acquisition.**

<table>
<thead>
<tr>
<th>Reader 2</th>
<th>Reader 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Nodular opacities</td>
</tr>
<tr>
<td>Normal</td>
<td>1</td>
</tr>
<tr>
<td>Nodular opacities</td>
<td>0</td>
</tr>
<tr>
<td>Linear opacities</td>
<td>0</td>
</tr>
<tr>
<td>Increased attenuation</td>
<td>0</td>
</tr>
<tr>
<td>Cystic lesion</td>
<td>1</td>
</tr>
<tr>
<td>Bronchi</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
</tr>
</tbody>
</table>

### CT protocol

CT examinations were acquired without the use of intravenous contrast on a GE Hi-Speed CT/I (GE Medical Systems, Milwaukee, USA). Incremental 1 mm thick images were obtained at 10 mm intervals. Parameters for the standard (manufacturer) acquisition were 140 kV and 170 mA with a 512 × 512 matrix. Parameters for the low-dose acquisition were 40 kV and 80 mA with a 512 × 512 matrix. Slice acquisition time was similar for both protocols: 1 second/image (gantry rotation time) or 24 seconds for 24 images. The reconstruction algorithm was the same for both protocols: LUNG algorithm for all and STANDARD algorithm for some. The DLP, calculated at the CT console, for each acquisition was recorded for statistical analysis.

### Statistical analysis

For each acquisition protocol, interobserver agreement (4) was calculated using the kappa value (k) with six categories (table I). Correlation between both acquisition protocols was also evaluated using the kappa value.

### RESULTS

#### Comparison of CT images

Interobserver agreement was perfect for 38 or 41 (92%) examinations for both standard and low-dose acquisitions. The inter-observer agreement for both types of acquisition was 0.91. The 3 standard acquisition cases of discordance were: non-visualization of septal thickening, bulla, or micronodules by one or the other observer (table II). The 3 low-dose acquisition cases of discordance were: non-visualization of septal thickening, ground glass, or micronodules by one or the other observer (table III). Two of the 3 cases of discordance were the same for each group: non-visualization of micronodules and septal thickening. Correlation between standard and low-dose acquisitions was perfect: 41 of 41 cases. The agreement between both techniques (kappa value) was 1 (table IV).

#### Comparison of patient dose

The mean DLP was 53.4 mGy. cm for the standard acquisition and 25.1 mGy. cm for the low-dose acquisition. Dose reduction using the low-dose protocol was 53%.
Values using the simulation software were 53.0 mGy cm for the standard acquisition and 25.0 mGy cm for the low-dose acquisition, for a 55% dose reduction. This software enabled calculation of organ specific doses for each protocol: these data are summarized in Table V along with the dose reduction related to the low-dose protocol.

By using a normalized coefficient adapted to the anatomical area of interest, it is possible to convert DLP into effective dose (1). As such, the effective dose was 0.74 mSv for the standard protocol and 0.35 mSv for the low-dose protocol. The dose from the low-dose protocol is thus equivalent to 2-3 months of radiation from natural sources.

**DISCUSSION**

Some authors (6, 7) have suggested that chest CT in women less than 35 years of age would increase by 35% the risk of breast cancer: if this risk is estimated at 10%, a chest CT would increase this risk to 13%. In addition, CT also causes direct radiation exposure to other radiosensitive organs including bone marrow and lower thyroid gland.

Following the increased awareness of the medical community and governmental agencies regarding the problem of medical radiation exposure, new radiation protection guidelines have been implemented. The main guideline is Euratom directive 97/43 (8), currently being incorporated to French law. This directive is equivalent to 2-3 months of radiation is available to provide the answer to the problem. Second, the optimization: for each type of examination, a protocol must be defined in order to keep exposure as low as reasonably achievable for the patient and consistent with obtaining the required diagnostic information.

In CT, the mAs is one of the most important factor affecting patient dose. For chest CT, mAs is usually set around 200 (1). Low-dose techniques have mainly been based on reducing the mA. In addition, spontaneous contrast in the chest is favorable. Therefore, the chest is a body area that seems appropriate for low-dose CT imaging.

Already in 1990, Naidich (9) showed that reducing the mA had very little effect on image quality for the chest. Several authors, including Itoh (10), Taka-

<table>
<thead>
<tr>
<th>Reader 2</th>
<th>Reader 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Nodular opacities</td>
</tr>
<tr>
<td>Normal</td>
<td>1</td>
</tr>
<tr>
<td>Nodular opacities</td>
<td>0</td>
</tr>
<tr>
<td>Linear opacities</td>
<td>0</td>
</tr>
<tr>
<td>Increased attenuation</td>
<td>1</td>
</tr>
<tr>
<td>Cystic lesion</td>
<td>0</td>
</tr>
<tr>
<td>Bronchi</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard acquisition</th>
<th>Low dose acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Nodular opacities</td>
</tr>
<tr>
<td>Normal</td>
<td>3</td>
</tr>
<tr>
<td>Nodular opacities</td>
<td>0</td>
</tr>
<tr>
<td>Linear opacities</td>
<td>0</td>
</tr>
<tr>
<td>Increased attenuation</td>
<td>0</td>
</tr>
<tr>
<td>Cystic lesion</td>
<td>0</td>
</tr>
<tr>
<td>Bronchi</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Organ</th>
<th>Equivalent Dose for standard acquisition</th>
<th>Equivalent Dose for low-dose acquisition</th>
<th>Dose reduction using low-dose acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thymus</td>
<td>3.0 mGy</td>
<td>1.4 mGy</td>
<td>53.33%</td>
</tr>
<tr>
<td>Heart</td>
<td>2.8 mGy</td>
<td>1.3 mGy</td>
<td>53.57%</td>
</tr>
<tr>
<td>Lungs</td>
<td>2.7 mGy</td>
<td>1.3 mGy</td>
<td>51.85%</td>
</tr>
<tr>
<td>Spine</td>
<td>2.6 mGy</td>
<td>1.2 mGy</td>
<td>53.85%</td>
</tr>
<tr>
<td>Breasts</td>
<td>2.3 mGy</td>
<td>1.1 mGy</td>
<td>52.17%</td>
</tr>
<tr>
<td>Esophagus</td>
<td>1.8 mGy</td>
<td>0.85 mGy</td>
<td>52.78%</td>
</tr>
<tr>
<td>Bone</td>
<td>1.4 mGy</td>
<td>0.65 mGy</td>
<td>53.57%</td>
</tr>
<tr>
<td>Liver</td>
<td>0.79 mGy</td>
<td>0.37 mGy</td>
<td>53.16%</td>
</tr>
<tr>
<td>Bone marrow</td>
<td>0.76 mGy</td>
<td>0.36 mGy</td>
<td>52.63%</td>
</tr>
<tr>
<td>Spleen</td>
<td>0.57 mGy</td>
<td>0.27 mGy</td>
<td>52.63%</td>
</tr>
<tr>
<td>Stomach</td>
<td>0.47 mGy</td>
<td>0.22 mGy</td>
<td>53.19%</td>
</tr>
<tr>
<td>Skin</td>
<td>0.46 mGy</td>
<td>0.22 mGy</td>
<td>52.17%</td>
</tr>
<tr>
<td>Thyroid</td>
<td>0.33 mGy</td>
<td>0.16 mGy</td>
<td>51.52%</td>
</tr>
<tr>
<td>Lens</td>
<td>24 µGy</td>
<td>11 µGy</td>
<td>54.17%</td>
</tr>
<tr>
<td>Colon</td>
<td>5.7 µGy</td>
<td>2.7 µGy</td>
<td>52.63%</td>
</tr>
<tr>
<td>Ovaries</td>
<td>3.9 µGy</td>
<td>1.9 µGy</td>
<td>51.28%</td>
</tr>
<tr>
<td>Uterus</td>
<td>1.1 µGy</td>
<td>0.51 µGy</td>
<td>53.64%</td>
</tr>
<tr>
<td>Testes</td>
<td>0 mGy</td>
<td>0 mGy</td>
<td>0.00%</td>
</tr>
</tbody>
</table>
hashi (11) and Mayo (12), have since demonstrated the potential of low-dose CT imaging for “thick” collimation CT imaging of the chest.

Few studies targeted the lung interstitium (Jung (13), Lee (14)). Most were limited to the evaluation of at best 5 findings analyzed on 3 low-dose images through the patient’s chest. The most complete study was from Zwirewich (15) and showed mixed results: the low-dose protocol was performed using a very low mA (20 mA). Using this protocol, the low-dose technique failed to demonstrate ground glass opacity in 20% of cases and emphysema in 11% of cases.

One of the main causes for this paucity of low-dose HRCT studies in the literature probably is the rich semiology of high resolution CT images of the chest that renders statistical analysis difficult. We have encountered this same problem: some of the examination contained up to 8 different findings. As such, our study is based on the main findings for each examination. A more exhaustive study including evaluation of secondary findings would thus be helpful. By using a protocol with good image quality (80 mA) and reasonable dose reduction (> 50%), our study provides excellent correlation between standard and low-dose acquisitions and excellent interobserver agreement (fig. 1 to 4).

The causes for interobserver discordance are more difficult to explain. Patient body habitus does not seem implicated: the involved cases were from “normal” patients as seen on the scout images. Most discordant findings between both observers were nearly subjective in nature: one recorded ground glass opacity when the other recorded a mosaic pattern. Similarly, one recorded normal pulmonary vessels when the other suspected slight prominence of pulmonary vessels with micronodules.

All dose reducing techniques necessarily reduce the signal to noise ratio due to increased quantum noise, the latter being inversely proportional to the dose. In our study, in spite of excellent interobserver agreement between both techniques, low-dose images do show a minimal general increase in the attenuation of the lung parenchyma. Even though no discordant results were noted in the category “increased attenuation” (ground glass opacities being more difficult to differentiate from normal parenchyma), it is possible that there may be a learning curve involved in reading low-dose examinations, if not a more attentive reading technique.

Because low-dose HRCT using 80 mA reduces the radiation dose by 53% compared to the standard protocol and this without loss of diagnostic accuracy, it

may be well adapted for patients requiring routine follow-up HRCT (interstitial lung disease for example). With the increasing availability of multi-detector CT (not yet available in our center), a similar study could be undertaken but would probably raise additional technical issues (15) regarding interslice gap and pitch factor (at MDCT, pitch affects dose both qualitatively and quantitatively). An additional radiation protection technique could include the use of bismuth shielding over the breast tissue. We have examined one patient (not included in this study) where we compared standard dose HRCT (fig. 5) without shielding and low-dose HRCT with dedicated bismuth shielding. There was no significant difference with regards to image quality. Low-dose CT and bismuth shielding may thus be complementary and their combined use could result in a four-fold decrease in breast tissue exposure. Further evaluation will be needed to confirm these preliminary data.

CONCLUSION

Because of the perfect inter-technique correlation and excellent interobserver agreement, low-dose HRCT appears to be an excellent alternative compared to standard dose HRCT while reducing patient dose by over 50%; low-dose HRCT is now being used routinely in our center. On the other hand, any dose reducing technique will result in decreased SNR. One of the challenges raised by Euratom directive 97/43, both for radiologists and referring physicians, will be to provide an answer to the following question: is a quality CT examination an examination that provides “esthetically pleasing” images or one that provides similar diagnostic information but less exposure to ionizing radiation to the patient?

Références