Image quality and radiation dose warrants routine use of abdominal dual energy CT

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Purpose

Dual-energy CT (DECT) uses two different energy spectra in a single data acquisition to better differentiate and characterize tissues. In abdominal imaging, DECT offers several potential benefits over traditional single-energy CT (SECT), such as virtual non-contrast imaging, iodine quantification (tumour volume assessment) and kidney stone differentiation [1-3]. However, DECT has rarely been implemented in routine protocols, likely due to misconceptions about radiation dose and/or image quality when using DECT. The purpose of this regional review board-approved study was to evaluate adoption of DECT into routine clinical use by comparing image quality and radiation doses of singular contrast-enhanced abdominal acquisitions from newly implemented DECT protocols with acquisitions from earlier corresponding SECT protocols.
Methods and materials

Patient population

Between February and July 2015, 495 patients aged 50 and over underwent contrast-enhanced abdominal CT examinations on a 128-slice dual-source CT system. Half-way, in April 2015, the routine abdominal CT protocol was switched from SECT acquisition to DECT acquisition. Of the 495 patients, 247 underwent SECT acquisition and 248 underwent DECT acquisition.

Since our routine SECT abdominal protocol balanced radiation dose and contrast dose against each other based on patient age, included patients were further stratified into subgroups; between 50 and 74 years (SECT n = 157, DECT n = 164) and aged 75 and over (SECT n = 90, DECT n = 84) [4].

Patients at least 50 years of age meeting standard inclusion criteria for contrast-enhanced abdominal CT were included. If a patient underwent more than one examination, only the first examination was included. Patient height and weight were collected, and body mass index (BMI) was calculated.

The included patients were either referred from our emergency department or scheduled for oncological follow-ups. A total of 60 patients were excluded, with the two predominant reasons being deviations from protocol (n =30) and the patient being incapable of raising his/her arms during the examination (n = 19) (Fig. 1).

CT protocols

All examinations were performed on a second generation 128-slice dual source scanner. After an unpublished internal pilot study, all DECT protocols were designed for routine clinical use and were set up to match the corresponding earlier used SECT protocols. The SECT examinations were acquired using the following parameters; tube potential 120 kVp, detector configuration 128 x 0.6 and pitch 1.5. An automatic kVp optimization algorithm was used, which lowered the nominal 120 kVp to 100 kVp for smaller patients. Reference mAs was 160 mAs for patients aged 50-74 and 210 mAs for patients aged 75 and over. The DECT examinations were performed using a detector configuration of 2 x 32 x 0.6 and pitch 0.6. For patients aged 50-74, tube A operated at a potential of 80 kVp with a reference tube charge of 250 mAs and tube B at 140 kVp with a tin (Sn) filter and a reference tube charge of 97 mAs. Patients aged 75 and over were examined with a tube A reference tube charge of 375 mAs and a tube B reference tube charge of 145 mAs. Automatic dose modulation was used for both SECT and DECT examinations.
All examinations were performed using a non-ionic iodinated contrast medium, concentration 350 mg I/ml. Portal venous phase images were acquired with aortic bolus triggering and an additional post trigger delay, resulting in approximately a 70 second total delay from the start of contrast medium injection. For SECT as well as DECT, patients aged 50-74 received 420 mg iodine / kg with a maximum of 90 ml, while patients aged 75 and above received 350 mg iodine / kg with a maximum of 75 ml. The contrast medium was administered using an automatic power injector and followed up with a 50 ml saline flush.

Image reconstruction

The SECT images were reconstructed using the I26f kernel and the weighted-average DECT images were reconstructed using the Q30f kernel. The DECT images of patients aged 50-74 were reconstructed using a mixing ratio of 0.5. For patients aged 75 and over, a mixing ratio of 0.6 was used in order to better visualize the decreased doses of contrast administered to this group. For the study, a slice thickness of 5 mm was used for both SECT and DECT. Sinogram-affirmed iterative reconstruction (SAFIRE) was set to level 1 for SECT and level 2 for DECT. The level of iterative reconstruction (strength of noise reduction) was selected after feedback from the pilot test concluded that setting 1 was subjectively considered too noisy and setting 3 too smudgy.

Objective image analysis

Image quality was evaluated in PACS by placing a circular region of interest approximately 30 mm in diameter in a homogeneous part of the right liver lobe, taking care to avoid vascular and biliary structures. The attenuation and its standard deviation were measured, allowing the calculation of signal-to-noise ratio (SNR).

Subjective image analysis

Subjective image quality was evaluated using visual grading characteristics (VGC) analysis, during which observers rated the reproduction or visibility of seven different structures within each examination [5]. Based on the 2004 European Guidelines for Multislice Computed Tomography, the following seven quality criteria were selected; (1) sharp reproduction of the gallbladder wall and major intrahepatic ducts, (2) sharp reproduction of the intrapancreatic part of the common bile duct, (3) sharp reproduction of major branches of the abdominal aorta, (4) sharp reproduction of renal pelvis and perirenal fascia, (5) sharp reproduction of urinary bladder wall, (6) sharp reproduction of the right adrenal gland and (7) reproduction of vessels in the liver [6]. Out of the 495 total examinations, 50 DECT and 50 SECT examinations were randomly selected and matched for age and gender. These examinations were then anonymized and all image annotations were removed and presented to three observers who were blinded to the image-acquisition technique when using PACS.
**Radiation dose analysis**

The radiation doses in CT dose index by volume (CTDI\textsubscript{vol}) and dose-length product (DLP) from each examination were registered from the CT dose report images. The effective dose was estimated by multiplying DLP with a standardized conversion factor (k = 0.0163 mSv/mGy-cm) [7].

**Statistical analysis**

The primary hypothesis was that the mean radiation dose and image noise were the same for SECT and DECT. The Mann-Whitney U test was used in SPSS v. 23 for OS X to compare radiation doses, noise levels, age and BMI between groups. The VGC analysis for comparison of subjective image quality was performed using the software VGC Analyzer version 1.01 [8]. The software establishes an ROC-like VGC curve and determines asymmetric 95% confidence intervals of the AUC\textsubscript{VGC}. A confidence interval of < 0.5 was interpreted as a statistically significant difference in image quality between SECT and DECT. Conversely, a confidence interval of > 0.5 corresponded to equal image quality between the two techniques.
Fig. 1: Flow chart of study population detailing included patients and reasons for exclusion.

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Results

Patient population

No significant difference was found between the mean BMI of SECT (25.5, range 14.3 - 42.6, SD = 4.8) and DECT (25.4, range 11.7 - 45.5, SD = 4.8) or the mean age of SECT (70.9, range 50 - 95, SD = 10.9) and DECT (70.8, range 50 - 97, SD = 11.0) (p = 0.761 and 0.974, respectively).

Radiation dose

The mean CTDI\textsubscript{vol} (7.1, SD = 2.4), DLP (375.6, SD = 128.6) and effective dose (6.1 mSv, SD = 2.1) of DECT was significantly lower than that of SECT, with CTDI\textsubscript{vol} (9.5, SD = 3.7), DLP (512.5, SD = 203.5) and effective dose (8.4 mSv, SD = 3.3) (p < 0.05) (Fig. 2). The mean effective dose of DECT was 27% lower than that of SECT. Looking at the subgroups, for patients aged 50-74, the mean CTDI\textsubscript{vol}, DLP and effective dose of DECT was significantly lower than that of SECT (p < 0.05) (Table 1). The same holds for patients aged 75 and over, as the DECT mean dose in CTDI\textsubscript{vol}, DLP and effective dose was significantly lower than respective SECT dose (p < 0.05) (Table 1). The dose difference between the two techniques was more pronounced the higher the BMI of the patient (Fig. 3).

Image quality

Noise levels (as measured in standard deviation) were significantly lower in DECT (13.9, SD = 2.1) compared with SECT (14.7, SD = 2.8) (p < 0.05). The SNR was significantly higher in DECT (7.1, SD = 1.7) compared with SECT (6.3, SD = 1.7) (p < 0.05). For patients aged 50-74, the DECT noise levels were significantly lower than SECT, while SNR was significantly higher with DECT than SECT (Table 1). In the older patient group, no significant difference was found in noise levels between DECT and SECT, while SNR was significantly lower in than SECT (p > 0.05 and < 0.05 respectively) (Table 1). With rising BMI, the SNR of DECT decreased at a higher rate than that of SECT (Fig. 4). No significant differences in subjective image quality were found between DECT and SECT acquisitions, except for one criterion in the 50-74 age group (Fig. 5). This criterion was gallbladder wall and major intrahepatic ducts.
**Fig. 2:** Boxplot illustrating effective dose (mSv) of SECT and DECT examinations, including subgroups. Outliers are represented with circles and stars.

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<table>
<thead>
<tr>
<th>Mean value (SD)</th>
<th>SECT (50-74)</th>
<th>DECT (50-74)</th>
<th>SECT (≥75)</th>
<th>DECT (≥75)</th>
<th>SECT (All)</th>
<th>DECT (All)</th>
</tr>
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<tr>
<td>CTDI_vol (mGy)</td>
<td>9.0 (3.5)</td>
<td>6.2 (1.7)</td>
<td>10.3 (3.9)</td>
<td>8.8 (2.8)</td>
<td>9.5 (3.7)</td>
<td>7.1 (2.4)</td>
</tr>
<tr>
<td>DLP (mGy·cm)</td>
<td>498.9 (203.9)</td>
<td>336.9 (97.8)</td>
<td>536.4 (200.5)</td>
<td>451.1 (146.9)</td>
<td>512.5 (203.5)</td>
<td>375.6 (128.6)</td>
</tr>
<tr>
<td>Effective dose (mSv)</td>
<td>8.1 (3.3)</td>
<td>5.5 (1.6)</td>
<td>8.7 (3.3)</td>
<td>7.4 (2.4)</td>
<td>8.4 (3.3)</td>
<td>6.1 (2.1)</td>
</tr>
<tr>
<td>Noise (HU)</td>
<td>15.5 (2.4)</td>
<td>14.6 (1.9)</td>
<td>13.4 (3.0)</td>
<td>12.5 (1.8)</td>
<td>14.7 (2.8)</td>
<td>13.9 (2.1)</td>
</tr>
<tr>
<td>SNR</td>
<td>6.0 (1.6)</td>
<td>6.8 (1.6)</td>
<td>7.0 (1.7)</td>
<td>7.8 (1.6)</td>
<td>6.3 (1.7)</td>
<td>7.1 (1.7)</td>
</tr>
</tbody>
</table>

**Table 1:** Mean values of CT dose index by volume (CTDI\_vol), dose-length product (DLP), effective dose, image noise and image signal-to-noise ratio (SNR).

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Fig. 3: Scatter plot illustrating the effective dose of SECT and DECT examinations in relation to patient BMI.

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Fig. 4: Scatter plot illustrating the SNR of SECT and DECT examinations in relation to patient BMI.

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**Fig. 5**: Graph that shows the values of area under the VGC curve per criterion for all observers combined. Error bars represent the 95% CI of AUC. If the error bars do not include 0.5, the subjective image quality of DECT examinations is statistically different from that of SECT examinations. Note that all error bars except that of 50-74 in the first criterion include 0.5.

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Conclusion

The results of our retrospective study show that DECT can be implemented in routine clinical use while lowering the radiation dose to the patient and without negatively impacting image quality. The radiation dose and noise levels were found to be significantly lower in DECT examinations compared to SECT. Overall, the mean radiation dose for DECT was found to be 27% lower than that of SECT. No statistically significant difference was found in subjective image quality except for one of the seven criteria in the 50-74 subgroup.

The results of the radiation reduction are in line with previous findings [9, 10]. Purysko et al also similarly found no reduction in image quality using DECT as measured by image noise [9].

In the present study, the higher objective measure of SNR of DECT acquisitions was not paralleled with a higher subjective image quality compared with SECT. Although the above results might seem contradictory, it is noteworthy that image quality is affected by several factors other than noise that the objective analysis does not take into account. The higher SNR of DECT images can likely be attributed to the fact that the DECT protocols used a higher setting in the iterative reconstruction algorithm than SECT protocols. The higher level was chosen on the basis of our pilot study, which concluded that lower settings were too noisy and would likely be met with resistance from fellow radiologists at our institution.

An interesting finding was that the difference in effective dose between SECT and DECT increased with the BMI of the patient. This finding was present for both subgroups, but more pronounced in patients aged 50-74 (not shown in presented figures). Similar results were reported by Purysko et al, but an immediate explanation is not available [9]. We hypothesize that the increasing difference is, at least in part, related to that the dose modulation for DECT makes use of two topograms (anterio-posterior and lateral) while SECT only uses one (anterio-posterior). This could theoretically make DECT acquisitions less prone to overestimate patient size and therefore lead to comparatively lower radiation doses. As an apparent consequence of the lower doses of DECT at higher BMI, the SNR decreases faster for DECT examinations than for SECT examinations (Fig. 4).

Another finding that emerged during our analysis was that despite our SECT protocols being set up according to the seesaw principle suggested by Fält et al, the radiation dose for SECT remained about the same between the younger and the older group (rather than the expected dose hike for the older group) (Fig. 6) [4]. Further investigation into the
cause of this is pending, but it may be a result of inadequate training of staff. It is possible that the manual steps required for adjustment of the reference mAs for patients aged 75 and over were occasionally missed, thus resulting in the older patients’ examinations being acquired with the same reference mAs as the younger patients’. If this is indeed the case, it would negatively affect the credence of image quality comparison between the older groups, but positively affect the credence of the radiation dose comparison.

Imaging with DECT has a number of potential advantages over SECT, such as virtual non-contrast imaging, kidney stone differentiation and iodine quantification for tumour volume assessment. During our data analysis, a number of cases that would directly benefit from DECT imaging were singled out. These cases and the associated potential gains with DECT will be further examined in a future study.

Our study had several limitations. First of all, this study was done retrospectively, which increases the risk for selection bias. We believe, however, that the size and homogeneity of our patient population minimize the negative effects of its retrospective design. Second, since our data came from clinical routine examinations, we did not have the fine grained control over every parameter that would be possible in a controlled lab environment. This is well illustrated by the question raised post-analysis regarding to what extent proper procedure was followed in raising the reference mAs for the older patient group. Third, the difference in protocol SAFIRE setting limits the usefulness of our objective image analysis.

In conclusion, the results of the present study warrant routine use of abdominal DECT protocols, which can be adopted while lowering radiation dose and maintaining image quality compared with corresponding SECT protocols.
Fig. 6: Scatter plot illustrating the effective dose of SECT and DECT examinations in relation to patient age.

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References


