Calibration of CT attenuation values and contrast for liver characterization

Poster No.: ESI-0055
Congress: EuroSafe Imaging 2019
Type: EuroSafe Imaging
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Keywords: Action 3 - Image quality assessment based on clinical indications, Liver, CT, Diagnostic procedure, Equipment, Physics, Image verification
DOI: 10.26044/esi2019/ESI-0055

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Computed Tomography (CT) values characterize the linear attenuation coefficient of the tissue in each volume element relative to the $\mu$-value of water. The Hounsfield Units (HU) or CT numbers are defined as a normalized index of X-ray attenuation based on a scale of -1000 HU (air) to +1000 HU (bone), including water equal to 0 HU at standard temperature and pressure [1]. According to most investigators, healthy liver tissue CT numbers must be between 50 HU and 70 HU [2, 3]. Some clinical recommendations advocate the use of HU values measurement for disease assessment, considering CT image matrix as reliable and accurate. For instance liver steatosis can be detected and characterized by the liver/spleen ratio measurement in HU [4, 5], while portal venous phase CT valued of liver metastases can be a marker of response to novel therapy regimens [6]. The follow-up of HU values has also already been used in patients with non-alcoholic fatty liver disease [7], and even in patients with idiopathic hemochromatosis treated by phlebotomy by providing an index of hepatic iron stores without requiring a liver biopsy [8]. Mean CT attenuation liver values were also used by Altenbernd et al. [9] for the detection of hepatic metastases in patients with uveal melanoma. All these medical studies do not provide specific information regarding the HU calibration criteria, which should be necessary to ensure the reproducibility and the accuracy of their conclusions. However, the CT numbers of tissues are not constant data; they may be influenced by the convolution kernel, the reconstruction algorithms [10] and the patient morphology. The HU variability may also be related to the difference in the energy spectra of the X-rays; this was already reported more than thirty five years ago [11, 12]. Recently, the variability of CT attenuation values had been confirmed [13, 14]: Birnbaum et al. showed in a phantom study that CT attenuation values were different for all tissues between manufacturers and among different generations of CT equipments. Thus by considering HU variability between MDCT scanners, Lamba et al. [14] concluded that established absolute HU thresholds can alter the diagnosis performance of CT examinations. These studies provided valuable information in HU variability understanding between MDCT manufacturers, however the reliability of CT attenuation values for a specific quantitative clinical CT application during lifetime of the same CT equipment, has never been considered. The aim of our study was therefore to evaluate the fluctuation of liver HU absolute values and contrast in a phantom over several years, with acquisitions being performed on two identical CT equipments and to propose some recommendations for CT scanner tissue calibrating.
Description of activity and work performed

Phantom study

Our study involved the CT Electron Density Phantom (CIRS, Norfolk, model 062). This phantom consists in two body parts made of soft tissue equivalent epoxy resin. The use of inserts with known elemental composition and Relative Electron Density (RED) indicated by the phantom’s manufacturer allowed a conversion of the RED value to the associated CT attenuation values of each pixel [14]. The following RED values were included in the phantom: 0.190, 0.489, 0.949, 0.976, 1.043, 1.052, 1.117 and 1.512. The RED values equal to 0.949, 1.043, 1.052 and 1.117 were defined as fat, muscle, liver and aorta substitutes respectively. A special insert dedicated to the use of a syringe filled of regular water was used. The phantom was scanned with inserts in identical locations between acquisitions.

The same phantom and inserts were used for all image acquisitions in order to avoid the variation of the RED values for the tissue substitute materials among several phantoms [15].

CT images acquisition

- CT scans were acquired on two identical 64-section multi-detector row helical CT scanners (LightSpeedTM VCT, General Electric Healthcare), with the following parameters: 120 kV, AutomA, automatic exposure time, 0.5 s gantry rotation time, 500 mm field of view, slice thickness and slice distance of 0.625 mm, pitch equal to 0.984, standard filter, noise index was 23, Filtered Back Projection reconstruction. This protocol for image acquisition suited to liver diagnosis was defined to meet the radiologists on-going needs at the beginning of the study. It had been set while installing CT scanners, and kept identical for quality control throughout the time of the study regardless of any changes came from radiation dose optimization or software update.
- CT scanners were calibrated according to the manufacturer’s specifications during maintenance operations.
- Twenty-two total phantom scanning sessions were performed just after maintenance within five and half years on each CT equipment.
- Phantom images were imported into a dedicated image processing software (ArtiscanCT software, version 4.0.1, Aquilab, France).
Image quality analysis

Regions of interest (ROIs) were automatically extracted by the software on one axial slice chosen at the mid-z-axis thickness of the phantom to ensure image uniformity and avoid partial volume effects. The mean Hounsfield numbers (HU) and standard deviations (SD) were determined in circular ROIs (diameter 10mm) with the center coinciding with the center of inserts. Standard deviations were defined as tissue noise. Therefore, the tissue-to-noise ratio was defined as the ratio between the average and the standard deviation of pixel values extracted from a ROI inside tissue inserts.

Statistical analysis

First, the CT attenuation values and tissue-to noise ratios were calculated for each RED value and were expressed in terms of mean, standard deviation of the mean, minimum, maximum for each CT scanner for five and half years.

For each RED value and for water, the HU values were compared between the two CT scanners by using a two-sided paired Student’s t test. If no significant difference was observed, measurements were considered reproducible (P>0.05) (Table 1 and 2).

Second, in order to assess the agreement between attenuation values and tissue-to-noise ratios from the two CT equipments, a Bland and Altman (B&A) analysis was performed [16, 17]. The regression line of the differences was drawn in order to help in detecting a proportional difference (Figure 2 and 3).

Analysis were performed in Microsoft Excel software (Microsoft Corp., Redmond, WA USA).
Fig. 2: Bland and Altman plot with the representation of the limits of agreement (green lines). The difference of the two paired measurements (HUCT1-HUCT2) is plotted against the mean of the two measurements ((HUCT1+HUCT2)/2). The mean of the differences is indicated by a red line. The regression line of the differences is represented by a black line.

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<table>
<thead>
<tr>
<th>Tissue types</th>
<th>Mean Attenuation ± Standard Deviation (HU)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat *</td>
<td>-57.2±12.2 [range: -76.9 – -18.8]</td>
<td>0.415</td>
</tr>
<tr>
<td>Fat **</td>
<td>-59.4±6.8 [range: -71.6 – -41.8]</td>
<td></td>
</tr>
<tr>
<td>Muscle *</td>
<td>57.1±14.1 [range: 29.9 – 104.5]</td>
<td>0.675</td>
</tr>
<tr>
<td>Muscle **</td>
<td>55.5±8.0 [range: 43.9 – 70.9]</td>
<td></td>
</tr>
<tr>
<td>Liver Parenchyma *</td>
<td>61.8±16.4 [range: 26.1 – 116.5]</td>
<td>0.825</td>
</tr>
<tr>
<td>Liver Parenchyma **</td>
<td>60.8±10.8 [range: 48.3 – 92.9]</td>
<td></td>
</tr>
<tr>
<td>Aorta *</td>
<td>261.8±15.9 [range: 236.8 – 308.4]</td>
<td>0.263</td>
</tr>
<tr>
<td>Aorta **</td>
<td>256.9±9.8 [range: 242.1 – 272.2]</td>
<td></td>
</tr>
<tr>
<td>Water *</td>
<td>-3.1±36.1 [range: -51.1 – 80.1]</td>
<td>0.258</td>
</tr>
<tr>
<td>Water **</td>
<td>0.6±6.2 [range: -5.2 – 11.2]</td>
<td></td>
</tr>
</tbody>
</table>

*: CT scanner 1; **: CT scanner 2.

**Table 1:** Attenuation values in different anatomical regions of the abdomen and for water calculated from the same acquisition protocol on two identical CT equipments over the study time. In the last column, the probability assuming the null hypothesis is indicated.

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Fig. 3: Bland and Altman plot with the representation of the limits of agreement (green lines) for fat, muscle, liver, aorta and water. The difference of the two paired measurements (SNR\textsubscript{CT1}-SNR\textsubscript{CT2}) is plotted against the mean of the two measurements ((SNR\textsubscript{CT1}+SNR\textsubscript{CT2})/2). The mean of the differences is indicated by a red line. The regression line of the differences is represented by a black line.

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Table 2: Tissue-to-noise ratio in different anatomical regions of the abdomen and for water calculated from the same acquisition protocol on two identical CT equipments over the study time. In the last column, the probability assuming the null hypothesis is indicated.

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Conclusion and recommendations

- Cross-calibration of tissue-to-noise ratios and absolute attenuation values between several CT scanners should be determined prior to patient studies.
- Large discrepancies in liver CT attenuation can occur during lifetime of the same multislice CT scanner.
- Radiologists must be careful when using absolute CT numbers for diagnosis.
- Specific calibration phantoms are highly recommended for quantitative applications as a reference.
Personal/organisational information

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References


