DUAL ENERGY ON DUAL SOURCE CT IN ABDOMINAL IMAGING
comparison between Virtual-Non-Contrast and True-Non-Contrast images using quantitative and qualitative analysis and evaluation of dose report

INTRODUCTION
Dual Energy CT (DECT) is one of the last frontiers in Computed Tomography technology, which bases its principle on the acquisition at two energy levels (keV) simultaneously (fig.1), obtaining image information from two different x-ray spectra. For this reason, DECT is also commonly defined as Spectral CT and provides images with different attenuation from two x-ray beams, to better characterize tissues.

When we talk about attenuation, we refer to the attenuation coefficient of tissue (mt) that can be described as mr that refers to the total mass attenuation coefficient for all photon/matter interactions. Particularly important interaction is the photoelectric absorption (\(t/r\)), which contributes mostly to imaging, and it is related to the atomic number (Z) of the medium and the photon energy of the radiation (E) cubed whereby:

\[ \text{In diagnostic imaging, the photoelectric effect is relevant for the elements with high atomic number (Z) like Iodine or Calcium, and it occurs when the photon energy is equal to, or greater than the binding energy of the electron in K-shell [1-2].} \]

Indeed, elements with low Z have minor differences, as soft tissues, while elements as Iodine and Calcium show a major difference at two energy levels (fig.2). Therefore, it is possible to decompose these materials using specific software as the Material Decomposition (MD), which can isolate and subtract the Iodine or Calcium from tissues. An application is the possibility to remove iodine material from post-contrast scans, obtaining images without contrast or “virtual non-contrast” [9-12] when they are required.

MATERIALS AND METHODS
Between April and June 2019, 72 abdominal CT studies were performed after intravenous contrast material acquired in dual-energy modality. 41 out of 72 underwent a preliminary un-enhanced scan and retrospectively analyzed. The patients, 25 males, and 15 females had a mean age of 68 years (minimum 30, maximum 88; average 73, median 70). Body Mass Index ranged from 20 to 29, and patients with values above 29 were excluded. Patients presenting with hepatic steatosis, splenectomy or nephrectomy were also excluded.

CT Protocol
The above-mentioned patients underwent a three-phase study protocol including un-enhanced scans followed by arterial and venous phases performed on a second-generation dual-source scanner. Dual Energy
spectral contrast. Note that Iodine has a major difference in this range and can well distinguish Iodine from the bone.

Fig. 1. Double x-ray spectra; the combination of 100 kVp and 140 kVp with the addition of 0.4 mm tin filter applied to the high energy (blue spectrum) allows to decrease the characteristic discrete peaks of tungsten and increase Bremsstrahlung effect that improves the distance between the two curves and it makes to grow spectral contrast.

(De) mode was applied on both post-contrast phases in 6 out of 41 patients, while in 20 in the arterial phase and in the remaining 15 in the venous phase. The scans without contrast media were acquired with kV modulator and automatic mAs about 170, the pitch was 0.6, gantry rotation of 0.5 seconds and collimation of 1.5 mm x 128 z focus. For dual-energy scans, the power of the two tubes was 100 kV (tube A) and Sn140 kV (tube B), while the mAs were dispensed automatically with a dose modulator. The pitch was 0.6 and the collimation 0.6 mm x 128 z focus, the rotation speed of the gantry was 0.5 seconds. All images were acquired with a thickness of 3 mm and reconstructed with the iterative algorithm. High iodinated contrast medium (400 mg/ml) was intravenously injected at 3 ml/sec flow rate followed by 50 ml saline solution. The time of the arterial phase was established by a ROI positioned on the thoracic descending aorta fixed at a value of 150 HU. The venous phase was acquired 40 seconds after the end of the arterial phase.

Post-processing
Dual Energy scans generated two data sets for each tube/detector system with different energy levels, afterward, the image sets were processed with material decomposition software for Iodine subtraction and un-enhanced images were generated. Virtual Non-contrast (VNC) images were used for the quantitative and qualitative comparison with the True Non-Contrast images (TNC) (fig.3).

Quantitative analysis
The quantitative analysis was performed by measuring the Hounsfield values using the ROIs on the different organs acquired in TNC and VNC, taking care to position them in the same points on the two sets of images (fig.4). ROIs were drawn with a diameter of 1 cm², for each data set three of them were placed on the liver, avoiding the portal vessels, on the spleen, on descending aorta from T11 to L1, on the kidneys bilaterally, on the para-vertebral muscles and retroperitoneal and subcutaneous fat. A total of 2160 ROIs were analyzed.

Qualitative analysis
The images were also subjected to a qualitative comparison through viewing by four readers with different experiences, from two to twenty years. Assessment concerned exclusively:
• Evaluation of hepatic parenchyma with surrounding structures;
• The distinction of the portal branches in the hepatic parenchyma;
• Rating of the renal parenchyma.

The evaluation was based on a scale of four qualitative values: 4=excellent, images without artifacts and well-defined structures, 3=good, presence of minor artifacts, but still readable, 2=fair, presence of some artifacts, images not easy to read, 1=poor, the artifacts do not allow to distinguish the structures, therefore not readable images. Each value was assigned to the single organ on the single image set and the results per patient were compared. Finally, a cut-off of reportable images was established, “sufficient” for 4 and 3 values, “insufficient” for 2 and 1 values.

Statistical analysis
Attenuation values were subjected to the Shapiro-Wilks normality test, afterward for normal distribution values a paired t-test was used, while for non-normal distributions a non-parametric Wilcoxon Signed Rank test was used. The qualitative evaluation has been subjected to the Mann Whitney U test and represented on histograms and 100% stacked column charts. All statistical analyses were performed by using an appropriate software the QtiPlot software www.qtiplot.com and www.statskingdom.com.

RESULTS
Attenuation values of TNC and VNC data sets demonstrated statistically significant differences in the arterial phase on liver (p<0.0001), aorta (p<0.0001), kidney (p=0.008), spleen (p<0.0001) and fat (p<0.0001), and in the venous phase (tab.2 and 3) on liver (p<0.0001), spleen (p<0.0001), kidney (p=0.001), muscle (p<0.0001) and fat (p<0.0001) (tab.1). Only aorta values had no statistically significant differences (p=0.1) (tab.2).

Comparative distributions of attenuation values were represented on the box-whisker diagram (fig.5),
which shows higher values for VNC than TNC. A further comparison was to evaluate the distribution of the average differences between the HU values using the Bland Altman diagram, which shows a good agreement between two data sets, with the majority of the values, included within the two error bars (average ±1.96 x standard deviation) (fig.6). Qualitative analysis showed statistically significant differences for kidneys $p<0.0001$, portal branches $p=0.02$ and liver $p<0.0001$. The stacked column graph (fig.7) shows the trend of the percentage in subjective evaluation. The liver, and kidneys in TNC images differ with more assessments as “excellent” (67%) compared to VNC who has been best evaluated as “good” (54%) (fig.8). However, the cut-off has included most values suitable for reporting of both true non-contrast images (91%) and virtual non-contrast images (81%) (fig.9).

**DISCUSSION**

TNC and VNC attenuation values were statistically different, due to a different X-ray spectrum. Measurement differences have been calculated as a percentage...
Table 1-2. To expect differences between attenuation values of two populations, Wilcoxon Signed Rank for non-normal distributions was performed; test shows only aorta values in venous phase have no statistical differences respect to the other organs.

Table 3 The normally distributed values were subjected to the t-test for paired samples, resulting in a statistically significant difference in all cases.

Table 4. Attenuation differences were evaluated as percentages which are referred to values within tolerance interval fixed to ±15 HU.

Table 5. Comparison dose differences in biphasic protocols with and without true non-contrast phase. Numbers are expressed as median and percentage of difference.
Fig. 5. Box-whisker plot graphics show the difference in attenuation values between the two acquisition types. Note the trend toward higher HUs in VNC images, except the aorta in the venous phase.
Fig. 6. Bland Altman plot analyses for attenuation differences between TNC and VNC dataset with a linear trend line. Note the majority of dots lying within the two standard deviation bars, resulting in a good agreement between the two datasets.

Table 4

| Tissue | Tolerance | P-value |
|--------|-----------|---------|
| Liver  | 77%       | 0.6     |
| Aorta  | 79%       | 0.5     |
| Kidney | 97%       | 0.6     |
| Spleen | 74% <0.001|         |
| Muscle | 93%       | 0.1     |
| Fat    | 74%       | 0.1     |

Fig. 7. Quality assessment represented on a 100% graph with stacked columns and divided by organs and acquisition type. TNC images show the best quality of kidney and liver compared to VNCs. The portal vessels were rated excellent lower for both acquisitions due to lower Contrast to Noise Ratio (CNR) that made the read most difficult compared to other tissues.
Fig. 8. Overall percentage values represented on 100% stacked columns per acquisition type. TNCs exceed VNCs in “excellent” values, however, good quality in VNCs is demonstrated.

Fig. 9. Cut-off that divided quality assessment in two categories, “readable” for excellent and good values, and not readable for fair and poor values. The majority of values are included in readable column, this means that VNC images has high percentage to be considered as true non contrast images.

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