Comparison of radiation dose and image quality between sequential and spiral brain CT

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Purpose

There are two modes of scanning techniques used in CT; these are: sequential and spiral CT scanning (Fig.1). In sequential scanning, the CT couch does not move during the rotation of the x-ray tube, it moves only after a single slice has been scanned, resulting in gaps between one slice and the next. This scanning technique is time-consuming and brings out some disadvantages such as the potential for respiration misregistration artifacts, motion artifacts and limited availability of overlapping images for post-processing [1,2].

In comparison, during spiral CT scanning, the patient moves at a constant speed while the x-ray tube and the detector array rotate continuously around the patient. This technique results in continuous radiation, continuous data acquisition and continuous table feed [3,4].

On reviewing the literature, one finds conflicting outcomes between these two scanning techniques. Some studies comparing image quality between the two techniques have indicated that image quality is similar in both scanning techniques [5]. Others indicated a preference to the sequential scanning technique especially when assessing small structures [6]. Recent literature also presented conflicting outcomes with regards to radiation dose. While spiral scans were regarded as having a better quality this was achieved with an increase in patient radiation dose especially on multi slice scanners [7]. On the contrary, other findings suggest much higher DLP values indicating a higher radiation dose during sequential scans [8].

Background to the study

At the local general hospital in Malta, Brain CT examinations are mainly performed using a dual slice CT scanner. Most examinations are carried out in sequential mode. On the other hand, one third of these examinations are scanned in spiral mode for the reason that it is faster and thus it’s easier to obtain good diagnostic images of confused or uncooperative patients especially paediatrics and geriatrics due to possible motion artefacts.

The purpose of this study was to evaluate and compare sequential CT to spiral CT examinations of the brain with regards to image quality by visually grading the reproduction of anatomical structures as outlined in EUR 16262 (European guidelines on quality criteria for CT) and radiation dose in terms of CTDi\textsubscript{vol} and DLP, on a GE HighSpeed Dual slice CT unit at the local general hospital. The study provides useful data to compare radiation doses and image quality of both protocols. The conclusions from this study could
be used by the medical imaging department to select the most appropriate protocol for clinical use which utilises the least possible radiation dose while maintaining diagnostic efficacy. The proper protocol selection will thus be a benefit for future patients.
Fig. 1: Sequential CT vs. Spiral CT

Methods and Materials

To achieve the aim of the study a research design and methodology was formulated. The research design chosen for this particular study is a comparative descriptive design using prospective data with a quantitative approach.

Target Population and Eligible Criteria

The target population involved the participation of two different subjects. The first category were the CT images of patients referred for CT of the brain as part of their diagnosis at the local general hospital out of which a random sample was selected in order to reduce sampling bias. These included an equal number for each scanning protocol. However, paediatric patients and patients having pathologies which disrupted the anatomical structures as outlined in the image quality criteria were excluded from the image set. On the other hand, the second category was made up of radiologists with reporting experience in CT. A convenience sample was chosen which depended on the availability of radiologists and their willingness to participate in the study during the time of data collection.

Research Tool

The research tools implemented to record the data for this study were two checklists were used (Fig.2). Checklists were considered the most appropriate tool to collect data from this study as they are easy to fill in, not time consuming and to the point.

The first checklist allowed the researcher to record information and parameters about the scanning technique for each brain CT examination. The information requested included: scanning technique used, scan parameters (these include slice-thickness, interslice distance, pitch factor, scan length, exposure factors, gantry tilt and reconstruction algorithm) and radiation dose indicators in terms of CTDi\textsubscript{vol} and DLP. These two important dose indicators are essential as they give an indication of the radiation dose "absorbed per unit mass of tissue, the volume of tissue exposed to radiation, and thus the total amount of energy deposited in the scan volume" [9].

The second checklist allowed the participating radiologists to evaluate image quality by grading six anatomical structures as outlined in the European guidelines on quality criteria for CT, according to their level of visibility. The aim of these guidelines is "to provide an operational framework for radiation protection initiatives, in which technical parameters required for image quality are considered in relation to patient radiation dose" [10]. The
radiologists graded the visibility of the criteria on a scale from 1-5 with Grade 1 indicating that the anatomical structure was not at all visible to Grade 5 indicating excellent and well defined visibility.

Data Collection

Data was collected from 40 CT brain examinations, out of which 20 were scanned using the sequential technique and an equal amount scanned using the spiral technique on GE HighSpeed Dual slice CT unit. The data from the first checklist related to radiations dose were recorded after every scan. Two examinations of each scanning technique were replicated for reliability testing purposes. Four radiologists were asked to evaluate a total of 44 CT brain examinations (including the replicas) in which all patient identification was ommitted from the images. They evaluated the images at their own convenience on a GE Advantage workstation with Barco Vaxar 3DTM- TeraRecon AquariusNET TM primary monitors of 3 megapixels.
Fig. 2: Figure showing the two research check-lists used in the study. Left: Technical data sheet and Right: Image quality assessment sheet.

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Results

A different separate protocol is used for the sequential and spiral techniques, both using different scanning parameters. (Fig. 3). When the brain examination is performed using sequential scanning, it uses two different scanning protocols: one for the posterior fossa and the other for the cerebrum. However, during the spiral scanning technique the brain is scanned with only one protocol. Automatic mA modulation using the Smart mA function is activated for both protocols which reduces the radiation dose and ensures a better image quality.

Data Analysis

The mean measures of radiation dose quantities from the 20 brain CT examinations of each scanning technique were compared using the independent sample t-test. Descriptive statistics representing the radiation dose quantities: CTDIvol and DLP were presented.

Visual Grading Analysis was essential to determine any difference in image quality between the two scanning techniques incorporated in the image set evaluated by radiologists. The rating scores assigned by radiologists for all CT brain examinations during VGA were statistically analysed using the Mann Whitney test which compares the mean ranking scores between the two techniques. Descriptive statistics were again used in order to present the average rating of the image quality scores.

Intra-observer reliability

Intra-observer reliability was measured by giving the four observers replicas of four images from the 40 CT brain examinations and it was measured throughout the whole study (Fig.4). Pearson's correlation was calculated and ranged between 0.107 and 0.904. On the other hand, Cronbach's Alpha was also calculated ranged between 0.19 and 0.95.

Inter-observer reliability

Inter-observer reliability was measured by comparing the scores given to each criterion among the four participating radiologists (Fig.5). The result show how ratings among the observers, differed. All correlations were positive indicating compliance among the evaluators. Pearson’s correlation was calculated and ranged between 0.341 and 0.767.
Radiation Dose Indicators - CTDIvol and DLP (Fig.6)

The purpose of the independent t-test is to compare the difference between the means of the two independent groups [11]. The results of the output from the independent samples t-test are both significant as both radiation dose indicators obtained a p-value < 0.05. The latter means that the mean CTDIvol and DLP scores of both scanning techniques differ significantly. The fact that both dose indicators in spiral technique were significantly lower than those obtained by the sequential technique, indicate that the radiation dose in spiral technique is significantly less than that in the sequential technique.

Image Quality Criteria (Fig.7)

The overall result showed that the mean rating scores provided for the sequential scanning technique in respect of all the criteria were significantly higher than the mean rating scores provided for the spiral scanning technique since the p-value < 0.05 level of significance. Therefore, it is deduced that this difference is not attributed to chance and, for all the five criteria, there is a significant difference in the mean visibility scores of sequential and spiral technique in CT brain examinations.

From the mean rating scores one can also deduce that the criteria which was mostly preferred with the sequential technique was criteria 2, that is the visually sharp reproduction of basal ganglia. Furthermore, less difference in the mean rating scores was observed in criteria 4 and 5, that is the visually sharp reproduction of the CSF space around the mesencephalon and the visually sharp reproduction of CSF space over the brain respectively.
### Dose Related Parameters

<table>
<thead>
<tr>
<th></th>
<th>Posterior Fossa</th>
<th>Cerebrum</th>
<th>Brain</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Slice Thickness (mm)</strong></td>
<td>4</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td><strong>Inter-slice thickness /Gap (mm)</strong></td>
<td>4</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td><strong>Pitch factor (mm/rotation)</strong></td>
<td>n/a</td>
<td>n/a</td>
<td>9</td>
</tr>
<tr>
<td><strong>Average scan length (cm)</strong></td>
<td>13.84</td>
<td></td>
<td>15.34</td>
</tr>
<tr>
<td><strong>kV</strong></td>
<td>120</td>
<td></td>
<td>120</td>
</tr>
<tr>
<td><strong>Smart mA (max)</strong></td>
<td>160</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td><strong>Rotation time (s)</strong></td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Gantry Tilt (degrees)</strong></td>
<td>5.5 – 20 (mean : 13)</td>
<td></td>
<td>No tilt</td>
</tr>
<tr>
<td><strong>Reconstruction Algorithm</strong></td>
<td>Standard</td>
<td>Standard</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 3:** Standard scanning protocol for brain CT

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<table>
<thead>
<tr>
<th>Intra-observer reliability</th>
<th>Pearson’s Corr. (r)</th>
<th>p-value</th>
<th>Cronbach’s Alpha (α)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observer 1</td>
<td>0.72</td>
<td>0.00*</td>
<td>0.81</td>
</tr>
<tr>
<td>Observer 2</td>
<td>0.11</td>
<td>0.66</td>
<td>0.19</td>
</tr>
<tr>
<td>Observer 3</td>
<td>0.50</td>
<td>0.02*</td>
<td>0.65</td>
</tr>
<tr>
<td>Observer 4</td>
<td>0.90</td>
<td>0.00*</td>
<td>0.95</td>
</tr>
</tbody>
</table>

*p-value statistically significant

**Fig. 4:** Intra-observer reliability. This table presents the Pearson's correlation, p-value and Cronbach's Alpha of the four different observers.

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**Fig. 5:** Inter-observer reliability. This table shows the Pearson's correlation value and the p-value for the images evaluated in respect of the four observers.

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<table>
<thead>
<tr>
<th>Observer 1</th>
<th>Pearson Correlation</th>
<th>Observer 2</th>
<th>Observer 3</th>
<th>Observer 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>p-value</td>
<td>1</td>
<td>0.52</td>
<td>1</td>
<td>0.59</td>
</tr>
<tr>
<td>Observer 2</td>
<td>Pearson Correlation</td>
<td>0.52</td>
<td>1</td>
<td>0.59</td>
</tr>
<tr>
<td>p-value</td>
<td>0.00*</td>
<td>0.00*</td>
<td>0.00*</td>
<td></td>
</tr>
<tr>
<td>Observer 3</td>
<td>Pearson Correlation</td>
<td>0.61</td>
<td>0.77</td>
<td>1</td>
</tr>
<tr>
<td>p-value</td>
<td>0.00*</td>
<td>0.00*</td>
<td>0.00*</td>
<td></td>
</tr>
<tr>
<td>Observer 4</td>
<td>Pearson Correlation</td>
<td>0.59</td>
<td>0.34</td>
<td>0.52</td>
</tr>
<tr>
<td>p-value</td>
<td>0.00*</td>
<td>0.00*</td>
<td>0.00*</td>
<td></td>
</tr>
</tbody>
</table>

*p-value statistically significant

**Fig. 6:** This table shows the mean score, standard deviation and p-value for each radiation dose indicator for both sequential and spiral technique.

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<table>
<thead>
<tr>
<th>Dose Indicators</th>
<th>Scanning Technique</th>
<th>N</th>
<th>Min. value</th>
<th>Max. value</th>
<th>Mean Score</th>
<th>Std. Deviation</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTDI$_{vol}$</td>
<td>Sequential</td>
<td>20</td>
<td>20.21</td>
<td>23.69</td>
<td>22.06</td>
<td>0.97</td>
<td>≤ 0.05*</td>
</tr>
<tr>
<td></td>
<td>Spiral</td>
<td>20</td>
<td>12.52</td>
<td>16.35</td>
<td>14.94</td>
<td>1.07</td>
<td></td>
</tr>
<tr>
<td>DLP</td>
<td>Sequential</td>
<td>20</td>
<td>282.90</td>
<td>342.45</td>
<td>304.60</td>
<td>15.01</td>
<td>≤ 0.05*</td>
</tr>
<tr>
<td></td>
<td>Spiral</td>
<td>20</td>
<td>191.51</td>
<td>258.64</td>
<td>229.10</td>
<td>18.43</td>
<td></td>
</tr>
</tbody>
</table>

*p-value statistically significant
**Fig. 7:** The mean rating score of each scanning technique for each criteria is presented along with the p-value and shows whether the difference in rating scores between the two subjects is significant or not.

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Conclusion

One can conclude that all the aims of the study were achieved.

Even though this was a small scale study, the results obtained were all statistically significant. Thus, conclusions could be generalised to the scanning of brain CT exam using a GE Highspeed Dual NX/1 Plus 2 slice CT scanner in line with the local CT protocol.

From the results of this study, spiral technique was found to have significantly lower radiation dose over sequential technique. These results match the findings of Abdeen et al. and Alberico et al. [8,12] where both showed a reduction in radiation dose for spiral technique.

The quality of the images produced using the spiral technique, is of a lower quality to those obtained using the sequential technique. In contrast to the local study, Straten et al. [7] showed a preference to the spiral technique with regards to improved overall image quality especially in the case of brain tissue near the skull. In this local study, an overall result showed a clear preference for the sequential technique with the visualisation of the basal ganglia scoring much higher in the examination scanned with this technique.

Further research is recommended investigating whether the level of image quality produced by the spiral technique is sufficient for diagnosis in order for patients to benefit from associated radiation dose reductions.
References

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