Lesion conspicuity and image quality of cerebral MDCT scans: comparison of filtered back projection and sinogram affirmed iterative reconstruction

Poster No.: C-0926
Congress: ECR 2013
Type: Scientific Exhibit
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Keywords: Technology assessment, Technical aspects, Radiation effects, Image manipulation / Reconstruction, CT, Radioprotection / Radiation dose, Computer applications, CNS, Quality assurance, Biological effects
DOI: 10.1594/ecr2013/C-0926

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Purpose

Iterative reconstruction (IR) of CT image offers significant image noise reduction when compared to filtered back projection (FBP), thus allowing CT acquisitions of comparable image quality with lower radiation dose. The advantages of iterative image reconstruction for dose reduction in various CT studies were recently demonstrated [1-7]. However, there is still a limited evidence of diagnostic image quality, diagnostic accuracy and lesion conspicuity of scans reconstructed with those different reconstruction algorithms.

The purpose of this prospective study is to compare lesion conspicuity, subjective and objective image quality of MDCT brain examinations reconstructed with standard FBP and iterative reconstruction technique, namely sinogram affirmed iterative reconstruction (SAFIRE).
Methods and Materials

Helical head MDCT scans in thirty adults (age 45 - 89 years) with cerebral neurologic symptoms were reconstructed with both FBP and SAFIRE (with three degrees of iteration: SAF1, SAF3, SAF5) on a 128-row single source MDCT scanner using 120 kV, reference mAs of 360, automatic 4D tube current modulation, and 5mm section thickness.

Images were reconstructed using convolution kernel H31 (FBP) and J30 (SAFIRE, with three degrees of iteration: 1, 3, 5). All images were stored and viewed with identical window settings (width 80 HU; center 35 HU).

Following objective image quality criteria were evaluated:

- Gray matter conspicuity defined as $\frac{\text{mean GM} - \text{mean WM}}{\text{mean WM}}$
- Lesion conspicuity defined as an absolute value of $\frac{\text{mean lesion} - \text{mean WM}}{\text{mean WM}}$
- Contrast-to-noise ratio defined as $\frac{\text{mean GM} - \text{mean WM}}{\text{SD GM}^2 + \text{SD WM}^2}$
- Image noise levels for gray, white matter and focal lesions defined as respective SD values

where \( GM \) = gray matter attenuation; \( WM \) = white matter attenuation; \( SD \) = standard deviation of mean attenuation values

Subjective visual quality criteria (with FBP considered as a standard of reference) included:

- Image sharpness
- Lesion conspicuity
- Overall image quality

where 1 = better than FBP; 2 = equal to FBP; 3 = slightly worse than FBP; 4 = significantly worse than FBP; 5 = non-diagnostic

In every subject, a minimum of one and a maximum of four focal cerebral lesions identified on standard FBP scans were used for lesion conspicuity evaluation. Readers were blinded to the type of image reconstruction algorithm used.

For qualitative comparison of reconstruction algorithms, analysis of variance with post hoc Fisher LSD test and Dunnett test were used. For non-parametric variables, Friedman
analysis of variance with Wilcoxon test was utilized. Subjective visual criteria were compared using McNemar test in contingency tables. $P$-values less than 0.05 were considered statistically significant.
Results

Objectively, neither gray matter nor lesion conspicuity differed significantly among all four image reconstruction categories. Contrast-to-noise ratios progressively and significantly improved from FBP to SAFIRE 5 (p<0.01 for each pair of categories): Table 1.

<table>
<thead>
<tr>
<th></th>
<th>FBP</th>
<th>SAF1</th>
<th>SAF3</th>
<th>SAF5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray matter conspicuity</td>
<td>0.253±0.065</td>
<td>0.256±0.069</td>
<td>0.257±0.069</td>
<td>0.254±0.067</td>
</tr>
<tr>
<td>Lesion conspicuity</td>
<td>0.375±0.414</td>
<td>0.376±0.421</td>
<td>0.376±0.429</td>
<td>0.375±0.429</td>
</tr>
<tr>
<td>Contrast to noise ratio</td>
<td>1.649±0.494</td>
<td>1.868±0.567</td>
<td>2.284±0.695</td>
<td>2.858±0.918</td>
</tr>
</tbody>
</table>

Table 1: Objective image quality criteria

Noise levels of gray, white matter and focal lesions progressively and significantly decreased from FBP to SAFIRE 5 (p<0.0001 for each pair of reconstruction categories): Table 2.

<table>
<thead>
<tr>
<th></th>
<th>FBP</th>
<th>SAF1</th>
<th>SAF3</th>
<th>SAF5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray matter</td>
<td>3.7±0.6</td>
<td>3.3±0.5</td>
<td>2.6±0.5</td>
<td>2.1±0.4</td>
</tr>
<tr>
<td>White matter</td>
<td>3.5±0.5</td>
<td>3.1±0.5</td>
<td>2.6±0.4</td>
<td>2.1±0.4</td>
</tr>
<tr>
<td>Lesion</td>
<td>3.6±0.7</td>
<td>3.2±0.7</td>
<td>2.7±0.8</td>
<td>2.2±0.9</td>
</tr>
</tbody>
</table>

Table 2: Image noise levels

Subjectively, there was improved lesion conspicuity in SAFIRE 5 category compared to SAFIRE 1 (p=0.027; kappa reliability test=0.238) and SAFIRE 3 (p=0.019; kappa reliability test=0.352) but there was a decline in image sharpness with increasing degree of iteration (p=0.03 and 0.04, respectively): Table 3.

<table>
<thead>
<tr>
<th></th>
<th>SAF 1 vs. FBP</th>
<th>SAF 3 vs. FBP</th>
<th>SAF 5 vs. FBP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesion conspicuity</td>
<td>2.0±0.3</td>
<td>1.9±0.5</td>
<td>1.7±0.7</td>
</tr>
<tr>
<td>Sharpness</td>
<td>2.1±0.2</td>
<td>2.2±0.4</td>
<td>2.6±0.5</td>
</tr>
<tr>
<td>Image quality</td>
<td>1.8±0.4</td>
<td>1.3±0.5</td>
<td>1.8±0.8</td>
</tr>
</tbody>
</table>
Table 3: Subjective image quality criteria

A total of 64 focal lesions (56 hypoattenuating + 8 hyperattenuating) were available for lesion conspicuity assessment. All lesions were identified in all four reconstruction groups, i.e. no missed lesions were noted in any category.

No score 4 (significantly worse than FBP) or 5 (non-diagnostic) results were encountered in any category.
Fig. 1: Acute subdural haematoma and traumatic intracerebral haemorrhage. The conspicuity of the lesions was rated equal to the original FBP in all three SAFIRE reconstructions. FBP (upper left), SAF1 (upper right), SAF3 (lower left), SAF5 (lower right).

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Fig. 2: Lacunar infarction within the left caudate nucleus. The lesion conspicuity was rated equal to FBP on SAF1 as well as SAF3, however better on SAF5 due to significantly reduced background noise of the caudate. The objective values of the gray matter noise are 3.6 for FBP (upper left), 3.1 for SAF1 (upper right), 2.8 for SAF3 (lower left), and 2.3 for SAF5 (lower right), respectively.
Fig. 3: Image contour sharpness was rated equal to FBP on SAF1 as well as SAF3 but slightly worse on SAF5 due to some blurring of the subarachnoid space interfaces. In contrast, the objective values of the white matter noise significantly decreased from FBP to SAF5: 3.5 for FBP (upper left), 3.2 for SAF1 (upper right), 2.5 for SAF3 (lower left), and 2.2 for SAF5 (lower right), respectively.

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Conclusion

In terms of objective gray matter as well as lesion conspicuity, all three modes of iterative reconstruction (SAF1, SAF3, SAF5) offered results fully comparable with the standard FBP.

As anticipated, the noise levels for gray matter, white matter as well as focal lesions significantly decreased from FBP over SAF1 and SAF3 to SAF5. These results confirm the ability of iterative algorithms to effectively reduce the image noise and are also in accordance with the pilot reports recently published [1, 2, 8, 9]. Logically, those calculated objective criteria which take in consideration the actual values of the image noise, showed the same tendency: contrast to noise ratios significantly improved from FBP to SAF5.

Our observations of mild image sharpness deterioration in protocols using high degree of iteration are in accordance with the results published by Kilic et al [8]. In contrast, Korn et al observed improved sharpness of subarachnoid space margins in IR protocols compared to FBP [9]. In the study of Rapalino et al, no statistically different performance of IR and FBP protocols in terms of image sharpness was found [2].

To our knowledge, this is the first study providing also an assessment of diagnostic performance of IR based protocols in head CT. None of the abovementioned studies dealt with the conspicuity of pathologic cerebral lesions or diagnostic accuracy of IR based algorithms when compared to the standard head CT protocols based on FBP. In our study, objective evaluation of lesion conspicuity showed comparable results in all four image reconstruction groups. Subjective assessment of lesion conspicuity showed equal performance of SAF1 compared to FBP and slightly improved lesion conspicuity in SAF3 and SAF5 groups when compared to FBP. It should be underlined that no missed focal lesions were noted in any image reconstruction group.

In terms of subjective overall image quality, SAF3 protocols showed better performance than SAF1 (showing increased noise levels) or SAF5 (showing decreased image sharpness). Therefore it seems that moderate degree of iteration (SAF3) offers subjectively better perceived overall image quality due to a balanced compromise between image sharpness (SAF1) and minimal image noise (SAF5).

Our study has few limitations. First, the number of subjects enrolled is limited, however, this is the pilot study on lesion conspicuity and diagnostic accuracy of IR head CT protocols. Second, the reconstructed datasets were derived from the same raw data acquired with identical mAs settings, therefore we were not able to simultaneously evaluate the potential of IR for image quality improvements together with radiation dose.
savings. This would require other methodological approaches, e.g. repeated scanning with different mAs settings (not acceptable from the ethical point of view), dual source CT acquisitions (not available at our institution), mathematical modelling of increased noise component over the raw data (introducing artificial manipulation with the raw data sets). Alternatively, at least two separate patient groups must have been scanned with different acquisition parameters (mAs), however, different lesions would have been evaluated in each group which might induce a bias in such case. Therefore, further stratified studies including larger samples will be necessary to address these issues in a more detail.

In conclusion, with increasing number of iterative steps SAFIRE showed decreasing image sharpness compensated by significant improvements in image noise. Despite these differences in objective parameters, the overall diagnostic performance of all SAFIRE protocols was comparable to the conventional FBP. Importantly, no missed lesions were noted in any SAFIRE category. In terms of subjective overall image quality perception, moderately iterated SAFIRE 3 protocols were slightly preferred over SAFIRE 1 or SAFIRE 5 options.