Efficacy of 'fine' focal spot CT abdominal angiography

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Authors: C. W. Oh\textsuperscript{1}, K. K. Lau\textsuperscript{2}, K. Buchan\textsuperscript{3}, N. Ardley\textsuperscript{3}; \textsuperscript{1}Melbourne/AU, \textsuperscript{2}Clayton/AU, \textsuperscript{3}Melbourne, Victoria/AU
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Aims and objectives

Introduction

In the past decade, CT abdominal angiography (CTAA) has been established as first line imaging modality for evaluation of abdominal vascular anatomy and pathology\(^1\). It plays a vital role in diagnosing and monitoring conditions such as abdominal aortic aneurysm, aortic dissection, acute mesenteric ischemia, ischemic colitis, endoleak and gastrointestinal bleed. Its advantages in comparison to digital subtraction angiography (DSA) are shorter acquisition time, non-invasive nature, less procedural complications and the ability to study soft tissue structure around the blood vessels\(^2\). This is especially useful in the emergency trauma setting.

CT image quality is described in terms of contrast, spatial resolution, image noise, and artifacts. Vessel wall calcification that may cause beam-hardening artifact, as well as low spatial resolution, can significantly impact the image quality of CTAA as it can lead to underestimation or overestimation of blood vessel stenosis\(^2-3\), and wall thickening.

The focal-spot size in the x-ray tube is an important factor that defines spatial resolution of a CT system. Many CT tubes have two focal-spot sizes, with the smaller spot size allowing more detailed imagery at a cost in intensity. Conventionally, body structures for which good low-contrast resolution is essential need to be scanned with a large focal spot and high power, whereas high resolution images with thin slices require a small focal spot. Tubes can, however, be operated at maximum power for a limited time only. These limits are defined by the properties of the anode and the generator. To prevent overloading of the X-ray tube, the power must be reduced for long scans, such as CTAA. The development of multi-row detector systems has practically excluded this limitation, since these detector systems make much more efficient use of the available tube power. In addition, latest x-ray generator can deliver higher mA values on a small focal spot size allows similar x-ray intensity as the larger focal spot. The use of fine focal-spot size in CT angiography may result in better vessel clarity and less vessel calcification beam-hardening artefact.

The aim of this prospective study was to assess the efficacy of fine focal spot scanning in calcification beam hardening artifact reduction and vessel clarity on CTAA.
Methods and materials

**Subjects**

All consecutive adult patients of all gender and ages who underwent CTAA at the Radiology Department in a tertiary hospital in Melbourne, Australia over 6 months period were included. Patients who could not give consent, had severe renal impairment or contrast allergy were excluded.

**Computed Tomography (CT)**

All CTAA were performed on Philips Ingenuity 128 row multi-detector CT (Cleveland, USA) which had two focal spot setting. Consecutive patients were scanned with standard focal spot size (SFSS) of 1x1 mm in the first three months of study while consecutive patients were scanned with fine focal spot size (FFSS) of 1 x 0.5mm in the following three months. All scans samples utilized identical protocols utilizing 100kV, 0.4 rotation time, a pitch of 0.98 and iDose$^4$ as standard with the current (mA) modulated as suggested per patient size. Each patient received 100ml of intravenous contrast agent (Ioxehol, Omnipaque-350, GE Healthcare, Milwaukee, WI, USA) at 5ml per second via a pressure injector.

**Imaging Review**

All axial images of CTAA were randomly reviewed on Picture Archiving and Communication System (PACS) by a blinded senior radiologist. For data analysis, the abdominal arterial system was divided into seven arterial segments: abdominal aorta, celiac axis, superior mesenteric artery, inferior mesenteric artery, renal arteries, common iliac arteries and external iliac arteries.

Each arterial segment was assessed for calcification beam-hardening artifact and blood vessel wall clarity using a five point grading scale (1: unable to interpret, 2: fair, 3: adequate for interpretation, 4: good, 5: excellent) (table 1). Window leveling was used liberally to help delineate the contrast filled lumen from calcification.

**Table 1.**
Five point grading scale

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Unable to interpret</td>
</tr>
<tr>
<td>2</td>
<td>Fair</td>
</tr>
<tr>
<td>3</td>
<td>Adequate for interpretation</td>
</tr>
<tr>
<td>4</td>
<td>Good</td>
</tr>
<tr>
<td>5</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

**Data analysis method**

As our data was non parametric, we utilized Mann-Whitney tests to compare SFSS and FFSS for both calcification artifact and vessel wall clarity. Derived statistics (e.g. U / Z / W) assist in ascertaining the significant differences between the two groups, with higher absolute values suggesting larger differences in each case.
Results

During the study period, 39 patients (17 female, 22 male, mean age of 65 years with age range of 20 - 86 years) were scanned in the SFSS group and 31 patients (13 female, 18 male, mean age of 70 years with age range of 31 - 88 years) were scanned in the FFSS group.

In SFSS group, a total of 268 arterial segments were studied, out of which 152 arterial segments had vessel wall calcifications. In FFSS group, a total of 217 arterial segments were studied, out of which 141 arterial segments had vessel wall calcifications (Table 2).

Table 2.

<table>
<thead>
<tr>
<th></th>
<th>SFSS</th>
<th>FFSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of arterial segments reviewed</td>
<td>268</td>
<td>217</td>
</tr>
<tr>
<td>Total number of arterial segments with calcification</td>
<td>152</td>
<td>141</td>
</tr>
</tbody>
</table>

**Calcification artifact**

For SFSS group, majority of the calcified arterial segments (97 out of 152) had grade four rating for calcification beam-hardening artifact. On the other hand, in FFSS group majority of the calcified arterial segments (103 out of 141) had grade five rating for calcification beam-hardening artifact (table 3) (Fig. 1 on page 8).

Table 3. Count and Percentage comparing standard focus CT scans and fine focus CT Scans for calcification artifact

<table>
<thead>
<tr>
<th>Standard focus CT</th>
<th>Count</th>
<th>%</th>
<th>Fine focus CT</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Grade 2</td>
<td>6</td>
<td>3.95%</td>
<td>0</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Grade 3</td>
<td>49</td>
<td>32.24%</td>
<td>1</td>
<td>0.71%</td>
<td></td>
</tr>
<tr>
<td>Grade 4</td>
<td>97</td>
<td>63.82%</td>
<td>37</td>
<td>26.24%</td>
<td></td>
</tr>
</tbody>
</table>
A Mann-Whitney test was also conducted to compare rating scores for calcification beam-hardening artifact between standard focus CT scans and fine focus CT scans. Results indicated a significant difference between the two groups, $U = 1916$, $p < .001$, $r = .77$, with the fine focus CT scans ($Med = 5$) performing significantly better, in terms of reviewer ratings, compared to the standard focus CT scans ($Med = 4$) (Table 4) (Fig. 2 on page 8, Fig. 3 on page 9, Fig. 4 on page 10).

Table 4. Mann-Whitney test for calcification artifact

<table>
<thead>
<tr>
<th>Ranks</th>
<th>Group</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratings</td>
<td>Standard focus CT</td>
<td>152</td>
<td>89.11</td>
<td>13544.00</td>
</tr>
<tr>
<td></td>
<td>Fine focus CT</td>
<td>141</td>
<td>209.41</td>
<td>29527.00</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>293</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Count and Percentage comparing standard focus CT scans and fine focus CT Scans for vessel wall clarity

<table>
<thead>
<tr>
<th>Vessel wall clarity</th>
<th>Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann-Whitney U</td>
<td>1916.00</td>
</tr>
<tr>
<td>Wilcoxon W</td>
<td>13544.00</td>
</tr>
<tr>
<td>Z</td>
<td>-13.126</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>.000</td>
</tr>
<tr>
<td>a. Grouping Variable: Group</td>
<td></td>
</tr>
</tbody>
</table>

In terms of rating for vessel wall clarity, SFSS group had 165 out of 268 arterial segments with grade four rating and FFSS group had 140 out of 217 arterial segments with grade five rating (table 5) (Fig. 5 on page 10).
A Mann-Whitney test was conducted to compare rating scores for vessel wall clarity between standard focus CT scans and fine focus CT scans. Results indicated a significant difference between the two groups, $U = 6481.50$, $p < .001$, $r = .73$, with the fine focus CT scans ($Med = 5$) performing significantly better, in terms of reviewer ratings, compared to the standard focus CT scans ($Med = 4$) (table 6) (Fig. 6 on page 11, Fig. 7 on page 12).

Table 6. Mann-Whitney test for vessel wall clarity

<table>
<thead>
<tr>
<th>Ranks</th>
<th>Group</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating</td>
<td>Standard focus CT</td>
<td>268</td>
<td>160.74</td>
<td>43882.50</td>
</tr>
<tr>
<td></td>
<td>Fine focus CT</td>
<td>217</td>
<td>352.13</td>
<td>76412.50</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>485</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Vessel wall clarity

<table>
<thead>
<tr>
<th></th>
<th>Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann-Whitney U</td>
<td>6481.500</td>
</tr>
<tr>
<td>Wilcoxon W</td>
<td>43882.500</td>
</tr>
<tr>
<td>Z</td>
<td>-16.114</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>.000</td>
</tr>
</tbody>
</table>

a. Grouping Variable: Group
Fig. 1: This bar chart demonstrated that the FFSS group had higher grading for calcification artifact than the SFSS group. Higher grading corresponded to less calcification beam-hardening artifact.

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Fig. 2: Axial images of CTAA in a 80 years old male demonstrated common iliac stents bilaterally. The fine focus CT scan produced less streak artifact from the iliac stents (b) compared to the standard focus CT scan (a). The vessel, soft tissue and bone details were of better clarity in fine focus CT images (b).

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**Fig. 3:** Axial images of CTAA in a 76 years old male demonstrated an abdominal aortic aneurysm, including the superior mesenteric artery. The standard focus CT scan (a) produced significantly more blooming artifact from vessel wall calcification (arrow) in superior mesenteric artery that obscured luminal details compared to the fine focus CT scan (b). The aortic calcifications also produced less blooming artifact with fine focus CT scanning.

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**Fig. 4:** Coronal images of the CTAA in a 70 years old male demonstrated that the fine focus CT scan (b) produced relatively less streak artifact from the iliac stent and better vessel clarity than the standard focus CT scan (a).

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**Fig. 5:** This bar chart demonstrated that the FFSS group again had a better rating from the reviewer for vessel wall clarity than the SFSS group.

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Fig. 6: Sagittal images of CT chest and abdominal angiography in a 62 years old male demonstrated an aortic dissection extending from the aortic arch to the abdominal aorta. The intimal flap was more clearly depicted on the fine focus CT scan (b) with much sharper contour. The superior mesenteric arterial wall was also noted to have a better vessel definition on the fine focus CT scan (b).

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Fig. 7: Axial images of CTAA in a 80 years old male demonstrated the celiac trunk branching out from the abdominal aorta. Vessel wall on the fine focus CT scan (b) was affected by less image noise than that on standard focus CT scan(a).

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Conclusion

Discussion

Spatial resolution of a CT system is defined as the ability to differentiate objects of different density a small distance apart against a uniform background\(^7\). In conventional CT system, the x-ray tube has dual filaments, which provide two focal spot sizes ranging from 0.5 to 2mm\(^4\). Focal spot size is one of the main geometric factors that affect the spatial resolution of a CT system\(^7-8\). X-ray photons emerging from various point on a measurable focal spot are responsible for producing blurred, unsharp edges of anatomic details\(^6\). A smaller or finer focal spot size will produce a CT image with higher spatial resolution or less blurriness\(^6\) (Fig. 8 on page 15). Thus, high resolution scanning involves the use of fine focal spot size.

Focal spot size is also associated with the buildup of heat within the x-ray tube. Fine focal spot will concentrate the heat to a small area, which can cause damage to the x-ray tube\(^6\). The x-ray intensity often needs to be limited or lowered down to deal with this problem\(^5\). Thus in the past, fine focal spot size may not be able to be utilized routinely for scanning of different parts of human body.

With recent advancement in CT scanner technology, the shorter scanning time with multi-detector CT that has superior temporal resolution and the latest x-ray tube that has a better cooling system overcomes the problem of heat build-up in the x-ray tube\(^9\). In other words, the x-ray tube can now handle higher mA values on a fine focal spot size, which allows similar x-ray intensity as the larger focal spot. Use of fine focal spot in routine body CT scanning, including CT angiography, has been made possible.

Vessel wall calcification typically produces a certain degree of blooming artefact. This artifact interfere with the assessment of arterial stenosis and it leads to either underestimation or overestimation of arterial stenosis\(^2,10\). This is more apparent in patients with diabetes mellitus, cardiac condition and elderly age (older than 84 years old) as they tend to have heavily calcified arteries\(^2\). Circumferential calcification can also accentuate the blooming artifact and may adversely affect smaller vessels\(^14\).

Several techniques have been developed to overcome calcification blooming artifact such as the use of wide bone window level setting, sharp kernel, multiplanar reconstruction...
and local subtraction technique\textsuperscript{12,13,15}. Recently, bone and plaque removal using dual energy CT has also been utilized to deal with this issue\textsuperscript{11,13,14}. Fine focus CT scanning can be another new and useful technique to help minimize calcification blooming artifact and thus improve the accuracy in assessment of luminal stenosis in calcified vessels.

The result of this study has demonstrated that the use of fine focus scanning in CT abdominal angiography produces image with better vessel wall clarity and less calcification blooming artifact. Limitations of this study were the relatively small number of subjects and only one blinded CT reviewer. Despite this, the result was highly significant when compared between the two groups. Future study of bigger number of subjects and blindly randomized into SFSS and FFSS groups with several blinded radiologists to review would be able to confirm these benefits of fine focal spot scanning in CTAA.

\textbf{Conclusion}

To our knowledge, this is the first study in the literature that assesses the efficacy of fine focus CT scan in medical imaging. It will become a promising and important CT scanning technique, which offers clearer images with fewer artifacts, and therefore, improves the blood vessel assessment.
Fig. 8: This diagram demonstrates that the area of blurriness expands as the focal spot size increases.

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Personal information

Dr. Chia Wei Oh, Lawrence
Resident Medical Officer
Monash Health
email: chia.wei.oh@gmail.com

A/Prof. Kenneth Lau
Consultant Radiologist
Monash Health

Mr. Kevin Buchan
Clinical Science Development Specialist
Philips Healthcare
email: kevin.a.buchan@philips.com

Mr. Nicholas Ardley
CT Supervisor
Monash Health
email: Nicholas.Ardley@monashhealth.org
References


