Detection and evaluation of intracranial aneurysms with 16-row multislice CT angiography


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AIM: The aim of this study was to assess the usefulness of 16-row multislice CT angiography (CTA) in evaluating intracranial aneurysms, by comparison with conventional digital subtraction angiography (DSA) and intraoperative findings.

METHODS: A consecutive series of 57 patients, scheduled for DSA for suspected intracranial aneurysm, was prospectively recruited to have CTA. This was performed with a 16-detector row machine, detector interval 0.75 mm, 0.5 rotation/s, table speed 10 mm/rotation and reconstruction interval 0.40 mm. CTA studies were independently and randomly assessed by two neuroradiologists and a vascular neurosurgeon blinded to the DSA and surgical findings. Review of CTA was performed on workstations with an interactive 3D volume-rendered algorithm.

RESULTS: DSA or intraoperative findings or both confirmed 53 aneurysms in 44 patients. For both independent readers, sensitivity and specificity per aneurysm of DSA were 96.2% and 100%, respectively. Sensitivity and specificity of CTA were also 96.2% and 100%, respectively. Mean diameter of aneurysms was 6.3 mm (range 1.9 to 28.1 mm, SD 5.2 mm). For aneurysms of less than 3 mm, CTA had a sensitivity of 91.7% for each reader. Although the neurosurgeon would have been happy to proceed to surgery on the basis of CTA alone in all cases, he judged that DSA might have provided helpful additional anatomical information in 5 patients.

CONCLUSION: The diagnostic accuracy of 16-slice CTA is promising and appears equivalent to that of DSA for detection and evaluation of intracranial aneurysms. A strategy of using CTA as the primary imaging method, with DSA reserved for cases of uncertainty, appears to be practical and safe.

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KEYWORDS
Computed tomography (CT); Angiography; Subarachnoid haemorrhage; Intracranial aneurysm

Introduction

Intra-arterial digital subtraction angiography (DSA) remains the accepted gold standard for the diagnostic work-up of suspected intracranial aneurysms. Concerns over the small but potentially significant risk of permanent neurological complications associated with DSA has generated growing interest in the use of alternative non-invasive techniques, among which CT angiography (CTA) has emerged as the method of choice. The advantages of CTA have been well described previously. CTA is safe, relatively inexpensive and can be performed immediately after routine un-enhanced CT of the brain with a single bolus of intravenous contrast medium, thereby allowing rapid diagnosis and treatment decisions. Moreover, images of diagnostic quality can be acquired swiftly in confused or uncooperative patients, obviating...
the need for intravenous sedation or general anaesthesia for the lengthier DSA. Early studies of CTA using single-slice technology have, however, shown limited diagnostic accuracy in the detection of small aneurysms less than 3 mm in diameter.\textsuperscript{3–7} Over the last few years, implementation of multi-detector row spiral CT technology has led to considerable improvement in the quality and spatial resolution of 2D and 3D reconstructions, which can now easily be viewed in any direction with commercially available workstations and software. Recent studies reporting on the use of four-detector row multislice CTA have generally shown promisingly high accuracy for the detection of small aneurysms as well as excellent depiction of morphological characteristics and related surgical anatomy.\textsuperscript{8–10} The main objective of this study is to report our early experience with 16-detector row multislice spiral CTA in the detection and pretreatment evaluation of intracranial aneurysms compared with DSA or findings at surgery or both, and coiling.

Materials and methods

Subjects

Between March and October 2003, consecutive adults who were scheduled for conventional DSA for suspected intracranial aneurysm were prospectively recruited in the study to have a CTA examination. The study was approved by the local ethics committee. Written informed participant consent or relative’s assent was obtained in all cases.

Imaging protocols

Conventional four-vessel DSA was performed by one of three attending neuroradiologists, on a digital angiographic unit (Angioskop, Siemens, Erlangen, Germany) via the femoral artery using the Seldinger method. Standard anteroposterior and lateral projections were routinely acquired, with additional selected oblique projections at the discretion of the neuroradiologist. Images were acquired with a 33-cm field of view, 1024×1024 matrix and resolution of 0.32×0.32 mm, and were recorded on hard-copy film.

The CTA examinations were performed on a 16 multi-detector row spiral CT machine (Somatom Sensation 16, Siemens, Erlangen, Germany), based on a standardized protocol. Using an intravenous cannula in the antecubital fossa, 100 ml of contrast agent (Niopam 300, Merck, Alton, UK) were injected with a powered injector at the rate of 5 ml/s. An automatic fluoroscopic bolus-triggered system, with the aortic arch as reference point and a delay of 6 s, determined the optimal timing of the data acquisition according to the following protocol: spiral mode, 0.5 rotation/s, 16-detector rows at 0.75 mm intervals, table speed 10 mm/rotation, reconstruction interval 0.40 mm at Kernel H20 and acquisition parameters 120 KVP/130 mA. Actual acquisition time was approximately 5 s. The volume of coverage extended from the first cervical vertebra to the superior aspect of the frontal sinuses.

In 4 participants with poor-grade subarachnoid haemorrhage (SAH), both DSA and CTA were performed under general anaesthetic. In the remainder DSA was performed under local anaesthesia, with intravenous sedation for 3 patients with confusion or agitation or both. Intravenous sedation was not administered before any of the CTA examinations.

Image review

The DSA studies were reviewed on hard-copy films by one of three attending neuroradiologists. The maximum diameter of the sac of any detected aneurysm was measured using a Vernier calliper calibrated to the nearest 0.1 mm. The CTA examinations were reviewed in a randomized order by two independent neuroradiologists on a workstation using a commercially available interactive 3D volume-rendering image viewer (Syngo InSpace, Siemens AG Medical Solutions, Erlangen, Germany). Mean time taken for CTA image reconstruction and interpretation was 12 min (range 9 to 18 min). The CTA examinations were masked for patient identifiers and review was performed blinded to the DSA results. For both DSA and CTA, readers had access to brief anonymized clinical details (as on the radiology request cards) as well as to the anonymized un-enhanced CT examinations, in order to reproduce the circumstances of routine clinical practice. In addition to diagnostic yield, DSA and CTA images were also evaluated for image quality based on arterial signal intensity, spatial resolution, artefacts and presence of venous contamination. Image quality was graded as: 1, excellent; 2, more than adequate; 3, adequate for diagnosis; and 4, inadequate for diagnosis.

All cases of negative DSA were confirmed by repeat DSA at an interval of 1 week. Although DSA is considered the gold standard diagnostic test, it is well recognized that it may occasionally fail to
detect aneurysms. In our study, all aneurysms detected at DSA were confirmed either by intraoperative findings or endovascular coiling. We therefore used the combination of DSA or findings at surgery or both, and coiling, as an ultimate reference standard against which the diagnostic accuracy of CTA and DSA were compared.

In our clinical practice, surgical and endovascular treatment decisions were mainly based on the results of the DSA alone. An experienced vascular neurosurgeon retrospectively reviewed all the CTA examinations, with access to brief anonymized clinical details and un-enhanced CT, in a randomized order and blinded to DSA and surgical findings. The aim was to assess whether the anatomical information provided would have been sufficient to proceed to treatment on the basis of CTA alone. Criteria for evaluation included characterization of aneurysmal morphology, parent and feeding vessels, collateral circulation at the circle of Willis such as contribution of the internal carotid artery (ICA) to the posterior circulation in participants with posterior communicating aneurysms, and finally relationship to other structures such as bone. In selected cases where he judged that DSA might have been helpful, the neurosurgeon proceeded to review the DSA and compare it with the CTA to assess whether DSA actually provided any additional information.

Results

Population

A total of 57 subjects (26 women, 31 men, mean age 53 years, range 22 to 81 years) was prospectively recruited and completed both examinations. One man was excluded because he refused consent. In another case, the CTA examination was abandoned because extravasation of contrast material caused local pain at the injection site after an intravenous cannula malfunctioned. Clinical indications for DSA were as follows: SAH on CT (n=45), xanthochromia on lumbar puncture (n=7), strong clinical suspicion of SAH (n=4) and cranial nerve palsy (n=1). The clinical status of the 56 participants who presented in the setting of SAH was, according to the World Federation of Neurosurgical Societies scale, as follows: grade 1, n=35; grade 2, n=14; grade 3, n=4; grade 4, n=3; and grade 5, n=0.

Detection of aneurysms

All CTA and DSA examinations were performed within a period of 3 days, without any intervening surgical or endovascular treatment. Complications of DSA included 2 cases of minor groin haematoma, but no neurological events. Quality of DSA, as judged by the neuroradiologists, was excellent in 50 cases, more than adequate in 5 cases and only adequate in 2 cases (because of motion artefacts and an occluded ICA). There were no complications related to CTA or use of contrast agent. All CTA examinations were diagnostic, with 51 cases judged as excellent, 4 cases as more than adequate and 2 cases as adequate. The quality of the last was due to inaccurate timing of CT acquisition and subsequent venous contamination for idiosyncratic reasons such as irregular cardiac output.

The combination of DSA or surgical findings or both was used as a reference standard against which the accuracy of DSA and CTA was compared. Overall, 53 aneurysms were found in 44 participants and no aneurysms were found in 13 participants; 5 subjects had 2 aneurysms each (Fig. 1) and 2 subjects had 3 aneurysms each. There were 18 anterior cerebral artery aneurysms (15 of the anterior communicating artery and 3 pericallosal); 21 ICA (18 of the posterior communicating artery, 2 intracavernous and 1 paracallosal); 8 MCA; and 6 posterior circulation (4 of the tip of the basilar artery and 2 posterior inferior cerebellar) aneurysms. Mean diameter of the aneurysms was 6.3 mm (range 1.9 to 28.1 mm, SD 5.2 mm). The distribution of aneurysms according to size was: 12 of < 3 mm; 20 of 3 to 5 mm; 14 of 5 to 10 mm; and 7 of > 10 mm.

DSA depicted 51 aneurysms in 42 participants, failing to detect 2 aneurysms in 2 participants. The accuracy of DSA per aneurysm and per patient is illustrated in Table 1. In 1 subject with negative DSA, very strong clinical suspicion prompted review of CTA which depicted a small right-sided MCA aneurysm of 3 mm. In another case, DSA revealed an area of irregularity in the ACoA but no definite aneurysm. This DSA was reported as technically difficult because of an ICA occlusion. CTA clearly depicted an anterior communicating artery (ACoA) aneurysm of 3 mm (Fig. 2). Both these patients proceeded to surgery on the basis of the CTA findings and aneurysms were subsequently confirmed intraoperatively.

The accuracy of CTA per aneurysm and per patient for each of the two independent reviewers is also illustrated in Table 1. Both reviewers thus failed to detect an incidental non-causative intracavernous ICA aneurysm of 3 mm, contralateral to the site of haemorrhage, which was apparent on DSA (Fig. 3). This aneurysm was not clearly depicted on retrospective of the CTA with
the volume-rendered software, but was better shown on the raw source images as well as the multiplanar reconstructions. In addition, reviewer 1 failed to detect a causative posterior communicating artery (PCoA) aneurysm of 2 mm, which was detected by reviewer 2. Reviewer 2 failed to detect a causative pericallosal aneurysm of 3 mm, but this aneurysm was detected by reviewer 1. These two missed aneurysms, which had bled, were depicted at consensus review of CTA and were subsequently coiled. For detection of the 12 aneurysms of less than 3 mm, the sensitivity of CTA was 91.7% (95% CI 65.6–98.5) for both readers independently. There were no cases of CTA false positives. Although per patient the negative predictive value of CTA was slightly higher than that of DSA (92.9% and 86.9%, respectively), this was not statistically significant (Fisher’s exact test, \( p = 1.000 \)).

**Pretreatment evaluation**

The vascular neurosurgeon would have been happy to proceed to surgical exploration and clipping on the basis of the anatomical information provided by CTA alone in all cases. However, in 5 cases, he would have preferred an additional DSA procedure to further help clarify the surgical anatomy. The reasons why he would have requested DSA in these 5 cases, as well as the actual additional information provided by the DSA are illustrated in **Table 2**. In 1 case DSA provided additional information, but in the remaining 4 cases DSA did not provide any better anatomical delineation or was actually less helpful than CTA (Fig. 4).

**Discussion**

There have been previous concerns regarding the ability of single-slice spiral CTA to detect small aneurysms of less than 3 mm in diameter.\(^3\)\(^-\)\(^6\) A systematic review published in 1998, focusing mainly on single-slice spiral CTA, found an alarmingly low sensitivity of 61% for such aneurysms.\(^3\) Recent initial reports of first-generation four-detector row multislice CTA have been generally encouraging, although a cut-off of 2 mm has emerged as the size below which aneurysm detection may be problematic.\(^8\)\(^-\)\(^10\) Kangasniemi et al. reported 99% sensitivity and 99% specificity in 179 patients for aneurysms of 2 mm or more, although 7 of 11 aneurysms of less than 2 mm were not depicted by four-slice CTA.\(^9\) Wintermark et al.

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**Table 1** Accuracy per aneurysm and per patient of DSA and CTA for detection of aneurysms by independent readings; 95% CIs are shown in parentheses. The combination of DSA and/or surgical findings was used as the reference standard for all comparisons.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Positive predictive value</th>
<th>Negative predictive value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per aneurysm (n = 53)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>DSA</td>
<td>96.2% (87.5–99.0)</td>
<td>100% (77.2–100)</td>
<td>100% (93.0–100)</td>
<td>86.7% (62.7–93.3)</td>
</tr>
<tr>
<td>CTA reviewer 1</td>
<td>96.2% (87.5–99.0)</td>
<td>100% (77.2–100)</td>
<td>100% (93.0–100)</td>
<td>86.7% (62.7–93.3)</td>
</tr>
<tr>
<td>CTA reviewer 2</td>
<td>96.2% (87.5–99.0)</td>
<td>100% (77.2–100)</td>
<td>100% (93.0–100)</td>
<td>86.7% (62.7–93.3)</td>
</tr>
<tr>
<td>Per patient (n = 44)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>DSA</td>
<td>95.4% (85.0–97.0)</td>
<td>100% (77.2–100)</td>
<td>100% (91.6–100)</td>
<td>86.7% (62.7–93.3)</td>
</tr>
<tr>
<td>CTA reviewer 1</td>
<td>97.7% (88.2–99.6)</td>
<td>100% (77.2–100)</td>
<td>100% (91.8–100)</td>
<td>92.9% (68.5–98.7)</td>
</tr>
<tr>
<td>CTA reviewer 2</td>
<td>95.5% (88.2–99.6)</td>
<td>100% (77.2–100)</td>
<td>100% (91.8–100)</td>
<td>92.9% (68.5–98.7)</td>
</tr>
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</table>
showed that four-slice CTA depicted 1 of 2 aneurysms of less than 2 mm, although they acknowledged the difficulty of drawing conclusions from such small numbers.8

We found overall sensitivities of 91.7% for our two readers for the detection of 12 aneurysms of less than 3 mm. Of these, 2 aneurysms of 2 mm and 1 aneurysm of less than 2 mm were all correctly depicted by CTA. Unfortunately, the low clinical prevalence of aneurysms of less than 2 mm again precludes the calculation of meaningful statistics. However, 16-detector row technology allows the acquisition of data with spatial resolution comparable with DSA in periods of 5 s or less. The reconstruction interval of our CTA slices was 0.4 mm compared with the spatial resolution of DSA (0.32×0.32 mm) and this impressive submillimetre resolution may help enhance the detection of very small aneurysms. In contrast, to achieve the same order of spatial resolution with our four-slice CT machine, a scanning time of approximately 30 s would have been required. This longer scanning time may have a negative effect on image quality due to the increased possibility of venous contamination as well as motion artefacts in a population which is often unwell. The fast acquisition times are reflected in the diagnostic quality of our CTA studies, in which 51 of 57 studies were classified excellent.

Review of CTA examinations using the 3D interactive volume-rendered viewer was unanimously judged to be very practical, operator-friendly and time-efficient by all our readers. It was found to be more useful than other reconstruction algorithms such as maximum intensity projections and surface shaded display and did not require post-processing time, which was a criticism of older volume-rendering software.11 The rapid multidirectional 3D image manipulation algorithm coupled with the Inspace application which allows real-time clip-plane melt-through, “peeling” away layers of bone to reveal the desired layers of vascular anatomy, enabled very high degrees of diagnostic confidence among our readers. Such review of images on the workstation has previously been shown more accurate than isolated hard-copy film review.12 Selected images in the desired projections can be easily stored or printed on hard-copy films for subsequent use in the operating theatre if PACS (Picture Archiving Communication Systems) is not available.

Overall, we found that CTA had a diagnostic accuracy which appeared equivalent to that of conventional DSA in the detection of aneurysms. The 2 cases of false-negative conventional DSA results were both directly due to acquisition of limited biplane projections that failed to depict aneurysms which were clearly revealed by the 3D CTA reconstructions. Such operator-related errors in performing conventional DSA unfortunately do occur in the real world. It is likely, however, that the latest generation 3D rotational DSA techniques, which eliminate the disadvantages of limited 2D

Figure 2 A 74-year-old man presented with sudden onset of headache and mild confusion, with no other neurological deficit. Cranial CT showed diffuse subarachnoid haemorrhage with early hydrocephalus. At DSA, the left internal carotid artery was occluded. (a) Although there was an irregularity in the region of the anterior communicating artery (ACoA) (arrow), no definite aneurysm was identified on DSA. (b) CTA clearly depicted an ACoA aneurysm of 3 mm (arrow), which was confirmed at surgical exploration.
projections associated with conventional DSA, would have revealed these aneurysms. This is therefore a limitation of our study, in that we are comparing the latest generation of CTA, which can be viewed in 3D on workstations, against an older generation of conventional DSA which is generally viewed in clinical practice on 2D hard-copy films. Such a comparison is still, however, practically relevant because many centres may not have access to rotational DSA and may be acquiring modern 16-slice CT machines. We therefore retain our cautious conclusion that 16-slice CTA may be as good as DSA, but we cannot conclude that it is actually better than DSA.

Although we generally found no difficulty in detecting aneurysms close to bone with the Inspace clip-plane algorithm, the incidental intracavernous aneurysm missed on CTA by both our reviewers was not convincingly demonstrated even on retrospective review of the CTA volume-rendered reconstructions. This was depicted on review of the CTA raw source images as well as the multiplanar reconstructions (Fig. 3). Although the potential clinical consequences of missing such an incidental extradural aneurysm (which would not have caused an SAH) are uncertain, this single case suggests that review of raw source images is crucial if volume-rendered reconstructions fail to demonstrate an aneurysm in the intracavernous or intrapetrous portions of the ICA in the face of strong clinical suspicion of aneurysms in those regions.

The additional 2 cases of detection failure for CTA were clearly the result of individual observer errors, seeing that each case was detected by the other reviewer. It is noteworthy that all the errors occurred in the early stages of CTA review in our study and may be partly associated with familiarity with the 3D CTA image viewing software. Our study

Table 2

<table>
<thead>
<tr>
<th>Case</th>
<th>Site of aneurysm</th>
<th>Reason why DSA judged potentially helpful</th>
<th>Additional information provided</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient 14</td>
<td>ACoA</td>
<td>Unable to determine if ACoA filled from one or both anterior cerebral arteries</td>
<td>ACoA filling from anterior cerebral arteries depicted</td>
</tr>
<tr>
<td>Patient 15</td>
<td>Cavernous ICA</td>
<td>Unable to assess cross-flow from ICA/ECA</td>
<td>No additional information provided</td>
</tr>
<tr>
<td>Patient 17</td>
<td>PICA</td>
<td>PICA filling not seen</td>
<td>PICA filling not seen</td>
</tr>
<tr>
<td>Patient 21</td>
<td>Basilar tip</td>
<td>Relationship of aneurysm to PCA difficult to define</td>
<td>Depiction of anatomy worse on DSA</td>
</tr>
<tr>
<td>Patient 23</td>
<td>PCoA</td>
<td>Anterior choroidal vessels not demonstrated</td>
<td>DSA did not display choroidal vessels</td>
</tr>
</tbody>
</table>

ACoA, anterior communicating artery; ICA, internal carotid artery; PICA, posterior inferior carotid artery; PCoA, posterior communicating artery; ECA, external carotid artery; PCA, posterior cerebral artery.

* Found to be absent at surgery.
also shows that CTA would have potentially provided enough anatomical information to proceed to surgery without DSA in the great majority of cases, a finding consistent with several previous studies.\textsuperscript{15,16} Such an approach has been prospectively shown to be reliable and safe by previous studies.\textsuperscript{7,17} In our study it is interesting that of the 5 cases where the neurosurgeon would have preferred an additional DSA, only in 1 case did DSA actually provide additional information over and above that of CTA (Table 2). This probably in part reflects a certain lack of confidence in relatively new imaging techniques such as CTA. The need for DSA should automatically decrease as the technology becomes increasingly available and clinicians become more familiar with the 3D image reconstructions. In the early stages of implementation of CTA it is, however, a perfectly reasonable approach to proceed to DSA in any case of even slight uncertainty.

It was outside the scope of the design of our study to try to answer the clinical question as to whether CTA alters the decision to select open or endovascular treatment for intracranial aneurysms.\textsuperscript{9} Wintermark et al. correlated sac/neck ratios for DSA and CTA and found a fair correlation and good interobserver agreement, suggesting that decisions based on CTA and DSA for suitability for endovascular coiling should be consistent.\textsuperscript{8} At many institutions, including ours, suitability for endovascular coiling is, however, often based on subjective assessment and “eye-balling” rather than arbitrary and formal sac/neck ratio measurements. Moreover, it is also difficult meaningfully and objectively to compare a 2D technique such as conventional DSA on hard-copy films with a 3D technique such as CTA reviewed on workstations with unlimited possible projections, by using an “eyeballing” approach. In context, the clinical possibility should be noted of an unnecessary general anaesthetic for a person referred on the basis of CTA alone for endovascular coiling of an aneurysm subsequently found to be unsuitable for coiling during intraprocedural DSA. Although this worse-case scenario would obviously have important clinical repercussions, it would not be totally catastrophic for the patient. The issue about how CTA may alter management decisions related to therapeutic options and any potential problems related to this can only be definitively answered as more and more institutions base treatment on CTA alone and report their experiences.\textsuperscript{18}

A point of interest is that our study was performed at a single academic centre. Whereas DSA is usually performed and interpreted by experienced neuroradiologists, CTA may now easily be performed in district general hospitals and may therefore be interpreted by general radiologists with limited experience in detection of such aneurysms. There is some evidence that interobserver experience may be important in accurate diagnosis.\textsuperscript{19}

\textbf{Figure 4} A 60-year-old woman presented with headaches and diplopia and was found to have a right oculomotor nerve palsy. Both DSA and CTA depicted a giant aneurysm at the tip of the basilar artery (arrowhead). However, CTA was superior at demonstrating the relationship of the surrounding vessels (such as the posterior cerebral artery, arrows) to the aneurysmal neck. The artery appeared fused to the aneurysmal wall on CTA, but this was related to “thresholding” artefact; at surgery both structures were found to be in very close apposition.
Finally, in our study all negative CTA and DSA results were followed by a repeat DSA at 1 week. Whether or not negative CTA and DSA results indicate a repeat examination in clinical practice should be determined at an individual level based on index of clinical suspicion, quality of examinations and local confidence and expertise in CTA.

In conclusion, 16-slice CTA shows promising diagnostic accuracy which appears to be equivalent to conventional DSA for detection of suspected intracranial aneurysms. CTA provides enough anatomical information for treatment planning in the majority of cases. A strategy of using CTA as the primary imaging method, with DSA reserved for any cases of uncertainty, appears safe and reliable.

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