Comparison of multislice computerized tomography angiography and digital subtraction angiography in the postoperative evaluation of patients with clipped aneurysms

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Object. In this study the accuracy of multislice computerized tomography (MSCT) angiography in the postoperative examination of clip-occluded intracranial aneurysms was compared with that of intraarterial digital subtraction (DS) angiography

Methods. Forty-nine consecutive patients with 60 clipped aneurysms (41 of which had ruptured) were studied with the aid of postoperative MSCT and DS angiography. Both types of radiological studies were reviewed independently by two observers to assess the quality of the images, the artifacts left by the clips, the completeness of aneurysm occlusion, the patency of the parent vessel, and the duration and cost of the examination.

The quality of MSCT angiography was good in 42 patients (86%). Poor-quality MSCT angiograms (14%) were a result of the late acquisition of images in three patients and the presence of clip or motion artifacts in four. Occlusion of the aneurysm on good-quality MSCT angiograms was confirmed in all but two patients in whom a small (2-mm) remnant was confirmed on DS angiograms. In one patient, occlusion of a parent vessel was seen on DS angiograms but missed on MSCT angiograms. The sensitivity and specificity for detecting neck remnants on MSCT angiography were both 100%, and the sensitivity and specificity for evaluating vessel patency were 80 and 100%, respectively (95% confidence interval 29.2–100%). Interobserver agreements were 0.765 and 0.86, respectively. The mean duration of the examination was 13 minutes for MSCT angiography and 75 minutes for DS angiography (p < 0.05). Multislice CT angiography was highly cost effective (p < 0.01).

Conclusions. Current-generation MSCT angiography is an accurate noninvasive tool used for assessment of clipped aneurysms in the anterior circulation. Its high sensitivity and low cost warrant its use for postoperative routine control examinations following clip placement on an aneurysm. Digital subtraction angiography must be performed if the interpretation of MSCT angiograms is doubtful or if the aneurysm is located in the posterior circulation.

KEY WORDS • aneurysm surgery • clip occlusion • computerized tomography angiography • digital subtraction angiography • postoperative evaluation

NEURYSMS can be treated by clip or coils—both of which lead to high short-term success rates and low rates of morbidity and mortality. Approximately 10% of cases in which morbidity and mortality occur following an SAH from a ruptured cerebral aneurysm, however, result from treatment complications such as major vessel occlusion and rebleeding.12 Ideal positioning of the clip is key for the prevention of rebleeding from an aneurysm neck or dome remnant and for preservation of the parent artery.

In our view, the difficulty encountered in achieving perfect clip positioning justifies the use of postoperative imaging studies in all patients. Nevertheless, postoperative control imaging studies are not performed at many neurosurgical centers, either because intraoperative inspection is considered sufficient or because intraarterial angiography is invasive and time consuming. Despite the fact that intraarterial DS angiography carries a 0.07 to 0.5% risk of permanent neurological complications,4,7,8,16 this imaging modality remains the gold standard to evaluate proper placement of the clip.

To reduce the risk associated with screening all patients with clipped aneurysms, accurate noninvasive imaging methods are of great interest. Both CT and MR angiography have proved to be valuable in the investigation of cerebral vascular anatomy.1,3,6,8,11,13,15,17,19,21,23,26,27,29,30,34–36,38,40,42 Recently, we reported that MSCT angiography is a reliable
Few reports were provided by a combination of imaging techniques for the re-
maining 29 aneurysms. Aneurysm treatment by embolization or surgical clip placement was decided according to a protocol reported earlier.24,25 In brief, surgical clipping was offered only if one of the following factors was present. 1) The anatomy shown on the angiogram appeared unfavorable for endovascular treatment. 2) The aneurysm was partially thrombosed. 3) An intracerebral hematoma was present with a mass effect. Periornital craniotomies were performed for all aneurysms, except for distal ACA aneu-
rysms, in which case a frontal parasagittal craniotomy was performed. All clips were made of titanium (Yaşargil tita-
nium aneurysm clip; Aesculap AG, Tuttingen, Germany). According to their sizes, these clips are classified as “mini-
clips” (blade length 3–7 mm), standard (blade length 5–20 mm), or fenestrated (diameter of fenestration 5 mm with a blade length of 3–8 mm).

Postoperative MSCT angiography was performed within 72 hours of surgery. Digital subtraction angiography was performed within 4 days after surgery for unruptured aneu-
rysms and between 9 and 11 days after rupture in patients who had suffered an SAH.

**Imaging Studies**

**Multislice CT Angiography.** Each MSCT angiography study was performed using a 16-detector-row CT unit and a standardized protocol that was published previously.40 A timed test injection was used to determine the optimal dura-
tion of MSCT angiography data acquisition. The data consisted of 20 identical 10-mm-thick slices (80 kVp/100 mA), which were obtained from the level of the top of the frontal sinuses in a cine mode at a rate of one image per second during intravenous administration of 20 ml of iodinated con-
trast material (300 mg/ml iodine). In the test injection, the contrast material was administered at a rate of 5 ml per sec-
ond into an antecubital vein by using a power injector; there was a 10-second delay between this injection and the onset of data acquisition. The MSCT angiography data acquisi-
tion was performed according to the following protocol: spi-
ral mode 0.8-second slices, 16-row collimation at 0.6 mm, pitch 0.75, slice thickness 0.6 mm, reconstruction interval 0.6 mm, and acquisition parameter 120 kVp/240 mA. A caudocranial scanning direction was selected, covering the volume extending from the top of the frontal sinuses down to a point 1 cm below the foramen magnum.

**Digital Subtraction Angiography.** The DS angiography study was performed via a transfemoral approach after in-
duction of sedation and analgesia or general anesthesia in uncooperative patients. Dedicated focused views were ob-
tained of the region of interest; additional 3D rotational im-
ages were obtained in 37 patients (76%). Between 17 and 20 ml of contrast material was selectively injected into the aneurysm-related ICA at a rate of 2.5 to 3 ml per second during the rotation time of the angiography, which was fixed at 7 seconds to cover a rotation of 180°.

**Review Process**

There were two sets of observers. The first set was the “treating team,” consisting of a neurosurgeon and a neu-
roradiologist who possessed all the relevant surgical in-
formation and prospectively reviewed the MSCT and DS angiography data. The second set consisted of a different

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**Clinical Material and Methods**

**Patient Population**

Between August 2003 and November 2004, 49 consecu-
tive patients underwent surgery for clipping of a total of 60 intracranial anterior circulation aneurysms. The distribution of the aneurysms was as follows: 18 ACoAs, three ACAs, 25 MCAs, 14 ICAs (seven posterior communicating arter-
ies, five paraclinoid arteries, and two AChAs). All surgeries were performed by the senior author (L.R.). Forty-one aneu-
rysms were ruptured and 19 were unruptured. Eleven pa-
tients were treated for multiple aneurysms; the number of aneurysms in these patients ranged from two to five. The mean aneurysm size was 10.2 ± 2.5 mm (range 2–27 mm). The demographic features of the patients and aneurysms are listed in Table 1.

**Case Management**

The preoperative workup and therapeutic decisions were based on MSCT angiogram findings alone for 24 aneu-
rysms, MR angiography alone for three aneurysms, DS angiography alone for four aneurysms, and on findings pro-
vided by a combination of imaging techniques for the re-

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**TABLE 1**

Characteristics of 49 patients harboring 60 aneurysms

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of patients</td>
<td>49</td>
</tr>
<tr>
<td>female</td>
<td>29</td>
</tr>
<tr>
<td>male</td>
<td>20</td>
</tr>
<tr>
<td>total</td>
<td>49</td>
</tr>
<tr>
<td>aneurysm location (no. of lesions)</td>
<td>18</td>
</tr>
<tr>
<td>ACoA</td>
<td>14</td>
</tr>
<tr>
<td>ACA</td>
<td>3</td>
</tr>
<tr>
<td>MCA</td>
<td>25</td>
</tr>
<tr>
<td>ICA</td>
<td>25</td>
</tr>
<tr>
<td>aneurysm (no. of lesions)</td>
<td>41</td>
</tr>
<tr>
<td>ruptured</td>
<td>41</td>
</tr>
<tr>
<td>unruptured</td>
<td>19</td>
</tr>
<tr>
<td>total</td>
<td>60</td>
</tr>
<tr>
<td>aneurysm size in mm (no. of lesions)*</td>
<td>2</td>
</tr>
<tr>
<td>≤7</td>
<td>23</td>
</tr>
<tr>
<td>7–12</td>
<td>27</td>
</tr>
<tr>
<td>13–24</td>
<td>8</td>
</tr>
<tr>
<td>≥25</td>
<td>2</td>
</tr>
</tbody>
</table>

* Mean aneurysm size was 10.2 ± 2.5 mm.
neuroradiologist, who was blinded to the surgical findings and who independently reviewed the MSCT and DS angiography data. Because DS angiography is the gold standard, the MSCT angiograms were interpreted without any knowledge of the DS angiography findings by both sets of observers. The review was performed using a workstation to allow interactive reconstruction and interpretation, which is more accurate than an isolated review of hard-copy images. The observers evaluated axial raw images, multiplanar 2D reconstructions, and MIP and 3D SSD reconstructions, which were segmented from the axial raw data by using commercial software. The review of the DS angiograms was performed on the same workstation to maintain a dynamic flow analysis and to modify the subtraction parameters of the angiographic images as required. The following parameters were assessed: the quality of the images, the duration of image processing and interpretation, the presence of clip and motion artifacts, the completeness of the occlusion of the aneurysm, the patency of the parent artery and its branches, and the cost of the study (Table 2). The quality of the MSCT angiograms was considered good if there was no clip or motion artifact and if the image acquisition had been performed during the arterial phase of contrast enhancement. Only MSCT angiograms of good quality were considered for the comparison because the ultimate goal of the study was to replace DS angiography with a good-quality noninvasive imaging modality. The duration of the examination consisted of the time from positioning of the patient to the interpretation of the processed images. Aneurysm occlusion was considered to be complete or incomplete; the presence of any lesion remnant, even the slightest “dog ear” (> 1 mm) was recorded as an incomplete occlusion. Procedure-related complications were evaluated separately, as well as the need for anesthesia to perform the imaging study. The costs for MSCT angiography include the routine cost of the examination, contrast material, and image printing; the costs for DS angiography include the routine angiography fee, angiography suite staff charges, and additional supplies. Anesthesia fees were added when necessary. Finally, the location of the clipped aneurysm and the number and type of clips were assessed to determine other possible confounding factors.

Statistical Analysis

The sensitivity, specificity, and positive and negative predictive values of MSCT angiography with respect to the completeness of aneurysm occlusion and the patency of the parent vessel were calculated based on the first (the treatment team) observer findings. Agreement about Fuhrman grading between the observers was assessed using the kappa index, which corrects for chance agreements. A kappa value of 0 indicates a level of agreement that would be expected strictly on the basis of chance, whereas a value of 1.00 indicates perfect agreement. With regard to positive kappa values, the following interpretations are generally accepted: fair agreement, 0.00 to 0.20; moderate to substantial agreement, 0.21 to 0.75; near-perfect agreement, 0.76 to 0.99; and perfect agreement, 1.00. To measure the kappa index, all cases were evaluated, including those in which the images were of poor quality, because each observer evaluated separately the image quality and the clip artifact. The mean duration and cost of both examinations were compared, and a probability value of 0.05 or less was set as statistically significant.

Results

Operative Results

Of the 60 aneurysms, 54 were treated with a single clip and six with two clips. Miniclips were used for 34 lesions, standard clips for 26, and fenestrated clips for six lesions. During surgery, we expected that a remnant neck had been left behind in our attempt to save a hypothalamic perforating artery in a patient harboring a posterior projecting ACoA aneurysm with a broad base. In another patient in whom there was a ruptured fusiform AChA aneurysm, we intentionally sacrificed the AChA. All other aneurysms were deemed completely occluded and all other arteries were thought to be patent.

Results of MSCT Angiography

In four comatose patients (8%), MSCT angiography was performed following the induction of general anesthesia, and in three patients short-acting sedation was used for an agitated state. Forty-two patients tolerated MSCT angiography without any sedation. Motion artifacts were present in three imaging sessions; in two of these cases the artifacts did not interfere with image interpretation.

The quality of the images was good in 42 patients (86%) and poor in seven patients (14%). Poor MSCT angiographic image quality was the result of the following: a late acquisition time with venous-phase imaging in three patients (Fig. 1A), the presence of clip artifacts in three patients (two double clips and one single standard clip; Fig. 1B), and the presence of motion artifacts in one patient. These seven patients were excluded from the comparative study to diminish selection bias, leaving a total of 42 patients (86%) harboring 53 clipped aneurysms for the comparative study. The titanium clips used to treat these 53 aneurysms did not appear to cause significant scatter artifacts (Fig. 2), or if there were some, they were slight, mainly in continuation with the axis of the clip and not interfering with image interpretation. Of six double clips, two (33%) showed significant artifacts and were excluded, indicating that the number of clips may influence the quality of the postoperative MSCT angiography. Conversely, the size of the single clips did not significantly influence image quality.

Using the information provided by surgery to target the MSCT angiography reconstructions, the first observer was able to identify two small (~ 2-mm) remnant necks on the

| TABLE 2 | Interpretation criteria applied to both MSCT and DS angiography |
|---------------------------------------------------------------|
| quality of the examination                                    |
| need for general anesthesia                                   |
| duration of the examination                                   |
| presence of a nearby clip artifact                            |
| exclusion of aneurysm or neck remnant                         |
| patency of parent vessel                                       |
| complications                                                 |
| cost                                                          |

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ACoA. One was adjacent to a fenestrated clip and one to a miniclip (Figs. 3 and 4). The second observer indicated that all aneurysms were totally occluded. Evaluation of arterial patency revealed occlusion of two proximal A\textsubscript{2} segments and one moderate stenosis of a distal A\textsubscript{1} segment. Patency of the MCA bifurcation could not be reliably evaluated close to the clip on an MCA bifurcation aneurysm, and the deliberate AChA occlusion was not detected on MSCT angiograms by either observer.

We did not observe any complication due to MSCT angiography. The mean duration of the MSCT angiography

\begin{figure}[ht]
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{Two MSCT angiograms of poor quality. A: A 2D MIP image obtained 24 hours after SAH, confirming occlusion of a 7-mm ruptured ACoA aneurysm treated with a miniclip. Note the presence of the venous phase, which indicates the late acquisition of the image. Deep venous drainage normally should not be seen in an MSCT angiogram of good quality. The exclusion of the ACoA aneurysm and the patency of parent vessel cannot be adequately defined in this image. A clip artifact is presented in this case. B: A 3D SSD MSCT angiogram showing a 10-mm MCA aneurysm with a large base, which has been occluded by a standard clip. This image cannot be used reliably to confirm the exclusion of the aneurysm.}
\end{figure}

\begin{figure}[ht]
\centering
\includegraphics[width=\textwidth]{fig2.png}
\caption{Angiographic images of a ruptured 11-mm aneurysm with a large base, which incorporates the ACoA and projects superiorly and posteriorly. The aneurysm was treated with a fenestrated clip through a right-sided craniotomy. A: Preoperative DS angiogram. B–D: Postoperative control studies, including a DS angiogram (B), a 2D MIP MSCT angiogram (C), and a 3D SSD reconstruction (D), demonstrating complete aneurysm occlusion and arterial patency. Note the absence of clip artifacts (despite the size of the clip) and the visualization of anatomical details, especially with reference to the A\textsubscript{2} segment passing through the fenestration.}
\end{figure}

\begin{figure}[ht]
\centering
\includegraphics[width=\textwidth]{fig3.png}
\caption{A: Preoperative DS angiogram revealing a 9-mm wide-based posteriorly projecting ACoA aneurysm that was later treated with clip placement. B and C: Two 3D SSD image reconstructions illustrating the importance of multiplanar rotation of images during review. The posteroinferior view clearly reveals a small (~2-mm) remnant of the aneurysm neck (arrowhead in B), whereas the anterior view of the same vessel gives the impression of complete aneurysm occlusion (C). D: Postoperative sagittal 2D DS angiogram confirming the presence of the residual lesion (arrowhead).}
\end{figure}
study was 13 minutes (range 10–20 minutes). This was the
time period required for scanning, processing, and interpre-
tation of the images. The average cost of an MSCT angiog-
raphy session in US currency was $750 (range $650–800).

Results of DS Angiography

General anesthesia had to be induced prior to DS angiog-
raphy in 11 patients (23%), four of whom were in a coma-
tose state and seven of whom were agitated. The quality of
the images was good in all of the DS angiography studies.

Both observers detected two small (~ 2-mm) remnant necks
on two ACoA aneurysms on DSA angiograms (two [3%] of
60 aneurysms). Arterial occlusion was detected in three pa-
tients: two cases of proximal A1 occlusion and one case of
deliberate AChA occlusion. In addition, there was one pa-
tient with moderate stenosis of the distal A1 segment.

Thromboembolic complications during DS angiography
occurred in two patients: one (2%) experienced no symp-
toms and the other (2%) suffered from a symptomatic distal
ACA occlusion. The mean duration of the DS angiography
study was 75 minutes (range 50–110 minutes). This time
period extended from the beginning of the examination to
the interpretation of the images. The average cost of DS an-
giography was $1650 (range $1500–1800).

Comparison of MSCT and DS Angiography

Imaging Features. The imaging quality was good for all
cases in which DS angiography was used, as opposed to 42
(86%) of 49 cases in which the MSCT technique was used
(Table 3). On MSCT angiograms, two small (~ 2-mm) rem-
nant necks were missed by the second observer, who was
blinded to the information provided by surgery. Benefiting
from the surgical information, the first observer was better
able to target the image reconstructions and could reliably
visualize both of these neck remnants on MSCT angio-
grams. Both residual lesions were found on an ACoA aneu-
rysm. The presence of one was expected at surgery in our
attempt to avoid the risk of obstruction of a hypothalamic
perforating artery (Fig. 3). The second was on an aneurysm
that ruptured during clip application. Exploration and visu-
alization of the distal clip blades had been limited during
surgery (Fig. 4).

Two occluded parent arteries and one instance of moder-
ate stenosis were detected by both observers on MSCT and
DS angiograms. On an MSCT angiogram the sacrifice of an
AChA in the case of a fusiform aneurysm was not visual-
ized and the patency of an MCA could not be assessed due
to clip artifacts on an MCA bifurcation aneurysm; on DS
angiography, however, both the AChA occlusion and per-
fect permeability of the MCA were apparent.

With respect to aneurysm occlusion, the sensitivity and
specificity of MSCT angiography were both 100% (95% con-
fidence interval 29.2–100%) and the positive and neg-
ative predictive values were 100 and 95.2%, respective-
ly (Table 3). For parent artery patency the sensitivity of
MSCT angiography was 80% (95% confidence interval
28.4–99.5%), the specificity was 100% (89.4–100%), and
the positive and negative predictive values were 100 and
97.2%, respectively. Aneurysm location did not statistically
influence the sensitivity and specificity of MSCT angiogra-
phy (p = 0.42).

The kappa values extracted from the interobserver con-
cordance analysis for agreement between observers regard-
ing the use of MSCT angiography for assessment of a rem-
nant neck was 0.765 and that for patency of the parent artery
was 0.86. The kappa values for evaluation of the quality of
MSCTA images and the presence of clip artifact were 0.921
and 0.846. All values show near-perfect agreement.

Other Features. The incidence of morbidity associated
with MSCT angiography was zero. During DS angiography
studies two embolic events were detected; one was symp-
tomatic and produced distal ACA ischemia (2% morbidity).

General anesthesia had to be induced to examine four co-
matose patients who underwent MSCT and DS angiogra-
phy (Table 3). Among agitated patients, only three required
short-acting sedation for MSCT angiography, as opposed to
seven who required general anesthesia for DS angiography
(11 [22%] of 49 patients). The duration and cost of the ex-
aminations were significantly lower for MSCT angiography
than for DS angiography (p < 0.05 and p < 0.01, respec-
tively).

Discussion

The goal of aneurysm treatment is the complete, imme-
diate, and safe exclusion of the aneurysm with preservation
of arterial patency. Regrowth and rebleeding of a partially

documented and require particu-
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TABLE 3
Comparison between postoperative MSCT and DS angiograms obtained to evaluate clipped aneurysms

<table>
<thead>
<tr>
<th>Factor</th>
<th>MSCT Angiograms</th>
<th>DS Angiograms</th>
</tr>
</thead>
<tbody>
<tr>
<td>good quality (%)</td>
<td>86</td>
<td>100</td>
</tr>
<tr>
<td>interobserver agreement for quality</td>
<td>0.92</td>
<td>1.00</td>
</tr>
<tr>
<td>mean duration in mins*</td>
<td>13</td>
<td>75</td>
</tr>
<tr>
<td>need for general anesthesia (no. of patients)</td>
<td>4 (all comatose)</td>
<td>11 (4 comatose)</td>
</tr>
<tr>
<td>presence of clip artifact (no. of aneurysms)</td>
<td>3 (2 for multiple clips)</td>
<td>0</td>
</tr>
<tr>
<td>interobserver agreement for clip artifact</td>
<td>0.84</td>
<td>1.00</td>
</tr>
<tr>
<td>remnant neck (no. of aneurysms)†</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>interobserver agreement for neck remnant</td>
<td>0.765</td>
<td>0.96</td>
</tr>
<tr>
<td>parent vessel stenosis or occlusion (no. of patients)‡</td>
<td>2 occlusions, 1 stenosis</td>
<td>3 occlusions, 1 stenosis</td>
</tr>
<tr>
<td>interobserver agreement on vessel patency complications</td>
<td>0.86</td>
<td>1.00</td>
</tr>
<tr>
<td>mean cost in US currency*</td>
<td>$750</td>
<td>$1650</td>
</tr>
<tr>
<td>sensitivity/specificity for evaluation of completeness of occlusion</td>
<td>100%/100%</td>
<td>100%/100%</td>
</tr>
<tr>
<td>sensitivity/specificity for evaluation of vessel patency</td>
<td>80%/100%</td>
<td>100%/100%</td>
</tr>
</tbody>
</table>

* p < 0.05.
† In 53 aneurysms.
‡ In 42 cases.

lar attention. Detection of unsuspected aneurysm remnants and inadvertent arterial compromise after treatment therefore are clinically important, and accurate postoperative imaging methods are of immense interest. It is our policy to obtain postoperative DS angiograms in all cases of surgically treated aneurysms and to consider even the slightest dog-ear lesion as a remnant. Nevertheless, DS angiography, performed intra- or postoperatively, remains invasive and carries an undeniable risk of morbidity. We do not perform intraoperative angiography routinely, believing that small residual aneurysms will not necessarily be detected because of a lesser image quality. The overall performance of CT angiography in the evaluation of patients with cerebral aneurysms was dramatically improved by the technological development of multidetector-row CT scanners. Preoperative evaluation of cerebral aneurysms is increasingly performed using MSCT angiography and, as reported recently, we use it routinely for workup in patients with ruptured and unruptured aneurysms. In the current study we explored whether MSCT angiography could replace DS angiography in the routine postoperative evaluation of patients with aneurysms treated with titanium clips.

The imaging quality of MSCT angiography was good in 86% of cases. Poor imaging quality (14%) was mainly the result of a delayed acquisition time during imaging of the venous phase and was rarely due to clip or motion artifacts. Future-generation MSCT angiography techniques should reduce this incidence as a result of shorter acquisition times. Remarkably, the quality of the MSCT angiograms was not significantly degraded by the presence of the titanium clips; there was only one substantial artifact in patients with a single clip (one [2%] of 54 aneurysms) and two in patients with double clips (two [33%] of six aneurysms). Despite the very thin collimation (0.6 mm) used in our study, as noted in previous reports, severe beam-hardening artifacts were not seen. Surprisingly, the shape of the clip (mini-, standard, or fenestrated clip) did not influence the quality of the images, and details of the clip itself could easily be seen, particularly on MIP images. This study confirms the finding that artifacts caused by titanium clips are limited and rarely (5%) interfere with the interpretation of the image, as opposed to artifacts caused by coils used for embolization, whose appearance on MSCT angiograms are highly significant, compromising the detailed evaluation of the vascular anatomy around the coils. For aneurysms packed with coils, MR angiography appears to be a more valuable postoperative study.

The sensitivity and specificity of good-quality MSCT angiography for evaluation of complete occlusion of the aneurysm were both 100% and the positive and negative predictive values were 100 and 95.2%, respectively. The interobserver agreement was 0.765, which suggests near-perfect agreement. Complete dome and base occlusion were reliably evaluated by MSCT angiography, based on the comparison with DS angiographic findings. On the initial evaluation of MSCT angiography, two small remnant necks (~ 2 mm wide) were overlooked by the blinded observer because of insufficient evaluation of the region of interest. In contrast, both of these residual lesions were prospectively identified by the observer who benefited from the surgical (but not the DS angiographic) information. The operative findings helped the observer focus the MSCT angiographic images on the region most at risk for a remnant. An evaluation of MSCT angiograms includes axial raw data and 2D and 3D reconstructions. The images can be rotated up to 360°, providing the viewer with optimal views and projections of the region at risk. This image processing is key to revealing the accurate relationships among the aneurysm, the clip, and the parent artery. To this end, it is of great importance that the neurosurgeon with detailed knowledge of the relevant anatomy participates with the neuroradiologist in the imaging review. When such collaborative work is possible during image appraisal on the workstation, appropriate changes in threshold and projections can be made to distinguish aneurysm remnants—as small as 2 mm—from the parent artery and the clip.
The sensitivity and specificity of good-quality MSCT angiograms for evaluating the patency of the parent vessel were 80 and 100%, and the positive and negative predictive values were 100 and 97.2%, respectively. The interobserver agreement was 0.86, which suggests near-perfect agreement. Multislice CT angiography confirmed the presence of two vessel occlusions and one moderate stenosis. Only the occlusion of the AChA was missed on MSCT angiography; this was due to its resolution capacity, which was too low to visualize the AChA on preoperative MSCT angiograms. Nevertheless, parenchymal CT images demonstrated ischemic changes in the AChA territory. Furthermore, in one case the patency of the MCA could not be assessed after the clipping of an MCA bifurcation aneurysm because of the clip artifacts. The sensitivity and specificity of MSCT angiography for aneurysm occlusion and arterial patency were equal no matter where the clipped aneurysm was located in the anterior circulation.

Vieco and colleagues stated in 1996 that CT angiography could not replace catheter angiography in postoperative clip evaluation. Their study suffered from a small series (three aneurysms) and the limited technical development of older generations of CT angiography techniques. In contrast, van Loon and associates suggested that spiral CT angiography may be a valuable technique in the postoperative control of clipped aneurysms. These researchers examined 13 clipped aneurysms and could evaluate occlusion of the aneurysm dome and patency of the parent vessel in all 13 cases. The neck could be evaluated in 11 cases, and the spiral CT technique showed two of the three remnants diagnosed by DS angiography. Our study confirms that MSCT angiography is capable of reliably detecting even small aneurysm remnants, supporting prior reports of the accurate performance of MSCT angiography for aneurysms smaller than 2 mm in diameter. Although MR angiography is used in some institutions for the evaluation of clipped aneurysms, in our hands titanium clips induce a small susceptibility artifact that shadows the angiographic anatomy around the clip. We therefore believe that MSCT angiography is superior in quality and reliability in demonstrating small residual aneurysms. Nevertheless, this study was not designed to compare these two techniques. Grieve, et al. have demonstrated that if the clip is imaged parallel to the main ferromagnetic field, the artifact can be significantly lowered with MR angiography.

General anesthesia was deemed indispensable for performing DS angiography in 11 cases (22%) because the duration of the examination was too long to be tolerated by the patient. For MSCT angiography, four patients needed anesthesia (8%) and three only required short-acting sedation. Because the duration of the MSCT angiography examination is significantly shorter than that of the DS angiography session (13 minutes compared with 75 minutes, p < 0.05), agitated patients can easily tolerate the examination with short-acting sedation and avoid general anesthesia. Similarly, the costs of MSCT angiography are significantly lower than those of DS angiography (p < 0.01). No morbidity was related to the MSCT technique, as opposed to the DS technique, which was associated with a cerebral ischemic complication in one patient.

In a retrospective study of patients who underwent surgery for clipping of 78 cerebral aneurysms, Macdonald and associates reported that occlusion of a major vessel was present in 21% of clipped aneurysms and that 12% of these occlusions were unexpected. In the same study, a residual or unclipped aneurysm was present in 14% of clipped aneurysms and 8% were unexpected. Recently, a large Finnish study of 808 surgically clipped aneurysms confirmed the usefulness of perioperative or postoperative control angiography. The investigators reported an overall incidence of incomplete aneurysm clipping of 12% and 7% were unexpected. In the same study, occlusion of a major artery occurred overall in 6% and 4% were unexpected. Our study confirms the importance of obtaining a postoperative control imaging study after the surgical clipping of cerebral aneurysms. In 60 consecutive aneurysms, a residual aneurysm was detected overall in two lesions (3%) and only one (2%) was unexpected. Occlusion of a major vessel occurred overall in three (5%) of 60 lesions and two (3%) were unexpected. These positive results, despite a strict definition of an aneurysm remnant, may be favored by the exclusion of posterior circulation aneurysms in this study. We also believe that it reflects, at least in part, the demand put on neurosurgeons trained in the endovascular era who have become accustomed to controlling and comparing their surgical results with those of endovascular interventions. Both arterial occlusions were due to dissection and may reflect the price that must be paid for a thorough operative inspection of the clip and the surrounding vasculature.

Study Limitations

It is noteworthy to insist on the fact that MSCT angiography in this particular clinical setting is not intended as a conventional and standardized radiological study, but appears to be highly operator dependent. Indeed, a consensus review process between the neuroradiologist and the involved neurosurgeon is key to the correct identification of aneurysm remnants.

All the aneurysms in this study were treated with titanium clips. Whether the same quality of MSCT angiography is obtained with combination alloy–based clips cannot be answered by this study. A study from the Zurich group showed that titanium alloy clips produce less image artifacts than other clips, based on MR imaging results.

Furthermore, the validity of MSCT angiography for clipped aneurysms cannot be generalized for posterior circulation aneurysms, and perforating arteries cannot be visualized using MSCT angiography. An evaluation of such structures still requires DS angiography. Finally, MSCT angiography was performed within a time frame in which significant radiologically confirmed vasospasm was absent. Whether the image quality of MSCT angiography remains good in the presence of significant vasospasm needs special consideration, which is currently under evaluation at our center.

Conclusions

An evaluation of surgically clipped aneurysms with up-to-date MSCT angiography provides accurate anatomical information concerning the completeness of aneurysm occlusion and the patency of major arteries, when compared with the findings of DS angiography. Significant artifacts interfering with the interpretation of the images are rare. Compared with DS angiography, MSCT angiography is associated with fewer complications, less need for general an-
esthesia, and a shorter examination time, and it is highly cost effective. Generalized use of noninvasive imaging for routine control examinations should further improve the results of surgically clipped aneurysms. According to these observations, we suggest that MSCT angiography should replace DS angiography for routine postoperative control of clipped aneurysms treated with titanium clips. Postoperative DS angiography is still indicated for patients in whom the results provided by MSCT angiography are unsatisfactory or in whom concomitant endovascular procedures are planned. Until proven otherwise, DS angiography is indicated for posterior circulation aneurysms, for evaluation of the AChA, and in the presence of significant vasospasm.

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