The Utility of Dual-Energy Computed Tomographic Angiography for the Evaluation of Brain Aneurysms After Surgical Clipping: A Prospective Study

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OBJECTIVE: **The purpose of this prospective study was to compare a novel dual-energy computed tomographic angiography (DECTA) method for postoperative assessment of clipped brain aneurysms to detect aneurysm remnants and parent artery patency, with catheter-based digital subtraction angiography (DSA).**

METHODS: **Patients who underwent microsurgical cerebral aneurysm repair were prospectively evaluated after surgery by both DECTA and conventional DSA. CTA was performed using a novel dual-energy method with single source and fast kilovoltage switching (Gemstone Spectral Imaging [GSI]). DSA was performed using biplanar cerebral angiography. An experienced neuroradiologist and a neurosurgeon, both blinded to the original radiologic results, reviewed the images.**

RESULTS: **On DSA, 8 of 15 aneurysms (53%) had a remnant after clipping. All of these remnants were <2 mm except for 1. The only residual aneurysm >2 mm was clearly detected by GSI CTA. Of those 7 DSA-confirmed <2-mm remnants, 5 were detected by GSI CTA. Metal artifacts compromised the image quality in 2 patients. The sensitivity and specificity of GSI CTA for remnant aneurysm <2-mm detection in single clip-treated patients were 100%. In all patients, these were 71.4 % and 100%, respectively. GSI CTA was 100% sensitive and 77% specific to detect parent vessel compromise, with associated positive and negative predictive values of 60% and 100%, respectively.**

CONCLUSIONS: **DECTA is a promising noninvasive alternative to conventional catheter-based angiography for identification of aneurysm remnants and assessment of adjacent arteries after surgical clipping of brain aneurysms treated by 2 or fewer clips. It allows for a more rapid image acquisition than DSA, is more cost effective, and is widely available at clinical centers.**

INTRODUCTION

The fundamental aim of neurosurgical and endovascular approaches for the treatment of cerebral aneurysms is complete aneurysm occlusion to minimize the risk of complications, such as hemorrhaging or further aneurysm growth, yet preserving the parent vessel. According to recent studies, angiographic aneurysm remnants after microsurgical clipping are found in 2.3%–14% of patients (1, 5, 13, 19, 24, 29, 32, 37). Therefore, after microsurgical aneurysm clipping, aneurysm reperfusion and residual aneurysm necks must be identified during the postoperative evaluation (10, 22). If significant aneurysm

Key words
- Aneurysm clipping
- Computed tomographic angiography (CTA)
- Digital subtraction angiography (DSA)
- Dual energy

Abbreviations and Acronyms
2 or 3D: Two- or three-dimensional
CT: Computed tomography
CTA: Computed tomographic angiography
DECT: Dual-energy computed tomography
DECTA: Dual-energy computed tomographic angiography
DSA: Digital subtraction angiography
GSI: Gemstone Spectral Imaging
ICGA: Indocyanin green video angiography
ISAT: International Subarachnoid Aneurysm trial
keV: Kiloelectron volt
MARS: Metal artifact reduction software
MCA: Middle cerebral artery
MRA: Magnetic resonance angiography
SAH: Subarachnoid hemorrhage
ssDECT: Single-source dual-energy computed tomography
VMS: Virtual monochromatic spectral

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remnants are discovered, retreatment is indicated as aneurysm remnants pose a hemorrhaging risk.

Because aneurysm clips complicate image acquisition and interpretation due to beam hardening and other metal-associated artifacts, noninvasive diagnostic workup of patients with clipped cerebral aneurysms is often problematic (**Figure 1**). Identification of aneurysm remnants can be hindered by the impaired image quality. Thus, catheter-based digital subtraction angiography (DSA) remains the gold standard for identifying aneurysm remnants and visualizing the parent artery after clipping (38, 41). Despite its high spatial resolution, DSA has significant disadvantages, such as invasiveness and high cost (11). In fact, risk of permanent neurological complication after DSA has been reported to be from 0.1%–0.5% (7, 8, 14, 17, 40). Although the image quality of conventional computed tomography angiography (CTA) has improved (18-23), it is still less accurate than DSA (9, 35) and is susceptible to beam hardening associated with titanium clips. Magnetic resonance imaging of patients with clipped aneurysms remains severely limited by susceptibility artifacts introduced by the metallic clips (39).

Novel imaging methods, such as dual-energy computed tomography (DECT), at present, enable the minimally invasive generation of high resolution CTA images (9). New methods of postprocessing the data, such as metal artifact reduction software (MARS), are able to significantly reduce interfering metal artifacts produced by aneurysm clips, as well as improve the visualization of adjacent structures. The purpose of this prospective study was to compare a DECT CTA method for the postoperative assessment of clipped brain aneurysms with the current gold standard imaging modality, catheter-based DSA.

PATIENTS AND METHODS

This study was approved by the hospital ethics committee. Because performing Gemstone Spectral Imaging (GSI) CTA and DSA exposes the patient to additional radiation, enrollment was on a volunteer basis. Therefore, our inclusion criteria were as follows: 1) patients who underwent craniotomy for brain aneurysm clipping, 2) preserved kidney function as evidenced by creatinine level within normal limits, 3) no history of contrast allergies, 4) no other metal foreign bodies in the head, and 5) alert, oriented, and competent to volunteer to undergo DSA and GSI CTA for the assessment of their clipped brain aneurysms. Our exclusion criteria were patients with 1) history of contrast allergies, 2) patients with foreign bodies in their head close to our target region, such as previously adjacent coiled aneurysms, 3) patients who had kidney dysfunction or single kidney, 4) patients in whom the elapsed time between their DSA and GSI CTA was more than 1 week, and 5) patients who had a subarachnoid hemorrhage (SAH) and were disoriented. These inclusion and exclusion criteria limited the number of our patients and increased the duration of our study.

Overall, a total of 14 patients (4 men and 10 women) with 15 clipped aneurysms were enrolled in our study between January

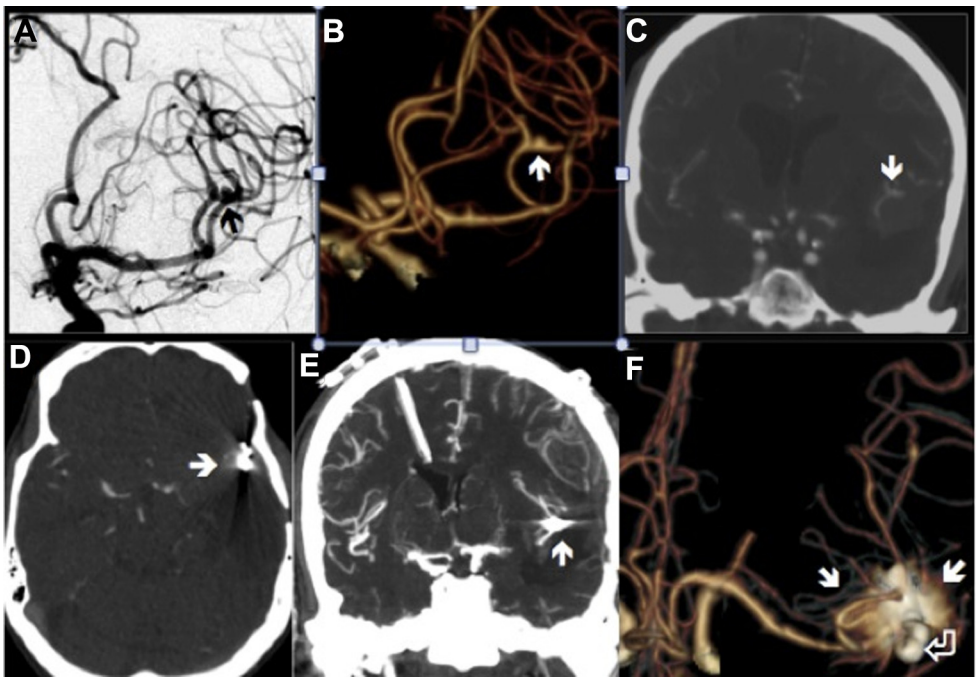

Figure 1. A 53-year-old woman presented with subarachnoid hemorrhage and left temporal intracerebral hemorrhage. Digital subtraction angiography showed a 3-mm aneurysm arising from left M2 (*arrows*; **A**–**C**). (**C**) Computed tomographic angiography (CTA) of the same patient with its 3-dimensional (3D) reconstruction (**B**). (*arrows*; **D** and **E**) After clipping CTA with nondual energy protocol (axial and coronal, respectively). As a result of significant clip-induced artifacts, assessment of the aneurysm occlusion and adjacent artery patency status is impossible. The 3D reconstruction was also severely affected by the clip (*curved arrow*; **F**).