ONLINE SUPPLEMENT

Supplemental Methods

Dynamic Four-Dimensional (4D) Computed Tomography (CT) Angiography (DFA)

A 64-detector multi-slice Aquilion CT scanner (Toshiba Medical Systems Corporation, Japan) was used to obtain dynamic scanning data in both experimental studies and clinical examinations. We applied DFA support software version 4.1 (Toshiba Medical Systems Corporation, Japan) for reconstructing DFA images. The dynamic scan technique used rapid and continuous image acquisition without table movement. Imaging was performed with a gantry rotation time of 0.4 s and a slice thickness of 0.5 mm with an effective scan width of 32 mm (64 × 0.5 mm). Tube current and voltage were set to 50 mA and 120 kV. DFA continuously scanned the stationary phantoms and virtual pulsating aneurysm model (VPAM) for 7.2 s and clinical subjects for 10 s while recording electrocardiograms (ECGs) to match acquisition to specific phases of the cardiac cycle. Source data image reconstructions were performed with 0.5-mm thickness. Before downloading reconstruction CT images to a visualization workstation (ZIO M900 Quadra; Amin, Tokyo, Japan), quantum noise was removed on the CT scanner computer. DFA included a new concept of time with a retrospective simulated R-R interval reconstruction algorithm that involved the rearrangement in absolute temporal order from the R wave (Figure S1). A collateral number was calculated on the computer attached to the Aquilion CT scanner, and the collateral number order meant the time interval between the newest R wave and the end of each scanning time. After rearrangement according to the collateral number and the CT series number, each 3D-CTA image was outputted as a JPEG. DFA movies were made using these JPEG files in relative temporal order.

ECG-Gated 4D-CT Angiography (CTA)
ECG-gated 4D-CTA was performed in the experimental studies using the stationary and pulsating phantoms to evaluate the artifacts on 4D-CT movies. Detailed description of this technique was reported previously.  

Stationary and Pulsating Phantoms

A titanium clip (Yasargil, model FT764T; Aesculap, San Francisco, CA) with a CT value of about 3000 Hounsfield units (HU) and a dry bone phantom with a CT value of about 500 HU were employed as stationary phantoms. The stationary phantom was placed at the center of the gantry. The VPAM with a 5-mm diameter lumen and a 5-mm aneurysm dome at the side wall was made from latex and connected to a pulsation pump, which provided pressure at a pulsatile frequency of 62 beats/min. Pulsation amplitude of the dome was 0.7 mm in diameter. The VPAM was filled using contrast material diluted 30× with saline to adjust the CT value to about 250-300 HU on the axial CT image reconstructed using the FC41 reconstruction formula (Figure S2). For quantitative analysis, surface area and volume of the VPAM at each phase were measured using INTAGE Volume Editor software (KGT, Tokyo, Japan).

Clinical DFA

DFA was performed in 4 patients with unruptured cerebral aneurysms at NHO Mie Chuo Medical Center (Table S1). Contrast medium injection was performed using a 100-ml dose of Omnipaque 370 nonionic contrast medium (Daiichi Pharmaceutical, Tokyo, Japan) delivered into an antecubital vein. To maintain a stable intra-arterial CT value during dynamic scanning, Dual Shot GX (Nemoto Kyorindo, Tokyo, Japan) was used in the variable injection method. Using this method, initial injection rate was determined based on patient body weight and then the injection rate was decreased to half the initial rate. At each phase when DFA was obtained, a CT value was measured in all reconstruction images in the DFA movie. All DFA movies were made using adequate reconstruction images, for which the variation in CT value was kept <25 HU (Figure S3). To analyze arterial pulsation, volume of the sphenoidal (M1) segment of middle cerebral arteries (MCAs) was measured in 54 phases of 8 MCAs.
Supplemental Table

**Table S1.** Summary of clinical DFA studies in patients with unruptured cerebral aneurysm.

<table>
<thead>
<tr>
<th>Case</th>
<th>Location</th>
<th>Size (mm)</th>
<th>Mean R-R interval (sec)</th>
<th>Phase number during one cardiac cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ICA</td>
<td>6.5</td>
<td>0.812</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>ICA</td>
<td>11.0</td>
<td>0.938</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>MCA</td>
<td>5.2</td>
<td>0.953</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>VA</td>
<td>4.8</td>
<td>0.820</td>
<td>7</td>
</tr>
</tbody>
</table>

ICA, internal carotid artery; MCA, middle cerebral artery; VA, vertebral artery.
Schema of DFA showing the concept of the retrospective simulated R-R interval reconstruction algorithm.
The virtual pulsating aneurysm model (VPAM) that was made using a latex tube with a 5-mm diameter lumen and a 5-mm aneurysm dome on the side wall, circulating diluted contrast material via a pulsation pump (A). The VPAM placed at the center of the gantry (B) is affected by pressure wave with a pulsation frequency of 62 beats/min (C).
CT values in intracranial arteries or aneurysms are evaluated during image acquisition on all dynamic CT images per 1 second. All clinical DFA movies are made only using source CT images with CT value variation <25 HU (green square).
Supplemental References

Supplemental Movie Legends

Movie S1. The titanium clip on ECG-gated 4D-CTA movie (A) and DFA movie (B).

Movie S2. The dry bone phantom on ECG-gated 4D-CTA movie (A) and DFA movie (B).

Movie S3. DFA movie showing dynamics of the VPAM.

Movie S4. Clinical DFA movie showing the movement of intracranial arteries without artifacts, as demonstrated by disappearance of movement of the external ear.

Movie S5. Clinical DFA movie showing two kinds of movement of intracranial arteries: pulsation and anatomical positional changes of the artery.

Movie S6. Dynamic multiscan technique 4D-CTA movie (A) and DFA movie (B) of a dry bone phantom.