Analysis of cross-sectional area and diameter of carotid artery using time-of-flight MR angiography and CT angiography

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**Purpose**

1. Stenosis arising from intimal thickening of the internal carotid artery puts patients at high risk of brain embolism and haemodynamics-related cerebral infarction. In carotid artery stenosis, it is important to precisely assess the vessel cross-sectional area and diameter because this result is used to determine the treatment strategy.

2. In recent years, time-of-flight magnetic resonance angiography (TOF-MRA) and computed tomography angiography (CTA), both non-invasive and objective imaging methods, have been used to evaluate stenosis. TOF-MRA is considered the preferred screening test because it can be used to collect objective measurements without contrast media and radiation exposure; however, this approach overestimates stenosis and cannot be used to distinguish high-grade stenosis from occlusion.

3. The purpose of our study was to evaluate differences in the vessel size between normal and stenotic carotid arteries using TOF-MRA and CTA.

**Methods and Materials**

**Image acquisition of TOF-MRA and CTA:**

**TOF-MRA**

TOF-MRA data were acquired using a 3D-TOF technique on a 1.5T MR scanner (Magnetom Avanto; Siemens, Germany) with the following parameters: TR/TE = 23/6.9 ms; flip angle = 21°; matrix = 256 × 230 pixels; slice thickness = 1 mm; FOV = 220 mm; slab number = 3; scan time = 2 min25sec; number of slices per slab = 40; and total number of slices = 92. The TOF-MRA imaging data were then transferred to a workstation (Ziostation; Amin, Inc, Japan) for analysis.

**CTA**

CTA data were obtained using multi-detector row CT (Aquilion 64; Toshiba, Japan) with the following parameters: 120 kV; FOV = 210 mm; 0.6-sec gantry rotation period; slice thickness of 0.5 mm; and CT auto-exposure control current. The imaging range was from
the sixth cervical spine to the calvarium. A non-ionic contrast agent was administered into an elbow vein using a power injector (Dual Shot GX; Nemoto Kyorindo Co., Ltd, Japan). We performed the scan using the bolus tracking method. The CTA imaging data were then transferred to a workstation as described above.

Vessel analysis:

1. Preliminary analysis

Methods

We examined inter-observer changes prior to the experiment in case an observer measured a lumen subjectively. The observer measured the right internal carotid artery (R-ICA), left ICA (L-ICA), right common carotid artery (R-CCA), and left CCA (L-CCA) data of 5 normal patients obtained using TOF-MRA and CTA. These same parameters were then measured by 5 radiographers using a measurement function at a workstation. We then calculated the coefficients of variation (CVs) for the R-ICA, L-ICA, R-CCA, and L-CCA, measurements.

Results

As shown in Fig. 1 on page 5, these CVs were 4-10% for both TOF-MRA and CTA for all blood vessels. CVs were higher for TOF-MRA between blood vessels (2-3%) than between TOF-MRA and CTA measurements. As mentioned above, artificial changes result from observers’ subjective measurements, so we decided to conduct measurements using a blood vessel analysis program at the automated workstation in this study.

2. Analytical procedure

Below is a description of the method of analysis we used that involved a blood vessel curved planar reconstruction (CPR) automatic indication system. The measurement consisted of the following 3 steps:

1. We identified the segment to be analysed by designating its starting and ending points in the planar cross-sections.
2. The software automatically detected the central line of the vascular model between the defined points.
3. The cross-sectional areas and mean diameters were automatically computed. The mean diameter was defined as the diameter of the circle that would have the same area as the vascular cross-section.

**Examination of the normal group:**

**Subjects**

Thirty-three normal patients (20 men, 13 women; mean age, 66.9 ± 9.0 years) were retrospectively evaluated. Each patient underwent both TOF-MRA and CTA within a 30-day period.

**Methods**

Using a vessel analysing program on the workstation, we measured the cross-sectional areas and diameters of each ICA and CCA in the normal group without carotid artery stenosis. We equalised the distance from the carotid bifurcation to a proximal portion (in the CCA) and from the carotid bifurcation to a distal portion (in the ICA) for the TOF-MRA and CTA imaging in every patient. The mean values of the distance between the carotid bifurcation to the measurement portions between patients were 32.4 ± 5.1 mm in the ICA and 20.7 ± 4.7 mm in the CCA.

**Statistical analysis**

The Wilcoxon signed-rank test was used to assess differences in the TOF-MRA and CTA measurements.

**Examination of the stenosis group:**

**Subject**

Eighteen patients (12 men, 6 women; mean age, 74.4 ± 6.4 years) with stenotic ICA were retrospectively evaluated, and each patient underwent both TOF-MRA and CTA within a 30-day period.

**Methods**
We measured the cross-sectional area and diameter of the stenotic lesions and the normal-appearing portion of the vessel distal to the lesions. We then calculated the percentage of area stenosis \( PS_a \) and the percentage of diameter stenosis \( PS_d \) by obtaining measurement values from the following expressions based on the North American Symptomatic Carotid Endarterectomy Trial (NASCET) method:

\[
PS_a (\%) = 100 \left(1 - \frac{S_a}{N_a}\right)
\]

\[
PS_d (\%) = 100 \left(1 - \frac{S_d}{N_d}\right)
\]

\( S_a \): vessel cross-sectional area of the stenotic lesion

\( N_a \): vessel cross-sectional area of the normal-appearing portion of the vessel distal to the stenotic lesion

\( S_d \): diameter of the stenotic lesion

\( N_d \): diameter of the normal-appearing portion of the vessel distal to the stenotic lesion

**Images for this section:**
Fig. 1: Coefficient of variation (CV) of the vessel diameter measurements between observers. R-ICA, right internal carotid arteries; L-ICA, left internal carotid arteries; R-CCA, right common carotid arteries; and L-CCA, left common carotid arteries.
Results

Examination of the normal group:

Cross-sectional areas

Results of the cross-sectional areas of the R-ICA, L-ICA, R-CCA, and L-CCA of the normal group are shown in Fig. 1 on page 8. The cross-sectional areas of the ICA and CCA obtained using TOF-MRA were respectively 17.4% and 14.0% higher than those obtained using CTA.

Mean diameters

Results of the measured diameters of the R-ICA, L-ICA, R-CCA, and L-CCA are shown in Fig. 2 on page 9. The mean diameters of the ICA and CCA obtained using TOF-MRA were respectively 9.0% and 7.2% smaller than those obtained using CTA.

Examination of the stenosis group:

Results of the calculated percentage of stenosis using the obtained measurements are shown in Fig. 3 on page 9. The percentages of area and diameter stenosis obtained using TOF-MRA for the 18 cases that we measured in this study were respectively 7.7% and 14.3% higher than those obtained using CTA. In 6 cases in the stenosis group, there was no sign of stenotic artery on TOF-MRA, but CTA could depict it.

Clinical cases:

Imaging of a model case is shown in Figs. 4 and 5.

- Fig. 4 on page 10 shows R-ICA stenosis with calcification in a 72-year-old woman. Note that the percentages of the area of stenosis were 100% and 57.6% on TOF-MRA and CTA, respectively, while the percentages of the diameter of stenosis were 100% and 34.0% on TOF-MRA and CTA, respectively. Calcification of the vessel wall was seen at all circumferences, and the vessel lumen was asymmetrical. This case is different in that the stenosis rate differed greatly between TOF-MRA and CTA.
- Fig. 5 on page 11 shows L-ICA stenosis with calcification in a 78-year-old woman. Note that the percentages of the area of stenosis were 77.0%
and 60.3% on TOF-MRA and CTA, respectively, and that the percentages of the diameter of stenosis were 51.1% and 37.2% on TOF-MRA and CTA, respectively. Calcification was seen in the vessel wall, and the lumen was asymmetrical.

Images for this section:

**Fig. 1**: A box-whisker plot of the 33 normal patients (20 men, 13 women; mean age, 66.9 ± 9.0 years) showing vessel cross-sectional areas of the common carotid arteries (CCAs) and internal carotid arteries (ICAs) on time-of-flight magnetic resonance angiography (TOF-MRA) and computed tomography angiography (CTA). The boxes represent the measured values between the 25th and 75th percentiles. The horizontal lines inside the boxes represent the medians. The vertical bars (whiskers) represent the 10th and 90th
percentiles. The mean cross-sectional areas of the normal ICAs and CCAs obtained using TOF-MRA were significantly smaller than those obtained using CTA.

Fig. 2: A box-whisker plot of the 33 normal patients (20 males, 13 females; mean age, 66.9 ± 9.0 years) showing vessel diameters of the common carotid arteries (CCAs) and internal carotid arteries (ICAs) on time-of-flight magnetic resonance angiography (TOF-MRA) and computed tomography angiography (CTA). See Figure 1 for a description of the box-plot components. The mean diameters of the normal ICAs and CCAs obtained using TOF-MRA were significantly smaller than those obtained using CTA.
Fig. 3: Percentages of (a) area stenosis and (b) diameter stenosis in internal carotid arteries obtained using time-of-flight magnetic resonance angiography (TOF-MRA) and computed tomography angiography (CTA). Percentages of area and diameter stenoses obtained using TOF-MRA were 7.7% and 14.3% higher than those obtained using CTA, respectively. # = mean value.
Fig. 4: Right internal carotid artery stenosis with calcification in a 72-year-old woman: (a) time-of-flight magnetic resonance angiography (TOF-MRA), curved planar reconstruction (CPR) image; (b) TOF-MRA, maximum intensity projection image; (c) computed tomography angiography (CTA), CPR image; and (d) CTA, volume-rendered image. Note that the percentages of area stenosis were 100% and 57.6% on TOF-MRA and CTA, respectively, and that the percentages of diameter stenosis were 100% and 34.0% on TOF-MRA and CTA, respectively.
Fig. 5: Left internal carotid artery stenosis with calcification in a 78-year-old woman: (a) time-of-flight magnetic resonance angiography (TOF-MRA), curved planar reconstruction (CPR) image; (b) TOF-MRA, maximum intensity projection image; (c) computed tomography angiography (CTA), CPR image; and (d) CTA, volume-rendered image. Note that the percentages of area stenosis were 77.0% and 60.3% on TOF-MRA and CTA, respectively, and that the percentages of diameter stenosis were 51.1% and 37.2% on TOF-MRA and CTA, respectively.
Conclusion

The TOF-MRA underestimates vessel-size than the CTA. Moreover, the TOF-MRA overestimates percentage of stenosis than the CTA. We must remain aware of this fact when using TOF-MRA in carotid artery stenosis cases.

In order to obtain accurate measurements in arterial occlusive disease, it is essential for clinicians to understand the technical considerations associated with the quantitative measurement and take advantage of the strengths and recognise the weaknesses of each modality.

References


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