Carotid artery plaque diagnosis using CT is useful for detecting ulcer formation or calcified lesions through the spatial-resolution-based rearrangement of multiplanar images. Quantitative assessment, in which the plaque volume (mm$^3$) is calculated, and qualitative assessment, in which plaque is classified into vulnerable or calcified plaque using the Hounsfield Unit (HU), are possible. Calcified plaque is clearly visualized on CT, with a high HU, and the grade of calcification can be evaluated. Carotid artery stenting (CAS) for carotid artery stenosis with marked calcification may not lead to sufficient dilation, and CT is useful for preoperative assessment. On the other hand, vulnerable plaque may show a low HU, and fresh post-CAS infarction/restenosis more frequently appear when the volume of plaque with a low HU is larger. However, in the presence of a hematoma in the site of vulnerable plaque with a low HU, the HU may increase; therefore, qualitative assessment is limited. Furthermore, the limitations of CT include renal toxicity related to the use of contrast medium, radiation exposure, and artifacts. However, CT is more advantageous than MRI from the viewpoints of exposure-time shortening and availability in case of emergency.

Keywords ▶ plaque, carotid artery stenosis, computed tomography, calcified plaque, vulnerable plaque

Introduction

CT was developed by Godfrey Hounsfield (Electrical and Musical Industries, United Kingdom) in 1968. Initially, one-row detectors had been used, but the number of rows has increased since 2000. Currently, precise imaging of the beating heart using 320- or 640-row detectors is possible.\(^1\) CT with such multi-detectors is expressed as multi-detector row CT (MDCT) or multi-slice CT (MSCT). Its spatial resolution facilitated detailed evaluation by the rearrangement of axial/coronal/sagittal sections to multiplanar images.\(^2\) To evaluate the plaque properties of stenotic carotid artery lesions, plaque imaging using MRI is more commonly used compared with CT. However, CT is advantageous for morphological plaque assessment, involving ulcer formation, percent stenosis, and length of stenosis, due to its spatial resolution. In addition, it is useful for the visualization of calcified lesions (Fig. 1A and 1B).\(^3\)

CT is more advantageous than MRI from the viewpoints of exposure-time shortening and availability in case of emergency, but its limitations include renal toxicity related to contrast medium, radiation exposure, and artifacts.\(^2,4\) The dose of contrast medium for CTA varies among studies (50–120 mL), but it is recommended that its dose should be minimized.\(^4,7\) The amount of exposure related to cervical CTA is reportedly 10–12 mGy.\(^4,9\) In the presence of plaque with marked calcification, blooming effects influence the accuracy of plaque assessment around calcified areas (Fig. 1C and 1D),\(^9\) but a study reported that dual-energy CTA facilitated the accurate assessment of the percent stenosis even in the presence of markedly calcified plaque.\(^10\) Dual-energy CT (dual-source CT) is an imaging method to differentiate tissue by releasing two X-ray energies from two different X-ray sources and generating different Hounsfield Units (HU$s$) in the same tissue.\(^10\) When denture and plaque are present at the same level, there may be great artifacts in the area of plaque (Fig. 1E).
In this study, we review the clinical significance of plaque diagnosis using CT.

### Plaque Diagnosis

The spatial resolution of CT is 0.5–0.6 mm. However, that of recent devices is reportedly 0.3 mm. Many studies regarding the plaque volume using CT evaluated the volume in the unit of mm³; the plaque volume was quantitatively evaluated in comparison with MRI. CT facilitates the assessment of tissue properties using the HU. The HU is proportional to the X-ray absorption coefficient, which is calculated, regarding water as zero and air as −1000. A study examined the relationship between the results of histological plaque diagnosis obtained by carotid artery endarterectomy and the HU on CT, and reported that the mean HUs of calcification, fibrous tissue, and lipid-rich/necrotic core (LR/NC) were $657 \pm 416$, $88 \pm 18$, and $25 \pm 19$, respectively. Another study indicated that the mean HUs of calcification, hemorrhage, fibrous tissue, and LR/NC were $256.7 \pm 30.2$, $97.5 \pm 22$, $46.4 \pm 19.9$, and $32.6 \pm 20.0$, respectively. Based on these results, the borders of HU-based plaque property assessment were established: lipid core, HU of ≤60; fibrous tissue, 60–130; and calcification, ≥130. Hemorrhage shows an HU of 50–130 (Fig. 2A and 2B).

### Calcified Plaque

The volume of calcified plaque measured on MDCT reportedly accounts for 4.8%–24.0% of the total plaque.

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**Fig. 1** On a 3D image (A) and sagittal section (B) of carotid artery CTA, ulcerative plaque was clearly visualized. On an axial image (C), calcified plaque was visualized. However, the vascular lumen was not clearly visualized due to marked calcification (D). The presence of denture (arrow) at the same level as stenosis made accurate plaque assessment difficult through artifacts (arrowheads) (E).
M isaki K, et al. calculated the degree of calcification on axial sections using the following formula: external circumference of the calcified plaque/external circumference of the carotid artery × 360°, and reported that there was a positive correlation between this angle and residual stenosis after CAS, suggesting that CAS should be avoided in patients with circumferential calcified lesions. Furthermore, another study indicated that, when conducting CAS in patients with marked calcification (≥75% of the vessel circumference), postoperative MDCT confirmed fragmentation of calcified plaque in 94% of the patients, suggesting plaque fragmentation as a mechanism by which stent dilation is.
achieved in the presence of hard, markedly calcified plaque.\(^6\) It was reported that calcification at the carotid bifurcation was involved in hemodynamic depression after CAS,\(^25\) but analysis of the plaque volume using MDCT showed that hemodynamic depression was associated with the total volume of plaque, but not with the calcified plaque volume.\(^15\)

### Vulnerable Plaque

The HU of vulnerable plaque, represented by lipid-rich plaque, is reportedly low. In many articles, it was defined as \(\leq 60\).\(^5,11,13,17,20,22\) On coronary plaque diagnosis using MDCT, low-density plaque is regarded as vulnerable, and the boundary HU between lipid-rich and non-lipid-rich plaque is established as 50–70.\(^12,26\) In particular, areas with an HU of \(\leq 0\) are regarded as lipid-pooled areas, and their presence in ruptured plaque was reported.\(^13\) In a study regarding plaque diagnosis using CT at Kanazawa University, there was a positive correlation between the number of high-signal-intensity areas on diffusion-weighted MR images after CAS and the preoperative volume of plaque with an HU of \(\leq 0\), suggesting the usefulness of CT for risk assessment before CAS.\(^11\) Furthermore, it was reported that the incidence of in-stent stenosis after CAS was significantly higher in patients with a large volume of plaque with an HU of \(\leq 0\).\(^5\) An area with a low HU is regarded as lipid-rich plaque, suggesting vulnerable plaque. However, if such vulnerable plaque is complicated by intra-plaque hemorrhage, the HU may increase; therefore, we cannot conclude that only low-HU plaque is vulnerable (Fig. 2C–2H).\(^2,5\) Concerning contrast enhancement, a study reported that contrast effects increased in the early to delayed (2 min later) phases in fibrous tissue, whereas they reduced in vulnerable plaque with neovascularization; serial changes in contrast effects may also be useful for detecting vulnerable plaque.\(^5\)

### Usefulness for Other Matters

Cervical CTA facilitates simultaneous systemic assessment. An access route is evaluated prior to CAS for preoperative risk assessment.\(^27,28\) It is possible to evaluate the level of stenosis before carotid endarterectomy or simulate the visualization of the superior thyroid or ascending pharyngeal arteries at an angle similar to the surgical field. Furthermore, a study indicated the association between the presence of calcified plaque or low-HU plaque and onset of myocardial infarction within 1 year.\(^29\) Several studies evaluated stent sliding or in-stent stenosis after CAS using CTA; it is also useful for post-treatment assessment.\(^30,31\) According to a study comparing ultrasonography with CT for plaque diagnosis, diagnoses of calcified or lipid-rich plaque were consistent, but diagnoses of ulcerative plaque were not consistent.\(^32\)

### Conclusion

Carotid artery plaque diagnosis using CT is useful for detecting ulcers or calcified lesions due to its spatial resolution. It facilitates the quantitative assessment of the plaque volume and HU-based classification of plaque properties such as vulnerable and calcified plaque (qualitative assessment). The limitations of CT include renal toxicity related to contrast medium, radiation exposure, and artifacts, but CT is more advantageous than MRI from the viewpoint of exposure-time shortening.

### Disclosure Statement

There is no conflict of interest for the first author and co-authors.

### References


