Preoperative Detection of the Composition of Atherosclerotic Plaque in the Carotid Artery Using Ultrasonography and Magnetic Resonance Imaging

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Abstract

Preoperative identification of the components of atherosclerotic plaque was attempted using ultrasonography in five patients and magnetic resonance (MR) imaging in three patients before carotid endarterectomy. The correlation between surgical and histological findings, and preoperative ultrasonography and MR imaging was evaluated. Plaque consisting predominantly of calcification appeared as bright echo on ultrasonography and was tough. Plaque consisting predominantly of hemorrhage was echolucent, appeared as low intensity on T2-weighted MR images and was fragile. Such preoperative assessment of plaque composition using ultrasonography and MR imaging is useful for manipulation of atherosclerotic plaque during carotid endarterectomy.

Key words: carotid endarterectomy, ultrasonography, magnetic resonance imaging, pathology

Introduction

Carotid endarterectomy is a common neurosurgical procedure indicated for patients with over 70% stenosis in the carotid artery.10 Some atherosclerotic plaque is tough and more difficult to remove, whereas other plaque is fragile and easily creates emboli during surgical manipulation. Embolus from atherosclerotic plaque is involved in the pathogenesis of transient ischemic attack, so such differences in the components of the plaque are important. Therefore, preoperative detection of the components of atherosclerotic plaque would allow planning of manipulation according to the type of atherosclerotic plaque. Ultrasonography5,6,12,17 and magnetic resonance (MR) imaging7,15,18 are both useful to investigate the components of atherosclerotic plaques, i.e. calcification and hemorrhage. This study investigated the composition of atherosclerotic plaques using preoperative ultrasonography and MR imaging and postoperative histological examination.

Patients and Methods

Carotid endarterectomy was performed in 14 patients between 1990 and 1995 at our institute and associated hospitals.11 The components of atherosclerotic plaques were investigated by ultrasonography in five patients and/or MR imaging in three patients before surgery (Table 1). Patient age ranged from 46 to 70 years. All patients had ischemic symptoms with over 70% stenosis in the ipsilateral carotid artery or subclavian artery on digital subtraction angiography, which are the standard indications of the North American Symptomatic Carotid Endarterectomy Trial.10 Endarterectomy was performed by common methods.14,10

B-mode images and color-flow Doppler ultrasonograms (SSD-2000; Aloka, Tokyo) were obtained using a 7.5 MHz probe (UST-5524-7.5; Aloka). Echolucent echo and bright echo were distinguished. T1-weighted, proton density, and T2-weight-
ed images were obtained by conventional spin echo methods (Magnetom H15SP; Siemens, Erlangen, Germany). At surgery, the atherosclerotic plaques were removed as far as possible to minimize contamination of blood during surgery. None of the patients showed any additional neurological deficit after surgery. Specimens were fixed in 10% buffered formalin solution, embedded in paraffin, and cut into 5 µm sections. The sections were stained with HE and were evaluated by an experienced pathologist. The correlations between surgical findings, histological findings, ultrasonographic images, and MR images were investigated.

### Results

The ultrasonography, MR imaging, surgical and histological findings are shown in Table 1. Ultrasonography found an atherosclerotic plaque with a bright echo in one patient (Case 4). This bright echo plaque was tough, and so the vessel wall could have easily been penetrated during surgery. The plaque was predominantly composed of calcification. Ultrasonography found echolucent atherosclerotic plaques in four patients. These echolucent atherosclerotic plaques had different MR imaging appearances which were correlated to surgical and histological findings. One plaque appeared as high intensity on the T₁-weighted images and low intensity on the T₂-weighted images (Case 2). One plaque appeared as inhomogeneous intensity on the T₂-weighted images (Case 3). Histological examination showed these two plaques were predominantly composed of hemorrhage. Atherosclerotic plaques which appeared as inhomogeneous on MR images were fragile, and might be a source of emboli in surgery. One plaque was isointense on T₁-weighted, proton density, and T₂-weighted images (Case 5). Intraoperative and histological examination found that this plaque was predominantly composed of fibrous tissue.

### Representative Cases

**Case 2**: A 46-year-old male presented with right hemiparesis. Angiography showed left common carotid artery stenosis (Fig. 1). Ultrasonography

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### Table 1 Summary of cases

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age</th>
<th>Sex</th>
<th>Diagnosis</th>
<th>Ultrasonography</th>
<th>Magnetic resonance imaging</th>
<th>Surgical findings</th>
<th>Histology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>70</td>
<td>M</td>
<td>Lt ICA stenosis</td>
<td>echolucent echo</td>
<td>T₁: high PD: iso</td>
<td>inhomogeneous fragile hard plaque</td>
<td>fibrous tissue, cholesterol</td>
</tr>
<tr>
<td>2</td>
<td>46</td>
<td>M</td>
<td>Lt CCA stenosis</td>
<td>echolucent echo</td>
<td>T₁: high PD: slightly high</td>
<td>soft and fragile plaque</td>
<td>blood, fibrous tissue, cholesterol</td>
</tr>
<tr>
<td>3</td>
<td>69</td>
<td>M</td>
<td>Lt subclavian artery</td>
<td>echolucent echo</td>
<td>T₁: high PD: iso</td>
<td>elastic hard plaque</td>
<td>thrombi, cholesterol</td>
</tr>
<tr>
<td>4</td>
<td>64</td>
<td>M</td>
<td>Lt ICA stenosis</td>
<td>bright echo</td>
<td>T₁: iso PD: iso</td>
<td>hard plaque</td>
<td>calcification, fibrous tissue</td>
</tr>
<tr>
<td>5</td>
<td>67</td>
<td>M</td>
<td>Lt ICA stenosis</td>
<td>echolucent echo</td>
<td>T₁: iso PD: iso</td>
<td>inhomogeneous elastic hard and fragile plaque</td>
<td>hyalinization, cholesterol</td>
</tr>
</tbody>
</table>


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*Fig. 1 Case 2. Angiogram showing left common carotid artery stenosis (arrow).*
showed echolucent atherosclerotic plaque and MR imaging showed high intensity on the T₁-weighted image, isointensity on the proton density image, and low intensity on the T₂-weighted image (Fig. 2). The atherosclerotic plaque was predicted to be fragile and a potential source of emboli before clamping of the carotid artery, so the arteries were carefully dissected. The plaque was fragile. Histological examination found hemorrhage in the plaque (Fig. 3).

Case 4: A 64-year-old male presented with onset of right hemiparesis. Angiography showed left internal carotid artery stenosis (Fig. 4). Ultrasonography showed an atherosclerotic plaque with a bright echo (Fig. 5). Carotid endarterectomy was performed. The atherosclerotic plaque was tough and required careful removal to avoid penetration of the vessel wall. Histological examination found predominantly calcification (Fig. 6).

Case 5: A 67-year-old male presented with right hemiparesis. Angiography showed left internal carotid artery stenosis (Fig. 7). Ultrasonography showed echolucent atherosclerotic plaque and MR imaging showed iso intensity on T₁ and T₂-weighted and proton density images (Fig. 8). Carotid endarterectomy found the atherosclerotic plaque was elastic hard and partly fragile. This plaque was predominantly composed of fibrous tissue (Fig. 9).
Discussion

Intravascular ultrasonography has been used to investigate the components of atherosclerotic plaque in coronary stenosis, but compatible pathological data are limited.\(^5\) Specimens obtained postmortem,\(^6,10\) at carotid endarterectomy,\(^5,6,12,17\) and at atherectomy\(^11\) were used to investigate the correlation between ultrasonography and histological findings. Generally, echolucent echo and bright echo were distinguished. Echolucent echo indicated loose fibrous tissue, fat, and hemorrhage, whereas bright echo indicated dense fibrous tissue and calcification.\(^5,6,9,11,17\) Some investigators have found a correlation between histological findings and ultrasonographic findings in the carotid artery.\(^5,6,12,17\) Fibrous plaque was predominant in asymptomatic patients.\(^3\) MR imaging has also been used for determining the composition of atherosclerotic plaque.\(^7\) MR imaging could distinguish free lipids in carotid cadaver studies and experimental studies.\(^1,4,15,16\) Moreover, intra-atheromatous hemorrhage could be distinguished due to the T\(_2\) insusceptibility of hemosiderin. Correlation of MR imaging and histological findings using carotid cadaver studies showed organized thrombus appeared as a high intensity on T\(_1\)-weighted and low intensity on T\(_2\)-weighted MR images.\(^10\)

This study found that atherosclerotic plaque containing abundant calcification could be distinguished using preoperative ultrasonography as a bright echo, whereas plaque containing little calcification appeared echolucent. Atherosclerotic plaque which was predominantly composed of hemorrhage could be detected as low intensity on T\(_2\)-weighted MR images. Ultrasonography is more sensitive to calcification and MR imaging is more sensitive to hemorrhage, so double examination is recommended.

Evaluating atherosclerotic plaque in the carotid artery needs the greatest care. A slow blood flow area is sometimes demonstrated as a high intensity area on T\(_1\)-weighted MR images and therefore mimics hemorrhage. Thus, careful prior diagnosis of the location of the stenosis by angiography is necessary.
before MR imaging. Intra-atheromatous bleeding is changeable and all atherosclerotic plaques are heterogeneous, so images can vary widely. However, such preoperative information about the components of atherosclerotic plaque can be very useful. Atherosclerotic plaque consisting predominantly of hemorrhage will be fragile and requires careful dissection of the vessels to avoid embolic complication. Plaque consisting predominantly of calcification will be tough and the surgeon should be careful not to penetrate the vessel.

Fig. 8 Case 5. T₁-weighted (left), proton density (center), and T₂-weighted magnetic resonance images (right), showing isointensity areas (arrow).

Fig. 9 Case 5. Photomicrograph showing fibrous plaque. HE stain, × 200.

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References

Commentary

This report describes interesting and useful preoperative information for the carotid endarterectomy (CEA). During the procedure of CEA, we sometimes have problems to manipulate the fragile or tough calcified carotid wall due to atherosclerotic plaque as the authors mentioned in their article. They had attempted to detect such lesions by ultrasonography and MR imaging techniques preoperatively and clarified the relationships between those images and histopathological findings. Atherosclerotic plaque consisting predominantly of hemorrhage will be fragile and requires surgeon’s careful dissection of the vessels to avoid embolic complication. Plaque consisting predominantly of calcification will be tough and the surgeon should be careful not to penetrate the vessel. We agree with these findings and such information is helpful to realize the risk of surgery preoperatively. The combination of non-invasive ultrasonography and MR imaging can elucidate the pathogenesis of carotid lesion and is useful for the postoperative follow-up study of CEA. Formation of mural thrombi or the mechanism of restenosis after CEA may be documented at its early stage. This study is still minor series and needs to accumulate further cases. Another trial, for example, combination with 3-D CT scan may also give us additional information.

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The authors studied atherosclerotic plaque components of the carotid artery in five patients using ultrasonography and MR imaging. This paper gives an important clinical contribution, since preoperative information regarding the atherosclerotic composition seems very useful in the surgical planning of this lesion. However, further clinical cases should be accumulated, because 1) only three cases of MRI studies were included in this series, 2) a question whether double assessment with ultrasonography and MRI are both required is still unknown, and 3) as the authors themselves mentioned, evaluation of atherosclerotic plaque both in the carotid artery with MRI needs the greatest care. The employment of presaturation pulse technique is desirable in order to eliminate the flow related enhancement. The next paper including larger series of patients is expected to answer these ques-
This work supports the view that color Doppler and magnetic resonance (MR) angiography are useful for screening carotid artery stenosis because of their safety and high accuracy.\(^1,3\) Though carotid MR angiographic studies tend to overestimate the degree of tight stenoses,\(^5\) this technique provides relevant information about intraluminal aspect of carotid stenosis as suggested by this study. Indeed plaque ulceration and lumen thrombus are the main sources of cerebral microemboli in high grade internal carotid artery stenosis.\(^4\)

Recently, two large multicenter trials have clearly established the beneficial effect of carotid endarterectomy in the secondary prevention of ischemic brain infarction in symptomatic patients with ipsilateral carotid artery stenosis of 70–99\%\(^2\) (see also ref. 8 of this article) but the correlation of symptomatic risk with \% of stenosis ignores potentially important features of plaque morphology which may be able to identify patients with high risk of stroke. The diagnosis of ulceration by conventional ultrasound is imperfect, however, color Doppler as shown in this study can identify irregular plaques in longitudinal views. Inhomogeneity of carotid plaque on ultrasound correlates with intraplaque hemorrhage, this latter is also easily approached by MR imaging. Intraplaque hemorrhage is believed to be important in the genesis of embolism but good prospective data regarding the relationship between intraplaque hemorrhage and symptomatic outcome is limited. It has also been recognized that intraplaque hemorrhage is common in asymptomatic severe stenosis, further weakening the relationship between the presence of intraplaque hemorrhage and the presence of symptoms. However, intraplaque hemorrhage in symptomatic endarterectomy specimens correlates with increased mortality. The hemorrhage content of plaques was recently found to diminish as the time from the last symptom increased, suggesting a relation between hemorrhage and symptoms. According to Tenjin et al. preoperative plaque assessment of plaque composition using ultrasonography and MR imaging might be useful for manipulation of atherosclerotic plaque during carotid endarterectomy and could identify a population at risk, therefore a subsequent decrease of perioperative stroke, which ranges between 3.7\% to 5.5\% in NASCET (ref. 8) and ECST,\(^2\) might be expected. In this study the comparison of the residual lumen diameter obtained from pathological specimens removed en bloc at carotid endarterectomy with carotid duplex ultrasound and MR imaging might be appropriate. The reason for correlating the actual residual lumen diameter with both techniques is that conventional angiography is less likely to be used in the future to estimate percent stenosis in symptomatic or asymptomatic patients. Angiography has approximately a 0.5\% to 1\% risk of stroke or death. This has clear effects on the decision to perform endarterectomy in asymptomatic patients in whom the risk reduction is modest and may be offset by the increased complication rate.

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