Initial Experience With Intravascular Ultrasound Imaging During Carotid Endarterectomy

Ronald Karnik, MD; Hans-Peter Ammerer, MD; Walther-Benedikt Winkler, MD; Andreas Valentin, MD; Jörg Slany, MD

Background and Purpose  To assess the feasibility of intravascular ultrasound imaging during carotid endarterectomy.

Methods  Intravascular ultrasound imaging was performed during carotid endarterectomy in eight patients using an over-the-wire catheter system with a 30-MHz ultrasound probe. In vitro studies were carried out before the intraoperative application, paying special attention to visualization of the wall layers of normal carotid arteries, structures of more or less diseased vessels, and surgically placed materials such as patch, suture material, and fibrin glue. Although intravascular ultrasound failed to distinguish between intima and media in areas of normal intima, fibrotic and calcified plaques were detected clearly. Dacron patch as well as sutures were identified as highly reflective structures.

Results  In seven of the eight patients studied, intravascular ultrasound yielded cross-sectional images of good quality allowing identification of the vessel layers and the structures at the endarterectomy site. In all patients the three layers of the vessel wall were clearly differentiated and the transition zone between the site of endarterectomy and the genuine vessel appeared smooth without intimal flaps or residual atherosclerotic plaques. In one patient severe eccentric thickening of the media was detected in the distal internal carotid artery. Neither damage of the vessel layers by the shunt nor thrombus formation in the operating area and the internal carotid artery were detected.

Conclusions  Intravascular ultrasound lends itself as a potentially valuable method of quality control during carotid endarterectomy. The method seems to enable an accurate evaluation of the endarterectomy site and the search for residual plaques. (Stroke. 1994;25:35-39.)

Key Words  • carotid arteries • carotid endarterectomy • ultrasonics

Carotid endarterectomy has proven its beneficial effect in symptomatic patients with high-grade carotid stenosis.1,2 A series of studies conducted over the last decade, however, reported a combined perioperative morbidity and mortality ranging from 2% to 21%.3-5 Hospital Discharge Registry data and data from other pooled sources document perioperative complication rates in the United States averaging close to 10%. Steed et al6 analyzed perioperative neurological complications in conscious patients: Only 1 complication occurred during carotid clamping, 2 occurred on release of the clamp, and 15 occurred in the first 5 postoperative days.

Intravascular ultrasound (IVUS) has been demonstrated to be reliable and feasible in the diagnosis of peripheral arterial diseases.7 Sheikh et al8 found an excellent correlation between IVUS, external ultrasound, and angiography. Intravascular ultrasound accurately determined vessel dimensions and geometry, and the vessel morphology characterized by IVUS was similar to morphological assessments made by external ultrasound.9,10 The present study was undertaken to assess the feasibility of IVUS imaging during carotid endarterectomy. Particular attention was paid to wall morphology, the transition zone between the endarterectomy area and genuine vessel wall, and the identification of patch, suture material, and fibrin glue.

Materials and Methods

Intravascular ultrasound was performed using a 5F over-the-wire catheter system (Cardiovascular Imaging System, Inc, Sunnyvale, Calif) with a 30-MHz 2-D rotating mirror IVUS probe.

In vitro studies investigating eight fresh postmortem carotid specimens and three endarterectomy preparations were performed before intraoperative application. The in vitro studies were carried out paying special attention to visualization of the wall layers of normal carotid arteries, structures of minimal and more severely diseased vessels, and surgically inserted material such as patch, suture material, and fibrin glue. The carotid specimens from two male and two female corpses aged between 35 and 91 years consisted of a long portion of the common carotid artery (CCA), the external carotid artery (ECA), and the internal carotid artery (ICA) measuring at least 3 cm from the bifurcation. The specimens were removed during autopsy and isolated from redundant surrounding tissue. The ends of the main arteries and all small branches were tied off with sutures. The arteries were then filled with physiological saline solution to prevent collapse of the artery. The IVUS catheter was inserted through a small perforation through a 6F sheath, which was sewn into the proximal part of the CCA. The endarterectomy preparations consisted of calcified and fibrotic plaques, on which Dacron woven patches were sewn. The patches were sealed with fibrin glue as routinely used in carotid surgery. These preparations were placed in a plastic tube filled with saline solution and examined by IVUS.

The study protocol was approved by the local ethical committee and written informed consent was obtained from all patients.
Main Characteristics of the Study Group

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>8</td>
</tr>
<tr>
<td>Age, y (mean)</td>
<td>71-78 (74±4)</td>
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<tr>
<td>Sex (women/men)</td>
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<tr>
<td>Risk factors</td>
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<td>Cigarette smoking</td>
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<td>Diabetes mellitus</td>
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<tr>
<td>Hypertension</td>
<td>6</td>
</tr>
<tr>
<td>Hyperlipemia*</td>
<td>6</td>
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<tr>
<td>Clinical symptoms</td>
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</tr>
<tr>
<td>Transient ischemia attack</td>
<td>3</td>
</tr>
<tr>
<td>Minor stroke</td>
<td>5</td>
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<tr>
<td>Site of Lesion</td>
<td></td>
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<tr>
<td>Right ICA</td>
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<tr>
<td>Left ICA</td>
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<tr>
<td>Degree of stenosis</td>
<td>80-95%</td>
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<tr>
<td>Contralateral ICA occlusion</td>
<td>1</td>
</tr>
<tr>
<td>Contralateral endarterectomy</td>
<td>3</td>
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</tbody>
</table>

ICA indicates internal carotid artery.
*Cholesterol >200 mg/dL, triglycerides >150 mg/dL.

Patients admitted to this study. Intraoperative studies were performed in eight patients under general anesthesia. Skin incision was made parallel to the sternocleidomastoid muscle. After dissecting the carotid artery, an arteriotomy was performed and the 0.014-in. guide wire (Hi-Torque intermediate, Advanced Cardiovascular Systems) of the ultrasound catheter was inserted and advanced as far as the base of the skull. Then endarterectomy was performed in the typical manner. In all cases a Brenner carotid shunt was introduced beside the guide wire, first into the ICA and then the CCA. A Dacron woven patch was routinely used. The running suture (Gore-tex CV 8) started at the distal end and left a small opening for the guide wire at the proximal end of the arteriotomy. In three patients a small arteriotomy was performed separately for the IVUS probe just above the proximal vessel loop. The guide wire remained in place during the whole procedure and after extracting the shunt the probing catheter was advanced over the guide wire up to the base of the skull. The carotid artery was then flushed and the remaining arteriotomy closed. The first pulsations of the CCA were directed into the ECA giving additional protection from cerebral embolism. Lumen and vessel wall were examined while the probing catheter was pulled back very slowly. After extraction of the device the insertion site was closed with one suture. The study group consisted of four women and four men with an average age of 74±4 years (age range, 71 to 78 years). The Table summarizes the main characteristics of the study group. In all patients neurological examinations were performed on days 1, 3, and 7 postoperatively. Follow-up studies by external ultrasound were accomplished 1, 3, and 6 months after the procedure.

Results

In Vitro Studies

IVUS yielded cross-sectional images of the arteries in real time, clearly identifying media and adventitia. Ultrasound failed to distinguish between intima and media in areas of normal intima. The intima was visualized only in case of a pathologically altered and thickened intimal layer. Fibrotic and calcified plaques were detected clearly; the latter provided a bright echo with shadowing behind the lesion (Fig 1). The Dacron woven patch and the sutures were identified as highly reflective structures by IVUS. Fibrin glue appeared as soft echoes with small hyperechogenic inclusions that proved to be air bubbles.

In Vivo Studies

In all patients endarterectomy and ultrasound examinations were performed without any complications. Neurological follow-up examinations showed all patients to be free of any transient or permanent neurological symptoms.

The average time of insertion for the device and the ultrasound examination was 8±3 minutes. In all pa-
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FIG 2. Left, In vivo ultrasonic cross-sectional image of the endarterectomy site before the internal carotid artery was flushed. The vessel is still collapsed. Right, Schematic illustration of the image. IVUS indicates intravascular ultrasound.

In seven of the eight subjects, IVUS yielded dynamic cross-sectional images of good quality allowing identification of the vessel layers and the structures at the endarterectomy site (Fig 2). In one female patient ultrasound imaging showed poor quality because of air bubbles in the probing system, which had not been flushed out completely before introducing the IVUS probe. A second attempt to introduce the probe after renewed flushing failed due to a kink in the guide wire. In this case the structures could not be analyzed accurately and the ultrasound images of this patient were excluded from further evaluation.

Special attention was directed to the transition zone between the site of endarterectomy with the patch and the genuine vessel and to the part of the ICA where the distal end of the shunt was placed. Sutures, Dacron patches, and the fibrin glue were clearly identified showing the same ultrasound characteristics as found by the in vitro studies (Fig 3). In all seven patients the transition zone and the suture lines appeared smooth without intimal flaps or residual arteriosclerotic plaques. In one patient eccentric thickening of the media was detected in the distal ICA. The plaque resulted in luminal diameter narrowing of 25% to 50% on intravascular ultrasound cross-sectional images (Fig 4). In all patients the three layers of the vessel wall were differentiated clearly. In two subjects the inner layer appeared markedly thickened. Neither damage of the vessel layers by the shunt nor thrombus formation in the operating area and the ICA were detected. Duplex sonographic follow-up studies revealed no pathological findings at the endarterectomy site. The distal ICA stenosis was not detected by external ultrasound due to the location of the lesion above the mandible.

Discussion

Technical factors have been suggested by some authors as being a major cause of neurological complications of carotid endarterectomy. Vascular clamp injury, incomplete removal of plaques, and all kinds of detritus, intimal flaps, suturing faults, and trauma to the artery by the shunt may result in perioperative stroke caused by acute closure of the vessel or artery-to-artery emboli. Recently, the North American Symptomatic Carotid Endarterectomy Trial (NASCET) investigators reported a total stroke morbidity and mortality rate of 5% in patients with high-grade stenosis (70% to 99%) of the ICA, which included a major stroke rate of just 2%. The increasing number of endarterectomies in all western countries and the still rather high complication rate require accurate methods to evaluate the instant results of this procedure. In our experience, intraoperative IVUS imaging is feasible during carotid endarterectomy and it is possible to clearly differentiate the vessel layers and the structures of the endarterectomy site. However, in our series, IVUS failed to distinguish between intima and media in areas of normal intima. This is in accordance with the literature that, in elastic arteries where the media has a high content of elastic fibers, the appearance of three layers may not be apparent. By contrast, muscular arteries show a typical three-layered wall: a hypoechoic media between the intima and adventitia, both showing bright echoes.

In the first five patients the guide wire and IVUS probe were inserted through the arteriotomy of the endarterectomy. In the last three patients we used a separate small arteriotomy in the CCA, which gave us better images of the suture lines and the whole transition zone.

Positioning of the guide wire before inserting the shunt and advancing the IVUS probe to the distal part of the ICA at the end of the endarterectomy were performed without any problems or complications. However, transcranial Doppler sonography was not
used to evaluate potential emboli during investigation. Therefore, detection of asymptomatic microemboli may have been missed. Images of good quality were recorded in seven of the eight subjects. The kink in the guide wire that prevented the reinsertion of the IVUS probe after rinsing occurred at the distal part of the wire due to a towel clip. The IVUS examination prolonged the operation time from 55 minutes to 63 minutes, an average of only 8 minutes.

Angioscopy has some potential advantages in application to IVUS.\textsuperscript{21,22} Newly developed high-resolution angioscopes providing a three-dimensional colored imaging field allow examination of the intimal surface detail and intramural processes, such as intimal flaps or thrombi. These images can be accomplished with the use of extremely small caliber catheters, in the range of 1 mm or less. The major limitation of this imaging technique is the requirement of displacement of blood by clear fluid. Further disadvantages are the stiffness of the catheter, which must be introduced without a guide wire, and the inability to see significantly below the level of the intimal layer. Intraoperative angiography can be
performed without major technical difficulties. However, intraoperative angiography is unlikely to provide the same accurate information as IVUS. Contrast images may demonstrate severe damage of the vessel wall, intimal flaps, and large residual plaques, but angiographic appearance is imprecise in characterization of smaller intraluminal processes like thrombus or dissection, and is often misleading in identifying the thickness of plaque present in any given radial direction.

The flexibility of the intravascular ultrasound catheter allows an easy advance even through tortuous vessels by means of a guide wire. Another practical advantage of the ultrasound catheter is the ability to image through blood without special requirements such as the need for a flushing system. These features, combined with the high resolution of the ultrasound system, make it an excellent modality for imaging both intraluminal and intramural processes. Thrombi can be imaged accurately with IVUS.

Current limitations of IVUS are physical factors influencing image quality: proper alignment of the catheter in the long axis is necessary to obtain adequate images. Eccentric positioning results in high-intensity echoes of the adjacent wall structures which appear thicker, while similar structures in the opposite more distant wall appear hypoechoogenic. The thickness of the ultrasound catheter (SF), the capability to provide slice views only, and the inability to aim forward are further disadvantages of this technique.

Despite these limitations, IVUS lends itself as a potentially valuable method of quality control during carotid endarterectomy. The method enables accurate evaluation of the transition zone between the genuine vessel and the endarterectomy site with the patch and the detection of residual plaques. In our small study group we found neither intimal flaps nor vascular clamp injuries, which was confirmed by external ultrasound in follow-up studies. A more extensive study is necessary to evaluate the accuracy of IVUS in the diagnosis of arterial trauma caused by the shunt as a possible contribution to the reduction of postoperative stroke and mortality rate of carotid endarterectomy.

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