J Korean Radiol Soc 1999;41:1101-1106

Efficiency of Ultrasonography and CT Angiography in Follow-up Studies of Carotid Stent and Percutaneous Transluminal Angioplasty[1]

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Purpose: The aim of this study was to determine a more appropriate method for follow-up of carotid stenting by comparing the efficiency of US and CT angiography.

Materials and Methods: Eleven carotid arteries of seven patients(men: 5, women: 2, mean age: 56.4years) who underwent stent placement and percutaneous transluminal angioplasty(PTA) because of carotid stenosis were studied. The follow-up periods ranged from three to eleven(mean, five) months, and US and CT angiography were performed in one day. Color duplex sonography was performed with a 10 MHz linear array transducer. After spiral CT scan were obtained, MPR images were reconstructed on a workstation. Retrospective imaging analysis specifically focused on [1] stent configuration, [2] the accuracy of internal diameter measurement, [3] the detection of blood flow and the measurement of blood flow velocity, [4] the presence of atheroma and intraluminal thrombi, [5] the measurement of stent location, and [6] artifacts.

Results: US was more accurate than CT angiography for measuring internal diameter. In all cases, US and CT angiography were able to detect the blood flow at carotid artery, and utilizing the Doppler spectrum, flow velocity was measured. US showed atheromas in all cases but CT angiography demonstrated calcified atheromas in three cases only. In six cases, US failed to determine stent location, though in this respect CT angiography was successful in all cases. Artifacts of US were small reverberation artifact(11/11) of the stent and a defective color Doppler signal caused by acoustic shadowing of atheroma calcification(3/11). Artifacts of CT angiogrpahy were hard-beam artifact of the stent(11/11) and motion artifact(3/11).

Conclusion: US was superior to CT angiography in accuracy of measuring stent diameter, hemodynamic assessment, high-resolution views of the luminal state of the stent and minimal artifacts for the non-invasive follow-up studies of carotid stenting.

Index words : Carotid arteries, interventional procedure
Carotid arteries, US
Carotid arteries, CT

Stent placement and percutaneous transluminal angioplasty(PTA) for treatment of carotid stenosis is currently increased because its therapeutic effect is excellent as carotid endarterectomy(CEA) (1-4). Follow-up study of

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carotid stent and PTA have thus been the focus of attention recently. Although the findings at conventional angiography are considered as the gold standard for vascular evaluation, it is an invasive and expensive procedure. Ultrasonography(US) and computed tomographic(CT) angiography are noninvasive, rapid, relatively inexpensive and good modalities for evaluating carotid artery (5-8). We could find several reports (9-14) on endovascular stent on US and CT angiography. Some were that US was performed for follow-up studies of carotid stent and it had merits in multiple aspects (9, 10), and other reports have noted that CT angiography was valuable for follow-up study of stent grafts of the aorta or iliac artery (11-14). Nevertheless, we failed to find any report describing the use of CT angiography for follow-up study of carotid stenting, or one in which US and CT angiogrphy were used simultaneously in follow-up studies of this procedure. Accordingly, the aim of this study was to determine a more appropriate follow-up method for assessing the therapeutic effects and ascertaining late complications of carotid stenting by comparing efficiencies of US and CT angiography in evaluating this procedure.

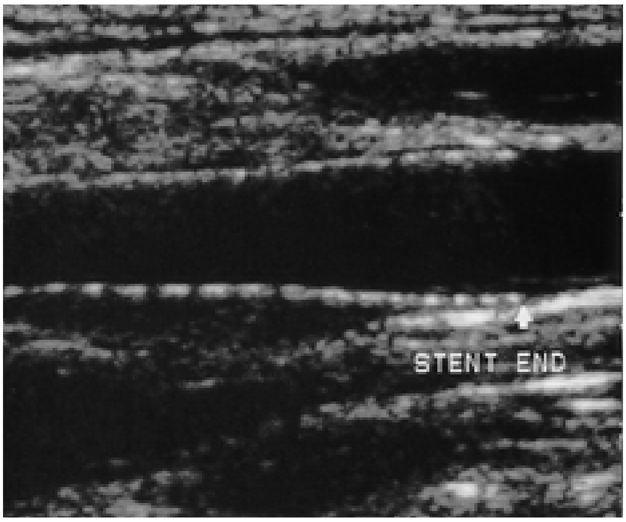
Materials and Methods

Patients

Eleven carotid arteries of seven patients who underwent stent placement and PTA at carotid stenosis were studied. In all cases, Wallstents(Schneider, Switzerland) with outer diameter of 5.5-8(average 7)mm, a length of 17-39(average 24.5)mm were used. Nine stents were located at the distal common carotid artery(CCA) to the proximal internal carotid artery(ICA) and two were located at the proximal ICA. After placing a stent, we expanded its diameter by balloon angioplasty. Follow-up periods were 3-11(mean, 5)months and both US and CT angiography were performed in one day.

Imaging

Conventional angiography performed within 24hours of stent placement at the carotid artery was used as a gold standard. For color duplex sonography, a 10 MHz linear array transducer(ATL, Ultramark9, U.S.A.) was used. In all cases, gray-scale images, Doppler spectrum, and color duplex images of carotid arteries were obtained, and blood flow velocity were recorded. For CT angiography, Somatom Plus CT scanner(Siemens, Germany) was used. Spiral CT scans were obtained using a 2mm/sec table speed or 40sec, 2mm beam collimation (nominal section thickness). Iodionated contrast (Xenetix 350mgI/ml, Guerber, France) was injected into the antecubital vein at a rate of 2.5ml/sec, and scanning began after a delay of 18-24sec. Two dimensional images parallel to the stent of long axis were created from



A

B

Fig. 1. 48-year-old man with severe stenosis of the left ICA underwent stent (6×20 mm) placement and percutaneous transluminal angioplasty.
A. On gray-scale US scan, Wallstent shows mesh-like structure with hyperechoic dotted lines.
B. On MPR image of CT angiography, Wallstent shows thick tubular radioopaque structure along the common carotid artery. Internal diameter of stent is underestimated by hard-beam artifact.

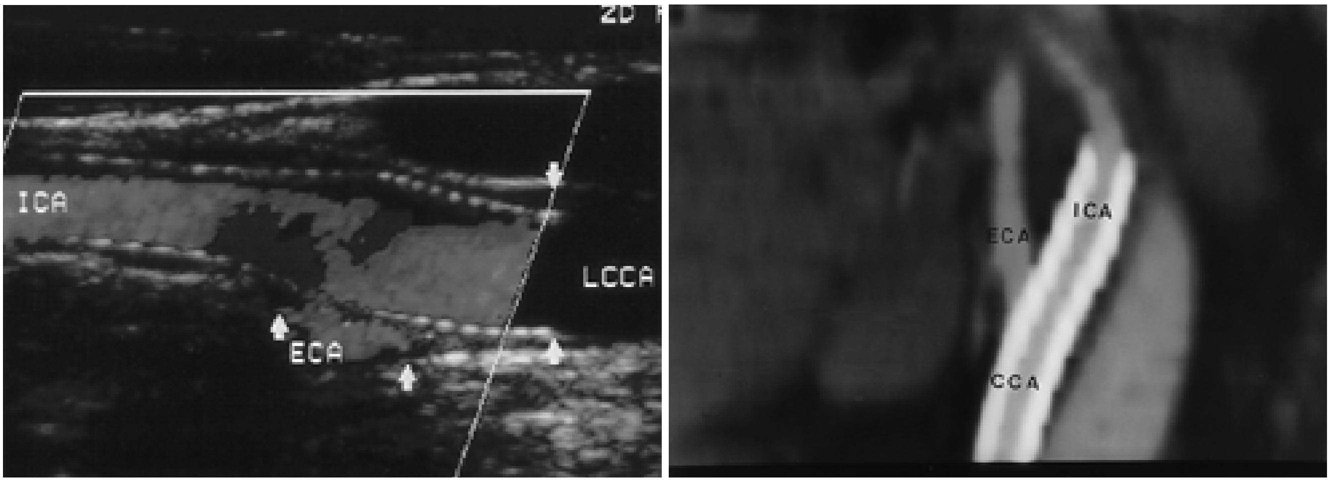
obtained spiral images using multiplanar reformation(M-PR) technique.

Analysis

The focus retrospective imaging analysis was as follows: First, we described stent configuration using the gray scale images obtained from US, and did so with the source spiral images and MPR images obtained by CT. Second, the accuracy of the measuring stent's internal diameter was determined by following a three-stage procedure: (1) from each image we measured the ratio of the internal diameter of the center part of the stent to the internal diameter of the distal CCA (just adjacent to the proximal end of the stent); (2) using conventional angiography, we followed the same procedure to obtain the ratio of the internal diameters; (3) by means of a T-test, we analyzed the differences between US or CT angiography and conventional angiography, as determined per $p < 0.05$ level. Third, utilizing US, we assessed blood flow by using color duplex image and Doppler spectrum, and measured blood flow velocity at three sites - stent lumen, the ICA and the CCA. Utilizing CT angiography, we assessed blood flow with intraluminal contrast filling. Fourth, we described the atheromas and intraluminal thrombi observed in each image. Fifth, to ascertain the position of the stent, we measured the distance from the carotid bifurcation to the proximal end of the stent. Sixth, described in detail the artifacts arising during US and CT angiography. Detailed artifacts were subdivided into those that imaging interpretation and those that do not.

Results

Stent configuration was visualized on US as hyperechoic dotted lines with small reverberation arti-facts (Fig. 1A). CT showed as thick tubular radioopaque structure without original stent filaments (Fig. 1B). Stent thickness was overestimated due to the hard-beam artifact occuring on CT angiography. There was no statistical difference ($p = 0.378$) between the ratio of internal diameter of the mid portion of the stent to that of the distal CCA, as determined by US and the ratio of respective parts, as determined by conventional angiography. The ratio derived from the results of CT angiography, on the other hand, was statistically significantly different from that determined by the findings of conventional angiography($p < 0.05$; see table). In all cases, blood flow of carotid arteries were well delineated by color encoding on US (Fig. 2A), and -also in all cases- flow velocities in three parts of the carotid arteries were measured. ICA/CCA peak systolic velocity rates were in all cases below the NASCET criteria of mild stenosis(< 1.4) (15). In all cases CT angiography revealed well-defined intraluminal contrast filling and defect-free continuous high attenuation(above 300 HU) in all lumens of ICA, ECA and CCA (Fig. 2B). In all cases US indicated the presence of atheromas between a stent and the arterial



A B

Fig. 2. 49-year-old man with moderate stenosis of the right ICA with large ulcer underwent stent(6×40mm) placement and percutaneous transluminal angioplasty.

A. Color encoded blood flow filled in the CCA, the ECA and the ICA appear as intravascular red and blue on color duplex sonogram.

B. continuous high attenuation(above 300 HU) in all lumens of the ICA, the ECA and the CCA are noted on MPR image of CT angiography, which represent blood flow mixed with contrast in vascular lumen.

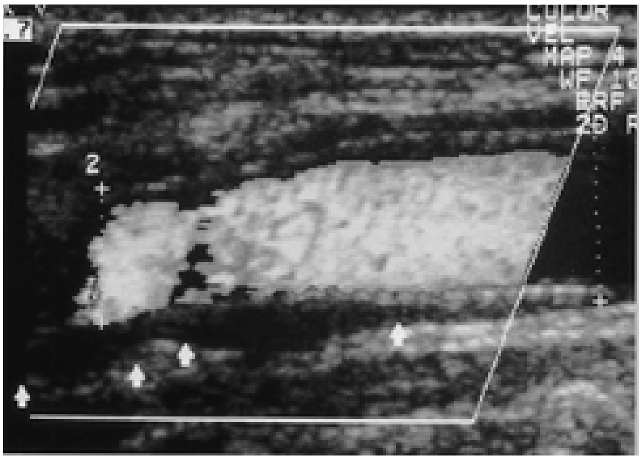


Fig. 3. 65-year-man with severe stenosis of right ICA underwent stent(8×30mm) placement and percutaneous transluminal angioplasty. A hypoechoic atheroma(arrows) is noted between stent and arterial wall on color duplex sonogram. US gives good delineation of a atheroma.

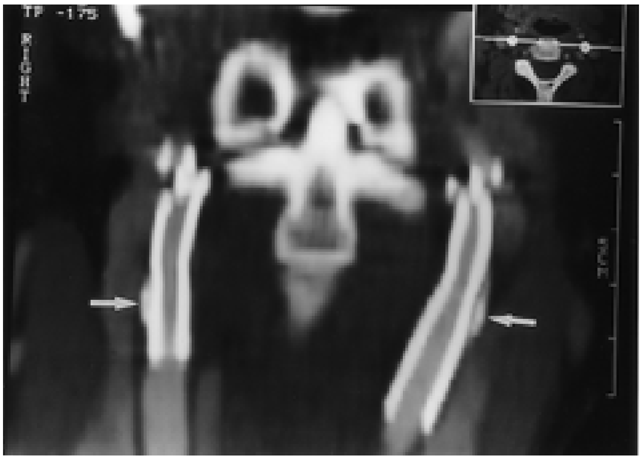


Fig. 4. 51-year-woman underwent bilateral carotid stents(right: 8×20mm, left: 8×30mm) placement. Calcified atheromas(arrows) between stent and arterial wall are well defined in MPR image of CT angiography.

Table 1. Ratios between the Internal Diameter of Midportion of Stent and That of Distal CCA Measured by *CA, US and CTA

Patient No.	1	2	3		4		5		6		7
Age/Sex	M/48	M/49	M/65		F/51		F/64		M/54		M/51
Stent Placement	Left	Right	Right	Left	Right	Left	Right	Left	Right	Left	Right
Ratio of CA(%)	100	60	61	61	65	74	66	27	39	89	94
Ratio of US(%)	84	55	58	58	55	55	56	31	44	76	80
Ratio of CTA(%)	49	50	30	33	38	42	36	15	18	54	60

CCA: Common Carotid Artery, CA: Conventional Angiography, US: Ultrasonography, CTA: Computed Tomographic Angiography

wall, but in no case were interluminal thrombi present (Fig. 3). In three cases (27.4 %) CT angiography demonstrated only calcified atheromas (Fig. 4). In six cases (54.5 %) US failed to indicate stent location. This was because the level of the carotid bifurcation could not be accurately determined; the ICA and the ECA could not be simultaneously imaged in the same longitudinal plane as the CCA. CT angiography in all cases revealed stent location. Artifacts of US were minor reverberation artifact in all cases and defect of color Doppler signal caused by acoustic shadow of atheroma calcification in three (27.3 %). We assessed, however, that these artifacts did not affect image interpretation. On CT angiography, hard-beam artifacts caused by a stent lead to underestimation of the stent's internal diameter(see table) and low resolution of the area adjacent to the stent. Image misregistration due to patient motion was noted in three (27.3 %). We assessed that the presence of such artifacts on CT angiogram affects the analysis of carotid stenting.

Discussion

Stroke is a common cause of death and the leading cause of serious long-term disability. Extracranial carotid artery stenosis is a major risk factor of the stroke (16). Percutaneous placement of a carotid artery stent, together with CEA, is currently being tried for the treatment of extracranial carotid stenosis. According to recent reports, carotid stenting has equal therapeutic effect as CEA and can be performed in high morbidity patients who are contraindicated in CEA and the patient can be completely monitoring because the procedure is performed without general anesthesia (1, 17). Compared with CEA, shortening of carotid occlusion time and hospitally days are good advantages of stenting. Therefore, carotid stent is more recommended in treating carotid stenosis.

Although the early results of carotid angioplasty with stenting have been widely reported (1,17,18), the incidence of restenosis during long term follow-up is less well documented. The restenosis rate six months after angioplasty has been reported as 2.85 % (18). Stent migration and stent deformity are also examples of the possible complications of cartoid stenting. The aim of follow-up testing in the evaluation of carotid stents should be the accurate detection of complications. Though conventional angiography is employed to help assess restenosis in carotid artery stents, US or CTA - non-invasive, low cost method of screening - may be a valid alternative. US and CTA are already regarded as good alternatives to conventional angiogaphy for screening extracranial carotid disease.

Our study showed that US accurately measured the internal diameter of a stent and was useful for the assessment of the carotid arterial blood flow. Color Doppler sonography permits not only detection of color-encoded blood flow, but also hemodynamic evaluation such as the quantitative display of flow velocity, resistance, and turbulent flow, all obtained through Doppler spectral analysis. Owing to such characteristics, US is an excellent investigative procedure that permits morphologic and hemodynamic diagnosis of restenosis. Since a stent almost never create artifacts in US and the carotid artery is a superficial structure that can be easily examined with US, the modality provides high resolution imaging of a carotid stent and adjacent structures. Observation of atheromas between a stent and arterial walls, as in a previous example in our study, readily verifies the presence of such characteristics. Because of this advantage, diagnosis of the complications of carotid stenting, such as neointimal hyperplasia and thrombi within the stent, would be rather easy. For measuring stent location and observing overall configuration, US less adequate than CT angiography the same parameters. This is because in some cases the exact level of carotid bifurcation cannot be detected on a single longitudinal plane, and the visual field is rather narrow. In approximately 60 % of patients, both vessels above the carotid bifurcation and the CCA can be imaged in the same plane; in the remainder, only a single vessel will be imaged in the same plane as the CCA (19). Such inadequacy could be compensated by also obtaining a neck X-ray.

To date, three rendering techniques have been employed in performing CTA: maximum intensity projection(MIP), shaded surface display(SSD) and MPR (20). Although MIP and SSD are mainly used for evaluating extracranial carotid diseases, MPR is more suitable than MIP or SSD for assessing endovascular metallic stent. MIP is not capable of demonstrating the stent lumen, which is obscured by the high-attenuation metallic cage. Because the stent was identified only as a bulging contour within the vessel, stent assessment with SSD is limited. MPR“ cuts ”through the wall of the stent and thus tends to be most valuable for assessing the interior of metallic prostheses and determining the presence of intimal hyperplasia or stent deformation (12, 14). CT angiography was less accurate than US for measuring a stent ’s internal diameter and had a lower resolution. According to some articles, CT angiography has been known to be an effective tool in diagnosing complications of a stent graft of aorta or iliac artery (12-14). Nevertheless, this study showed otherwise. The reason comes from the fact that carotid artery is relatively smaller than aorta or iliac artery, and the masking of adjacent structures by the hard-beam artifacts would be larger to that extent. We could easily confirm stent location and anatomy that had a similar appearance as what conventional angiography did. For the diagnosis of migration or severe deformity, these characteristics are advantageous.

A limitations of this study is that conventional angiography was not performed same time as US and CT angiography. To know more practical potential of two follow-up exams, an evaluation of the accuracy of US and CT angiography used in complicated cases is needed.

US was superior to CT angiography in terms of the accuracy of stent diameter measurment, hemodynamic assessment of blood flow in the carotid artery, high-resolution views of the luminal state of the stent and minimal artifacts on which non-invasive follow-up studies of carotid stenting.

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대한방사선의학회지 1999;41: 1101- 1106

경동맥스텐트 삽입 후 추적검사로서의 초음파와 CT 혈관조영술의 유용성[1]

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류창우 · 이병희 · 정봉섭[2] · 안정용[2] · 허 경[3] · 고영식

목적 : 경동맥에 금속스텐트 삽입술을 한 후 추적검사로 시행한 초음파와 CT 혈관조영술을 비교하고 어느 검사가 더 유용한지 알아보고자 하였다.
대상 및 방법 : 경동맥협착 치료를 위해 금속스텐트를 삽입한 7명의 환자 (남:녀=5:2, 평균연령:56.4세)의 11개의 경동맥을 대상으로 하였다. 추적기간은 3-11개월(평균5.4개월)이었다. 초음파영상은 10MHz 선형배열 탐촉자를 이용하여 회색조영상, 색도플러영상을 얻고 경동맥내 혈류 속도를 구하였다. CT 혈관조영술은 나선식 CT로 스캔한 후 MPR 기법으로 재구성하였다. 각 검사에서 얻은 영상은 다음과 같은 항목 - [1] 스텐트의 모양, [2] 스텐트의 내경 측정의 정확성, [3] 경동맥내의 혈류관찰과 혈류속도 측정, [4] 스텐트 외측의 죽종 또는 혈전 유무, [5] 스텐트의 위치, [6] 스텐트에 의한 인공물- 을 중심으로 후향적으로 분석하였다.
결과 : 스텐트의 내경 측정은 초음파가 CT 혈관조영술보다 정확하였다. 경동맥내의 혈류 유무는 초음파와 CT 혈관조영술 모두에서 관찰이 가능하였고 초음파는 혈류속도를 정량적으로 측정할 수 있었다. 초음파는 전예에서 스텐트 외측의 죽종을 관찰할 수 있었으나 CT 혈관조영술은 3예의 석회화된 죽종을 관찰할 수 있었다. 초음파에서는 11예 중 6예에서 스텐트의 위치를 측정할 수 없었으나 CT 혈관조영술에서는 전예에서 측정이 가능하였다. 초음파에서 관찰되는 인공물은 스텐트에 의한 반향(11/11)과 혈관내막석회화에 의한 그림자(3/11)였으나 영상분석에 영향을 주지 않았다. CT 혈관조영술의 인공물은 스텐트에 의한 하드-빔 인공물(11/11)와 환자의 움직임에 의한 잘못된 재구성(3/11)이었고 영상분석에 큰 영향을 주었다.
결론 : 초음파는 내경측정이 정확하고, 혈류속도를 정량적으로 측정할 수 있으며 고해상도의 영상을 얻을 수 있어 CT 혈관조영술보다 우수한 경동맥 스텐트의 비침습적 추적검사였다.