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Contrast-Enhanced 3-D MRA in Decision Making for Carotid Endarterectomy: A 6-Year Experience

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Key Words

Carotid artery · Carotid stenosis · Contrast-enhanced 3-D magnetic resonance angiography · Endarterectomy

Abstract

Background: Systematic need for angiography in diagnosis of carotid artery stenosis and indication of surgical therapy is still debated. Noninvasive imaging techniques such as MR angiography (MRA) or CT angiography (CTA) offer an alternative to digital subtraction angiography (DSA) and are increasingly used in clinical practice. In this study, we present the radiological characteristics and clinical results of a series of patients operated on the basis of combined ultrasonography (US)/MRA. ***Methods:*** This observational study included all the patients consecutively operated for a carotid stenosis in our Department from October 1998 to December 2004. The applied MRA protocol had previously been established in a large correlation study with DSA. DSA was used only in case of discordance between US and MRA. The preoperative radiological information furnished by MRA was compared with intraoperative findings. The outcome of the operation was assessed according to ECST criteria. ***Results:*** Among 327 patients, preoperative MRA was performed in 278 (85%), DSA in 44 (13.5%) and CT angiography in 5 (1.5%). Most of DSA studies were performed as emergency for preparation of endovascular therapy or for reasons other than carotid stenosis. Eleven additional DSA (3.3%) complemented US/MRA, mostly because diverging diagnosis of subocclusion of ICA. No direct morbidity or intraoperative difficulty was related to preoperative MRA. Combined mortality/major morbidity rate was 0.9% (3 patients) and minor morbidity rate 5.5% (18 patients). ***Conclusions:*** This observational study describes a well-established practice of carotid surgery and supports the exclusive use of noninvasive diagnostic imaging for indicating and deciding the operation.

Introduction

The decision to recommend carotid endarterectomy (CEA) is based on the accurate determination of stenosis degree in order to match prevailing indications from outcome trials. The need for systematic digital subtraction angiography (DSA) in the diagnosis of carotid stenosis and indication of surgical therapy is still a matter of debate [1–5]. This has been the case since the early development of noninvasive diagnostic tools in the 80s when some authors proposed to base the operation on ultrasonography (US) alone in selected cases [6–8]. The debate

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continued in the 90s with the advent of new vascular imaging methods such as MR angiography (MRA) and CT angiography (CTA) [9–11]. MRA and CTA rose the possibility to confirm the results of ultrasound noninvasively and to avoid the risks of angiography. Numerous studies have compared the advantages of MRA and CTA with golden standard DSA and assessed the reliability of noninvasive diagnosis of carotid stenosis [12–17]. In parallel, other studies have reported significant deficits in the accuracy of stenosis grading and the quality of surgical indication when conventional DSA was skipped [1]. A deep discrepancy seems to have developed between surgical praxis which relies exclusively on noninvasive diagnosis for the operation, and academic medicine which still recommends DSA as proven standard and warrant of quality. The proponents of CEA without DSA aim at reducing the overall risks of the management of carotid stenosis, which also include the risks of DSA. For those who recommend DSA routinely, the risks of exposing patients with misclassified stenoses to potentially harmful surgical complications are still high enough to justify invasive preoperative examinations. Two aspects have to be considered to resolve this contradiction. The first aspect is the quest for still better noninvasive imaging methods able to detect and grade carotid stenosis accurately without DSA. With further developments of MRA and CTA technology, it can be expected that these methods will soon equal the quality of golden standard DSA, particularly when they are used in combination [18]. Taking the problem from the other end, the second aspect to be considered is the quality of surgery based on noninvasive diagnosis alone. There is a need for clinical outcome studies of patients undergoing CEA without DSA. If the rate of surgical complications can be kept low without DSA, the risk taken by the few patients with misgraded stenosis will also remain low, making the omission of DSA epidemiologically and ethically acceptable.

A fast first-pass contrast-enhanced 3-D MR angiographic sequence was developed in 1996 in our Department of Neuroradiology to image the precerebral arteries. MRA of the carotid and vertebral arteries complemented a newly designed noninvasive MR-based protocol for stroke investigations. The method was applicable using a 1.5-tesla MR scanner. A preliminary comparison study with DSA revealed a high potential for clinical reliability [19]. The method was then established in a larger MRA/DSA correlation study which included 120 patients with different grades of carotid stenosis. The study showed a highly significant correlation of MRA with DSA (r = 0.91). The overall sensitivity of MRA for the detection of carotid stenosis was 98%, the specificity 96%, the positive predictive value 95%, and the negative predictive value 98% [20]. All internal carotid occlusions (n = 28) and seven of nine pseudo-occlusions were accurately demonstrated on MRA. Based on these excellent results and systematic ultrasound studies [21, 22], we decided in October 1998 to stop systematic preoperative DSA and to rely exclusively on MRA for the confirmation of US screening and the indication of CEA. The present study reports the surgical results and early clinical outcome of the patients consecutively operated in our Department during the last 6 years. It completes our neuroradiological studies [19, 20] and aims at contributing to the establishment of a purely noninvasive preoperative protocol for patients having to undergo CEA.

Methods

Patient Selection

This observational cohort study included all the patients consecutively operated for a symptomatic or asymptomatic carotid stenosis during the last 6 years in our Department of Neurosurgery. Screening, diagnosis and grading of stenoses were based on Doppler/Duplex US [21, 22]. Only the patients with a high-grade symptomatic or asymptomatic stenosis (70–99% according to NASCET) and those with an evidently symptomatic middle-grade stenosis (50–69%) were considered for surgery [23–25]. No patient having a low-grade stenosis (<50%) was selected for operation. Whenever possible, confirmation of the sonographic results was performed with first-pass contrast-enhanced 3-D MRA of the carotid bifurcation according to the described protocol [19, 20]. Reasons for not performing MRA were: patient refusal, claustrophobia, pacemaker, previously performed DSA, or emergency DSA for thrombolysis therapy or angioplasty/stenting. A few patients in whom MRA was not feasible were examined noninvasively with CTA. As a rule, DSA was performed only in patients with discordant noninvasive results so that a clear recommendation for or against surgery was not possible. Patients showing congruently an occlusion of the ICA on US and MRA were excluded from the operation without performing a confirmatory DSA. We thereby accepted the very small risk of losing a few patients with suboccluded, potentially salvageable carotid arteries. All patients gave written informed consent for the operation. The study protocol was examined and approved by the ethical committee of our hospital. Patient data were stored in a registry containing the complete clinical, sonographic, radiologic and surgical information collected during the observation period.

Preoperative MR Angiographic Examination

The preoperative MR angiographic protocol has been described in details [19, 20]. All MRA studies were performed with a 1.5-tesla imaging system (Magneton Vision/Sonata, Siemens Medical Systems). 3-D contrast-enhanced MRA was generated after intravenous bolus injection of 0.1 mmol/kg gadolinium (gadobutrolum, Gadovist 1.0, Schering AG) using a fast acquisition sequence of 9–9.5 s. The 3-D image set acquired during the arterial phase of the

gadolinium circulation was identified visually and subtracted from the precontrast data set, with elimination of disturbing background fat signals. Postprocessing subvolumes were generated interactively using the MR postprocessing console to isolate each carotid artery and create 19 maximum-intensity projection images at 10° rotational angles. Voxels of interest on magnified images were used to facilitate determination of the arterial disease extent. All MRA studies were performed routinely by the neuroradiological staff and reviewed preoperatively by one of both senior authors (G.S. and L.R.).

Different anatomical characteristics of the carotid bifurcation, which are important to know before the operation, but not easily visible on ultrasounds, were systematically studied and quantified on the preoperative MRA images [26]. (1) The craniocaudal position of the carotid bifurcation in the neck was determined by measuring its distance to the horizontal portion of the vertebral artery along the posterior arch of C_1 on strict anteroposterior MRA views of the neck arteries. The position of the bifurcation was expressed according to the corresponding cervical vertebral body. (2) A possible rotation of the carotid bifurcation with medial position of the internal carotid artery (ICA) was evaluated on strict anteroposterior MRA images. (3) The grade of stenosis was measured as described [19, 20] according to the NASCET method [27] and expressed in 10% increments, a 50–69% stenosis being defined as middle grade and a 70–99% stenosis as high grade. The results of MRA were compared with those of US. (4) The length of the stenosis was measured in millimeters and classified into 3 groups: short (<10 mm), long (10–25 mm) and very long (>25 mm). (5) The presence of ulcerations in the atherosclerotic plaques was suspected in the form of caliber irregularities on the preoperative MRA images and correlated with the intraoperative findings. Plaques were classified at macroscopic examination as smooth when the intima was intact, and ulcerated when the intima was ruptured with or without intramural thrombus. (6) The presence of a tandem stenosis was looked for proximally and distally from the carotid bifurcation.

Carotid Endarterectomy

CEA was performed by two experienced neurosurgeons from our Department. All the patients considered for surgery underwent standard preoperative investigations including head CT or MRI, cardiologic examinations, chest X-rays and conventional blood tests [28, 29]. Platelet antiaggregation or oral anticoagulation were continued perioperatively. The operation was performed with the patient in general anesthesia. Neuroprotective measures included moderate hypothermia (34–35°C) and propofol coma during cross-clamping. Use of an intraoperative shunt was based on intraoperative transcranial Doppler monitoring of the ipsilateral middle cerebral artery. Our surgical technique [28, 29] followed closely the different steps of microsurgical CEA described by Bailes [30, 31]. The excised atherosclerotic plaque was described macroscopically as smooth or ruptured/ulcerated.

Follow-up Evaluation

The first postoperative neurologic examination was performed by the surgeon at awakening. An early sonographic examination was performed 1½–3 h after the end of the operation to exclude persisting cerebral embolism or hyperperfusion. All patients were examined clinically and sonographically after 1 and 5–6 weeks by board-certified neurologists independently of the surgeon. Postoperative complications were defined according to ECST [32] as any adverse events occurring during the operation or the following 4 weeks and comprising mortality, major cardiac or neurologic morbidity (deficits persisting after 7 days), and minor morbidity (local complications, minor cardiac complications or neurologic deficits resolving in 7 days).

Results

Diagnostic Performance

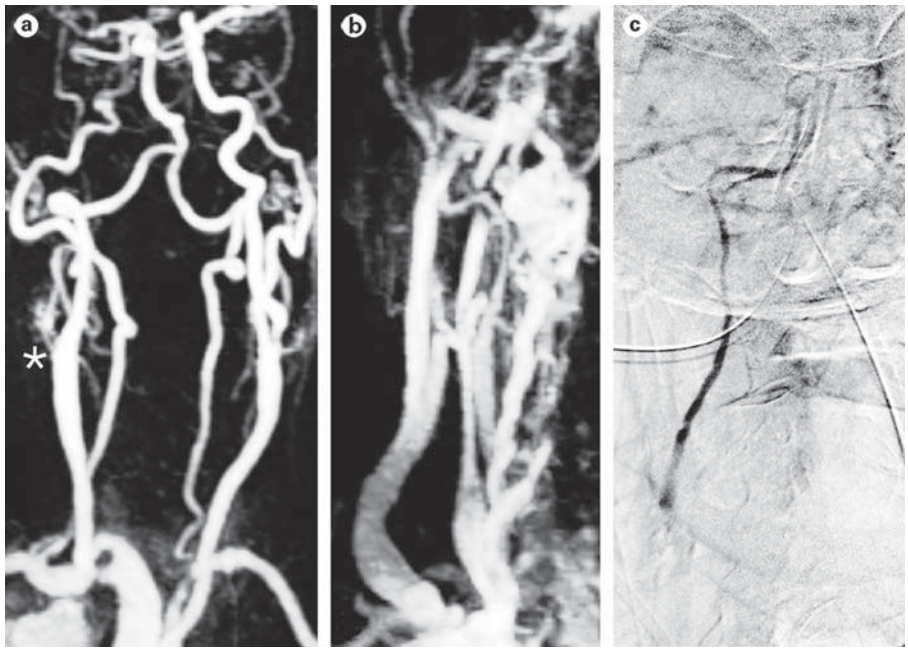
From October 1998 to December 2004, 327 patients (104 women, 223 men; mean age: 69 years, range 32–88 years) were consecutively operated for a carotid stenosis and included into the study. This represented 2.5% of the 12,831 patients examined in our Cerebrovascular Diagnostic Laboratory during the same period, among whom 7,433 were first time patients. According to the used ultrasonographic criteria, 228 patients (69.8%) had a symptomatic carotid stenosis, classified as high grade in 223 and middle grade in 5. Ninety-nine patients (30.2%) had an asymptomatic, by definition high-grade stenosis. The stenosis was located on the right side in 161 patients (49.2%) and on the left side in 166 (50.8%).

Noninvasive preoperative MRA was performed in 278 patients (85%). Among the 49 patients (15%) who were not examined with MRA, the ultrasonographic diagnosis of carotid stenosis was confirmed by DSA in 44 (13.5%) and CTA in 5 (1.5%). Most of the DSA studies (20 patients) were performed on an emergency basis before MRA as a preparation for intra-arterial thrombolysis or angioplasty/stenting. Another group of 15 patients had had cerebral DSA in recent past for other reasons and did not need MRA at the time of their carotid operation. MRA could not be performed because of the presence of a pacemaker in 5 patients and because of refusal/claustrophobia in 4 patients.

Eleven additional DSA studies (3.3%) had to be performed in order to complement ultrasound and MRA, mostly because the noninvasive examinations diverged in the diagnosis of subocclusion vs. occlusion of the internal carotid artery (9 patients; fig. 1). In 2 patients, the noninvasive studies could not differentiate with certainty a middle-grade stenosis from a high-grade stenosis, MRA having sometimes the tendency to exaggerate the grade of stenosis (fig. 2).

Radiological Information

No direct morbidity was related to the 278 MRA studies performed preoperatively. MRA appeared to be very reliable in the planning and preparation of carotid sur-



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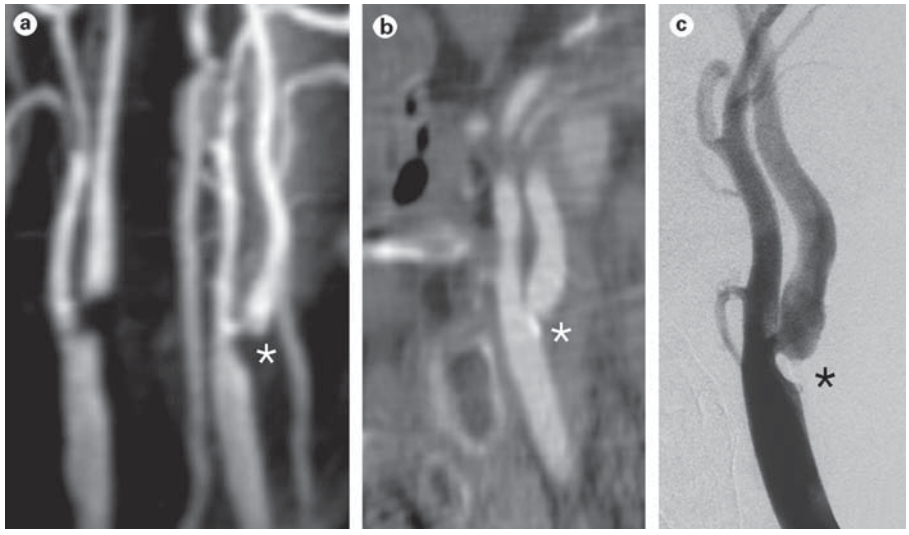

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Fig. 1. a 3-D first-pass gadolinium-enhanced MRA of the precerebral arteries in a 78-year-old patient with right frontal infarct. On the right side, MRA showed a pointed ICA stump with prompt filling of the carotid bulb (*). Highest-grade stenosis (>99%) with ICA subocclusion was suspected although an occlusion could not be definitively excluded. On the left side, the patient had an asymptomatic high-grade carotid stenosis. **b** On the late MRA sequence following first passage of gadolinium, vessel superpositions did not allow to exclude an occlusion with certainty, although the ICA filled further as compared to first-pass MRA. **c** As US could not confirm or exclude an occlusion, DSA was performed preoperatively. This examination demonstrated residual perfusion and patency of the right ICA on the late images, confirming subocclusion of the vessel at the bifurcation.

Fig. 2. a 3-D first-pass gadolinium-enhanced MRA of the precerebral arteries in a 75-year-old patient. On the left side, MRA showed a carotid stenosis which was measured around 70%. The lesion was classified at the lowest range of high-grade although a middle-grade 50–69% stenosis could not be definitively excluded (*). The patient also had a clearly high-grade stenosis on the right side. **b** As the patient was neurologically asymptomatic and US measured a middle-grade 50–59% stenosis on the left side, complementary noninvasive CT angiography was performed preoperatively (*). This examination did not confirm the ultrasonographic findings but rather supported the MRA diagnosis of a high-grade stenosis. **c** The definitive decision not to operate the left carotid bifurcation was taken after the DSA had demonstrated a middle-grade 50–59% stenosis (*) caused by a large atherosclerotic plaque. The patient was included into our study because he was subsequently operated for the high-grade stenosis of his right internal carotid artery.

gery. No surgical problem was encountered during the operation which would not have been predicted by preoperative MRA. The detailed information furnished by preoperative MRA is given in table 1. Most carotid bifurcations (90.6%) were located at the level of C_4. In patients with a bifurcation placed above C_4, preoperative MRA allowed for preparing the ICA very distally in order to remove the plaque completely. Rotation of the carotid bifurcation with a medial position of the ICA represents a surgical difficulty which was clearly demonstrated by MRA in 5.7% of the patients. Extensive preparation of the bifurcation with derotation of the ICA was necessary in these cases to perform arteriotomy and plaque removal. Most patients (86.3%) had a 90–99% stenosis. In 2 patients diagnosed preoperatively with a highest-grade stenosis, the ICA was occluded at the time of surgery 2 weeks later and could not be recanalized. The length of stenosis was found to be 10–25 mm in the majority of the patients (80.2%). Particularly long stenoses (>25 mm) required extended preparation of the ICA to allow complete removal of the plaque. Concerning the anatomical characteristics of the plaque, as compared with intraoperative findings, MRA was able to predict 119 out of 155 smooth plaques (76.7%) and 110 out of 123 ruptured/ulcerated plaques (89.4%). Finally, tandem stenosis of the ICA was rare in this series (2.5% of patients) and reliably detected by preoperative MRA.

Clinical Results

Out of 327 consecutively operated patients, 21 (6.4%) suffered a complication during the operation or during the following month. The combined mortality/major morbidity rate was 0.9%. One patient died suddenly of acute heart failure on the second postoperative day (mortality rate: 0.3%). Two patients suffered a major complication: one had an ipsilateral brain infarct due to acute rethrombosis of the operated ICA and one developed a severe postoperative heart failure leading to death 3 months later (major morbidity rate: 0.6%). A minor complication occurred in 18 patients (minor morbidity rate: 5.5%): 6 mild heart failures (1.8%); 4 TIA/minor neurologic deficits (1.2%); 4 wound abscesses or hematomas (1.2%); 3 recurrent nerve pareses (0.9%) and 1 epileptic seizure (0.3%). Remarkably, no patient suffered any postoperative hyperperfusion syndrome or intracerebral hemorrhage in this series. The complication rates in symptomatic and asymptomatic patients are detailed in table 2.

Table 1. Radiological information furnished by preoperative MRA of the carotid bifurcation in 278 patients consecutively operated between 1998 and 2004

Position of bifurcation	
Cervical 2	2 (0.7)
Cervical 3	11 (4)
Cervical 4	252 (90.6)
Cervical 5	13 (4.7)
Rotation of ICA	
Lateral	262 (94.3)
Medial	16 (5.7)
Grade of stenosis	
50–69%	5 (1.8)
70–79%	8 (2.9)
80–89%	25 (9)
90–99%	240 (86.3)
Length of stenosis	
<10 mm	21 (7.6)
10–25 mm	223 (80.2)
>25 mm	34 (12.2)
Plaque characteristics	
Smooth	119/155 (76.7)
Ulcerated	110/123 (89.4)
Tandem stenosis	7 (2.5)

Figures in parentheses indicate percentages.

Table 2. Clinical results of CEA consecutively performed on the basis of noninvasive preoperative US/MRA protocol ('intention to treat') in 327 symptomatic and asymptomatic patients between 1998 and 2004

	Symptomatic	Asymptomatic	Total
Patients	228	99	327
Total complications	18 (7.8)	3 (3)	21 (6.4)
Mortality + major morbidity	2 (0.8)	1 (1)	3 (0.9)
Mortality	–	1 (1)	1 (0.3)
Major morbidity	2 (0.8)	–	2 (0.6)
Severe heart failure	1 (0.4)	–	1 (0.3)
Deficits >7 days	1 (0.4)	–	1 (0.3)
Minor morbidity	16 (6.4)	2 (2)	18 (5.5)
Mild heart failure	6 (2.4)	–	6 (1.9)
Deficits <7 days	4 (1.6)	–	4 (1.2)
Abscess, hematoma	3 (1.2)	1 (1)	4 (1.2)
Recurrent nerve paresis	2 (0.8)	1 (1)	3 (0.9)
Seizure	1 (0.4)	–	1 (0.3)

Figures in parentheses indicate percentages.

Discussion

Six years ago, our decision to abandon DSA for the preoperative diagnosis of carotid disease was based on a well-established experience of stenosis screening and grading with ultrasound and the development of a new first-pass contrast-enhanced MR angiographic sequence. The diagnostic reliability of MRA was compared with DSA in a large sample of patients before being applied to decision making for CEA [19, 20]. The results of the present study confirm that the patients referred to our center and submitted to CEA since then did not globally suffer any disadvantage from this noninvasive diagnostic protocol.

This study was not designed to determine the failure rate of combined ultrasound/MRA potentially leading to exclude patients with operable lesions or, inversely, to include patients not qualifying for CEA. Our previous MRA/DSA correlation study [20] had demonstrated a high ability of fast contrast-enhanced MRA to differentiate between a suboccluded and occluded ICA so that we can assume that very few patients with highest-grade stenosis were missed. On the other hand, only 2 patients (0.7%) were found to have an occluded ICA at the operation in our series; the occlusion could well have occurred in the interval between diagnostic MRA and CEA. It is also likely that very few patients, if any, with a middle- or even low-grade stenosis have been falsely recruited for the operation because only 5 patients (1.8%) with an overtly symptomatic 50–69% stenosis were operated on in our series. As a rule, patients with a middle-grade stenosis and uncertain neurologic symptoms were followed with ultrasound and an operation was only discussed in case of stenosis progression to 70% or above. These figures can be considered optimistic in regard of the much higher mismatch rates and inadequate indications of CEA reported in several studies comparing the performance of noninvasive diagnosis with golden standard DSA. The difference can be explained by differing methodologies or because several studies examined the performance of ultrasound alone as compared with DSA, or applied other methods of MRA (e.g. 2-D time-of-flight, 3-D time-of-flight, non-first-pass contrast enhanced) [1, 15, 16, 33–37]. Combination of ultrasound with MRA, as was systematically performed in our series, probably improves the reliability of noninvasive preoperative diagnosis [1, 38]. Based on the newest imaging methods, the rate of misclassification of carotid stenosis should realistically not exceed 2–3% anymore, supporting the trend to rely on combined noninvasive tests in routine clinical practice and to use DSA only in situations with divergent noninvasive findings [18, 39, 40].

Much has been written on the necessity to constantly improve the quality and safety of carotid surgery as the success of this prophylactic intervention not only depends on diagnosis and indication, but also directly on the rate of perioperative complications [41–48]. The clinical results of surgery should be assessed by independent neurological specialists, a reasonable goal being to reduce the rate of mortality/severe morbidity below 1–2% [49]. Noninvasive preoperative MRA influences surgical results by eliminating the small, but well-known risks of DSA. This fact is particularly important for patients with an asymptomatic stenosis. In addition, in our series, first-pass contrast-enhanced MRA revealed itself as a very useful tool to prepare and perform CEA with practically no risk for the patient. The location and anatomical characteristics of the carotid bifurcation were clearly depicted on preoperative MRA. The grade and length of stenosis as well as the presence of tandem stenoses were also exactly demonstrated. Our MRA protocol tended to overestimate the presence of plaque ulcerations, but this had no influence on the clinical outcome.

Combined US/MRA had to be complemented by DSA for diagnostic reasons in only 3.3% of the patients included in our series, which is slightly inferior to the percentages published in recent correlation studies [17, 37–39]. Despite the fact that MRA was established as first imaging option after ultrasound, no less than 13.5% of the operated patients (44/327) were subjected to diagnostic DSA independently of MRA. Most of them had already had DSA for other reasons before investigation of the carotid bifurcations. Some of them were also potential candidates for angioplasty and stenting, which could not be performed afterwards. As the number of endovascular procedures for carotid stenosis will probably increase in the future, it is possible that more patients will paradoxally be referred for CEA on the basis of invasive preoperative diagnosis.

In conclusion, our observational study reflects a well-established practice of CEA and supports the exclusive use of noninvasive diagnostic imaging for deciding the operation. Preoperative MRA gives an important anatomical information not easily visible on ultrasounds. In our opinion, a morphological radiological examination of the precerebral arteries should always be added to US in order to facilitate the planning and to increase the safety of CEA.

References

1 Johnston DC, Goldstein LB: Clinical carotid endarterectomy decision making. Noninvasive vascular imaging versus angiography. Neurology 2001;56:1009–1015.
2 Rothwell PM: Noninvasive carotid imaging to select patients for endarterectomy. Is it really safer than conventional angiography? Neurology 2001;56:990–991.
3 Moore WS: For severe carotid stenosis found on ultrasound, further arterial evaluation is unnecessary. Stroke 2003;34:1816–1817.
4 Rothwell PM: For severe carotid stenosis found on ultrasound, further arterial evaluation prior to carotid endarterectomy is unnecessary: the argument against. Stroke 2003;34:1817–1819.
5 Davis SM, Donnan GA: Is carotid angiography necessary? Editors disagree. Stroke 2003;34:1819.
6 Blackshear WM, Connar RG: Carotid endarterectomy without angiography. J Cardiovasc Surg 1982;23:477–482.
7 Crew JR, Dean M, Johnson JM, Knighton D, Bashour TT, Ellertson D, Hanna ES: Carotid surgery without angiography. Am J Surg 1984;148:217–220.
8 Chervu A, Moore WS: Carotid angiography without arteriography. Ann Vasc Surg 1994;8:296–302.
9 Anson JA, Heiserman JE, Drayer BP, Spetzler RF: Surgical decisions on the basis of magnetic resonance angiography of the carotid arteries. Neurosurgery 1993;32:335–343.
10 Lustgarten JH, Solomon RA, Quest DO, Khanjdi AG, Mohr JP: Carotid endarterectomy after noninvasive evaluation by duplex ultrasonography and magnetic resonance angiography. Neurosurgery 1994;34:612–619.
11 Anderson GB, Ashforth R, Steinke DE, Ferdinandy R, Findlay JM: CT angiography for the detection and characterization of carotid artery bifurcation disease. Stroke 2000;31:2168–2174.
12 Jackson MR, Chang AS, Robles HA, Gillespie DL, Olsen SB, Kaiser WJ, Goff JM, O'Donnell SD, Rich NM: Determination of 60% or greater carotid stenosis: a prospective comparison of magnetic resonance angiography and duplex ultrasound with conventional angiography. Ann Vasc Surg 1998;12:236–243.
13 Modaresi KB, Cox TC, Summers PE, Jarosz JM, Verma H, Taylor PR, Padayachee TS: Comparison of intra-arterial digital subtraction angiography, magnetic resonance angiography and duplex ultrasonography for measuring carotid artery stenosis. Br J Surg 1999;86:1422–1426.
14 Serfaty JM, Chirossel P, Chevalier JM, Ecochard R, Froment JC, Douck PC: Accuracy of three-dimensional gadolinium-enhanced MR angiography in the assessment of extracranial carotid artery disease. Am J Roentgenol 2000;175:455–463.
15 Nederkoorn PJ, Mali WP, Eikelboom BC, Elgersma OE, Buskens E, Hunink MG, Kappelle LJ, Buijs PC, Wust AF, van der Lugt A, van der Graaf Y: Preoperative diagnosis of carotid artery stenosis. Accuracy of noninvasive testing. Stroke 2002;33:2003–2008.
16 Nederkoorn PJ, van der Graaf Y, Hunink MG: Duplex ultrasound and magnetic resonance angiography compared with digital subtraction angiography in carotid artery stenosis: a systematic review. Stroke 2003;34:1324–1332.
17 U-King-Im JM, Trivedi RA, Graves MJ, Higgins NJ, Cross JJ, Tom BD, Hollingworth W, Eales H, Warburton EA, Kirkpatrick PJ, Antoun NM, Gillard JH: Contrast-enhanced MR angiography for carotid disease: diagnostic and potential clinical impact. Neurology 2004;62:1282–1290.
18 Kennedy J, Quan H, Ghali WA, Feasby TE: Importance of the imaging modality in decision making about carotid endarterectomy. Neurology 2004;62:901–904.
19 Remonda L, Heid O, Schroth G: Carotid artery stenosis, occlusion, and pseudo-occlusion: first-pass, gadolinium-enhanced, three-dimensional MR angiography – preliminary study. Radiology 1998;209:95–102.
20 Remonda L, Senn P, Barth A, Arnold M, Lovblad KO, Schroth G: Contrast-enhanced 3D MR angiography of the carotid artery: comparison with conventional digital subtraction angiography. Am J Neuroradiol 2002;23:213–219.
21 Staikov IN, Arnold M, Mattle HP, Remonda L, Sturzenegger M, Baumgartner RW, Schroth G: Comparison of ECST, CC, and NASCET grading methods and ultrasound for assessing carotid stenosis. European Carotid Surgery Trial. North American Symptomatic Carotid Endarterectomy Trial. J Neurol 2000;247:681–686.
22 Staikov IN, Nedeltchev K, Arnold M, Remonda L, Schroth G, Sturzenegger M, Herrmann C, Rivoir A, Mattle HP: Duplex sonographic criteria for measuring carotid stenoses. J Clin Ultrasound 2002;30:275–281.
23 Moore WS, Barnett HJ, Beebe HG, Bernstein EF, Brener BJ, Brott T, Caplan LR, Day A, Goldstone J, Hobson RW 2nd: Guidelines for carotid endarterectomy. A multidisciplinary consensus statement from the ad hoc Committee, American Heart Association. Stroke 1995;26:188–201.
24 Biller J, Feinberg WM, Castaldo JE, Whittemore AD, Harbaugh RE, Dempsey RJ, Caplan LR, Dresowik TF, Matchar DB, Toole J, Easton JD, Adams HP Jr, Brass LM, Hobson RW 2nd, Brott TG, Sternau L: Guidelines for carotid endarterectomy: a statement for healthcare professionals from a special writing group of the Stroke Council, American Stroke Association. Stroke 1998;29:554–562.
25 Barnett HJ, Taylor DW, Eliasziw M, Fox AJ, Ferguson GG, Haynes RB, Rankin RN, Clagett GP, Hachinski VC, Sackett DL, Thorpe KE, Meldrum HE, Spence JD: Benefit of carotid endarterectomy in patients with symptomatic moderate or severe stenosis. North American Symptomatic Carotid Endarterectomy Trial Collaborators. N Eng J Med 1998;339:1415–1425.
26 Goldstein LB, McCrory DC, Landsman PB, Samsa GP, Ancukiewicz M, Oddone EZ, Matchar DB: Multicenter review of preoperative risk factors for carotid endarterectomy in patients with ipsilateral symptoms. Stroke 1994;25:1116–1121.
27 North American Symptomatic Carotid Endarterectomy Trialists' Collaborative Group: Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. N Eng J Med 1991;325:445–453.
28 Barth A, Remonda L, Lovblad KO, Schroth G, Seiler RW: Silent cerebral ischemia detected by diffusion-weighted MRI after carotid endarterectomy. Stroke 2000;31:1824–1828.
29 Barth A, Lukes A, Remonda L, Mattle H, Seiler RW: Ergebnisse und Stellenwert der Karotisthrombendarterektomie. Schweiz Med Wochenschr 2000;130:1062–1071.
30 Bailes JE: Carotid endarterectomy. Neurosurgery 2002;50:1290–1295.
31 Bailes JE, Spetzler RF: Microsurgical carotid endarterectomy. Philadelphia, Lippincott-Raven, 1996.
32 ECST Collaborative Group: MRC European Carotid Surgery Trial: interim results for symptomatic patients with severe (70–99%) or with mild (0–29%) carotid stenosis. Lancet 1991;337:1235–1243.
33 Blakeley DD, Oddone EZ, Hasselblad V, Simet DL, Matchar DB: Non-invasive carotid artery testing. Ann Intern Med 1995;122:360–365.
34 Rothwell PM, Pendlebury ST, Wardlaw J, Warlow CP: Critical appraisal of the design and reporting of studies of the imaging and measurement of carotid stenosis. Stroke 2000;31:1444–1450.
35 Rothwell PM: Analysis of agreement between measurements of continuous variables: general principles and lessons from studies of the imaging of carotid stenosis. J Neurol 2000;415:825–834.
36 Halm EA, Chassin MR, Tuhrim S, Hollier LH, Popp AJ, Ascher E, Dardik H, Faust G, Riles TS: Revisiting the appropriateness of carotid endarterectomy. Stroke 2003;34:1464–1472.
37 Nonent M, Serfaty JM, Nighoghossian N, Rouhart F, Derex L, Rotaru C, Chirossel P, Guias B, Heautot JF, Gouny P, Langella B, Buthion V, Jars I, Pachai C, Veyret C, Gauvrit JY, Lamure M, Douek PC; for the CARMEDAS Study Group: Concordance rate differences of 3 noninvasive imaging techniques to measure carotid stenosis in clinical routine practice. Results of the CARMEDAS Multicenter Study. Stroke 2004;35:682–686.

38 Johnston DC, Eastwood JD, Nguyen T, Goldstein LB: Contrast-enhanced magnetic resonance angiography of carotid arteries: utility in routine clinical practice. Stroke 2002;33:2834–2838.
39 Cosottini M, Pingitore A, Puglioli M, Michelassi MC, Lupi G, Abbruzzese A, Calabrese R, Lombardi M, Parenti G, Bartolozzi C: Contrast-enhanced three-dimensional magnetic resonance angiography of atherosclerotic internal carotid stenosis as the noninvasive imaging modality in revascularization decision making. Stroke 2003;34:660–664.
40 Forsting M, Wanke I: Editorial comment – funeral for a friend. Stroke 2003;34:1331.
41 Barnett HJM, Eliasziw M, Meldrum HE, Taylor DW: Do the facts and figures warrant a 10-fold increase in the performance of carotid endarterectomy on asymptomatic patients? Neurology 1996;46:603–608.
42 Goldstein LB, Moore WS, Robertson JT, Chaturvedi S: Complication rates for carotid endarterectomy. A call to action. Stroke 1997;28:889–890.
43 Wong JH, Findlay JM, Suarez-Almazor ME: Regional performance of carotid endarterectomy. Appropriateness, outcomes, and risk factors for complications. Stroke 1997;28:891–898.
44 Gorelick PB: Carotid endarterectomy. Where do we draw the line? Stroke 1999;30:1745–1750.
45 Barnett HJM, Broderick JP: Carotid endarterectomy. Another wake-up call. Neurology 2000;55:746–747.
46 Chaturvedi S, Aggarwal R, Murugappan A: Results of carotid endarterectomy with prospective neurologist follow-up. Neurology 2000;55:769–772.
47 O'Neill L, Lanska DJ, Hartz A: Surgeon characteristics associated with mortality and morbidity following carotid endarterectomy. Neurology 2000;55:773–781.
48 Norris JW, Rothwell PM: Noninvasive carotid imaging to select patients for endarterectomy. Is it really safer than conventional angiography? Neurology 2001;56:990–991.
49 Executive Committee for the Asymptomatic Carotid Atherosclerosis Study: Endarterectomy for asymptomatic carotid artery stenosis. JAMA 1995;273:1421–1428.