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RADIOLOGICAL DIAGNOSIS AND THERAPY OF EXTRACRANIAL CAROTID ARTERY STENOSIS

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Abbreviations used in the dissertation

a.	artery
ACI	internal carotid artery
AV	vertebral artery
CCDS	color coded duplex sonography
cm	centimeter
CT	computed tomography
CTA	computed tomography angiography
DSA	digital subtraction angiography
FOV	field of view
HU	Hounsfield units
iv.	intravenous
kV	kilovolt
mA	milliamper
MIP	maximum intensity projection
ml	milliliter
mm	millimeter
MPR	multiplanar reconstruction
MR	magnetic resonance
MRA	magnetic resonance angiography
MRI	magnetic resonance imaging
msec	millisecundum
ROI	region of interest
S	stenosis
sec	secundum
SSD	surface shaded display
T	tesla

VRT	volume rendering technique
2D	two-dimensional
3D	three dimensional

1. INTRODUCTION

Approximately 1.3 million people die in Europe each year because of stroke[1]. Already Shakespeare had some idea about stroke: "This apoplexy is, as I take it, a kind of lethargy . . . a kind of sleeping in the blood." (*King Henry IV, Part II).* In 1905, Chiari of Prague found thrombus superimposed on carotid artery atherosclerotic plaques of seven patients in a series of 400 consecutive autopsies. Four of these patients had suffered cerebral embolism, and he suggested that embolic material could arise from the carotid artery and affect the brain[2]. Hunt in 1914 proposed "the cerebral lesions in most stroke victims could be the effect and not the cause."[3] A major step in recognition of the importance of carotid artery disease (CAD) was, when the Canadian C. Miller Fisher published his clinicoanatomic correlations on occlusion of the carotid arteries[4]. Dr Fisher was also the first to associate the occurrence of loss of vision in one eye, which he termed transient unilateral blindness, with ipsilateral CAD. Until then, some 55% of strokes were thought to be caused by vasospasm[5]. The medical therapy of stroke began in 1941 with Hedenius, who reported "favorable" outcome in five of 18 patients treated with heparin for cerebral thrombosis[6]. An important milestone in the history of surgical therapy of carotid stroke occurred in 1953, when DeBakey performed the first carotid endarterectomy[7]. It became clear in the seventies, that aspirin was not only effective in preventing myocardial infarct, but also in preventing stroke[8]. 30 years after the first endarterectomy, interventional radiologists became active in this field, too: Bockenheimer and Mathias[9] performed the first percutaneous transluminal angioplasty (PTA) in arteriosclerotic internal carotid artery stenosis. In the early nineties, the North American Symptomatic Carotid Endarterectomy Trial (NASCET) and the European Carotid Surgery Trial (ECST) proved, that the restoration of blood flow and elimination of the cause of emboli by means of carotid endarterectomy successfully prevents stroke in symptomatic patients with stenoses of 70-99%[10, 11]. NASCET later also demonstrated that for those patients with stenoses in the 50%–69% range, endarterectomy also lowered the overall stroke risk significantly, but the benefit was somewhat less than for the severe stenosis group. The Asymptomatic Carotid Atherosclerosis Study (ACAS) proved that asymptomatic patients with stenoses over 60% benefit from surgical therapy. The benefit was found to be modest as compared to the previous studies mentioned[12]. Since the choice of treatment is based on catheter-based angiographic determination of carotid narrowing, this prompts radiologists to quite precise stenosis measurements. All trials used digital subtraction angiography (DSA), the gold standard in imaging cerebral circulation, for determination of carotid artery stenosis. DSA is, however, an invasive procedure with relatively high risk involved, with total complication rates up to 5%[13-16].

These results gave new importance to safe, standardized and cost-effective diagnostic imaging methods. Since the early 90’s, several attempts have been made to substitute preoperative DSA examinations with noninvasive techniques.

Color Coded Duplex Sonography (CCDS) is the safest and least expensive imaging method. The greatest limitation of this method is the inaccuracy in differentiating total occlusion from critical stenosis[17]. Many surgical centers therefore do not accept CCDS alone for preoperative imaging. Contrast enhanced MR-angiography is an accurate technique which also has the advantage of demonstrating intracranial vasculature[18]. However, MRI is unable to depict plaque calcification, which is an important feature of plaque evaluation. The limited availability of MR-units, relatively high expense, and the typically long waiting list does not allow at present its use as a routine tool, since in the case of severe carotid stenosis the vessel may occlude within weeks, resulting in stroke.

The minimal-invasive CT-angiography is available since the early nineties, and today most Hungarian CT scanners are able to perform this type of examination. Its risk does not exceed the risk of a simple contrast-enhanced CT examination. Both MR-angiography and DSA are much more expensive examinations then CT-angiography. It seems therefore plausible to substitute DSA with CT-angiography, which is usually available within a few days. Since the first step of endovascular therapy of the carotids is a diagnostic angiography, the purpose of this study was to find out, if CT-angiography could substitute DSA in the preoperative decision-making before carotid endarterectomy and stenting.

In the region of the peripheral arteries, surgical procedures are often substituted by interventional radiological techniques. Andreas Grüntzig has already treated atherosclerotic stenoses of the limb arteries with balloon catheters in 1973.

Percutaneous carotid angioplasty was first reported in 1981 for fibromuscular dysplasia[19, 20] and 2 years later in atherosclerotic disease[9]. The first results were not very encouraging, since elastic recoil, embolisation and restenosis were quite frequent complications. In the nineties, when stent supported angioplasty became available also for carotids[21], the endovascular method became much safer. Although stenting – this emerging technique – is typically performed in high-risk patients with significant comorbidities, who would have been excluded from the previous surgical trials, it seems encouraging, that procedural results are similar to that of endarterectomy. Risks of anesthesia, wound infection, myocardial infarction, cranial nerve palsy and complications related to relatively long clamp-time are also avoided with stenting. The second purpose of this study was to prove, that CAS is effective in the treatment of primary atherosclerotic lesions, and it carries a low risk of complications.

2. PURPOSE

2.1. To determine, how accurate is the single slice spiral CT-angiography in grading of carotid stenosis.

2.2. To determine how reliable is CT-angiography in the plaque evaluation?

2.3. To determine, if single slice spiral CT-angiography is able to detect every abnormality that could alter the decision-making before carotid endarterectomy.

2.5. To determine if the endovascular therapy (stent placement) could be carried out with similar or lower perioperative complication rate as carotid endarterectomy.

2.6. To determine the impact of our own periprocedural distal embolisation rate by means of MR FLAIR imaging.

2.7. To determine the long-term efficacy of endovascular therapy in stroke prevention and brain perfusion.

3. PHYSICS AND HISTORY OF CT-ANGIOGRAPHY

CT-angiography can be carried out on spiral-CT scanners, which are capable of continuous volume data acquisition instead of the traditional way of scanning slice by slice successively. In 1989 Willi Kalender, a German physicist at the University of Erlangen had a revolutionary idea. He replaced the old table feed mechanism of their Siemens Somatom scanner by a stepper motor that allowed continuous patient transportation at low, but accurately controlled speeds (0,1-11,0 mm/sec) during scanning[22]. Volume scanning was enabled by the simultaneous application of the slip-ring technology that replaced the power supply cables of the X-ray tube, and the previously mentioned continuous patient transportation. The X-ray tube and the detectors can be rotated in the same direction and a whole body volume can be depicted. In this type of scanning, the x-ray focus performs a spiral motion on a virtual cylinder surface with a constant radius equal to the distance of focus to the center of rotation. To the contrary of the planar geometry of conventional CT, spiral CT is a volume scanning procedure in non-planar geometry. While the tube completes a 360 degree circulation, the patient typically travels 1-15 mm, depending on the beam collimation (slice thickness) and other scanning parameters. Selection of scan parameters is similar to conventional CT: slice thickness (mm), tube current (mA), tube voltage (kV). Additional parameter to be selected is the ratio of table feed/slice thickness, called pitch, which is a dimensionless quantity.

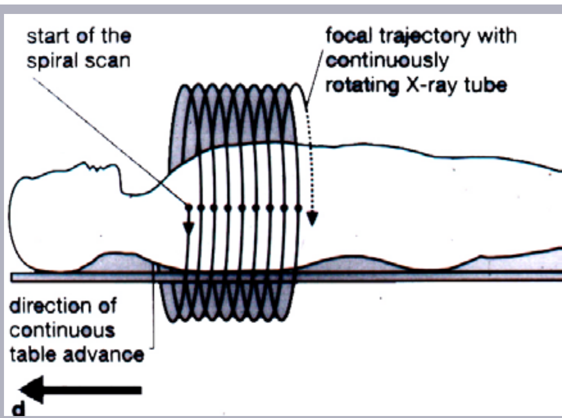


Figure 1.

Scan principle in spiral CT.

Intravenous contrast material, administered with high flow, after passing the pulmonary circulation, will move in bolus in the arteries. Timing the thin-slice scanning accurately to the arrival of the bolus, pictures of high quality can be obtained[23]. This has lead to a new radiological technique, called CT-angiography, which was developed in 1991 by Willi Kalender and Mathias Prokop[24, 25]. Usually 100-150 ml of contrast material is administered with flow rates of 2-4 ml/sec. The duration of scanning is between 15-40 seconds. The thin-slice pictures can be postprocessed by the computer, creating angiogramm-like pictures. Two or three-dimensional vascular models are generated after the patient is released, on a separate computer. The best known rendering modes are maximum intensity projection (MIP), shaded surface display (SSD), volume rendering technique (VRT), and the two-dimensional multiplanar reconstruction (MPR). The generated 2-D or 3-D models are viewed and filmed in several planes to reveal fully in detail the pathology of the vessels.

Both MIP and SSD require previous “editing”, by which unwanted structures (e.g. bones) are removed. These edited images, which only contain the vessels of interest, are displayed.

Figure 2.
Editing: Region of interest (ROI) is placed on the axial images around the internal and external carotid artery. Only the sructures within the ROI will be included into the 3D models.

By MIP parallel rays cast through the volume, and the maximum CT number along each projecting ray is displayed as an MIP image. MIP preserves all attenuation information and therefore structures with high CT numbers obscure the vessels. MIP images do not have depth information[26].

Figure 3.
MIP image of the unedited volume, AP view. The intracranial vessels are lost in the high-density bones of the skull. Vessels of the neck are displayed, and the calcification (arrow) of the arterial wall.

By SSD a range of CT numbers (Hounsfield units) are chosen by the investigator. Each voxel (volume element) that falls into this range will be the part of the model. External light source illuminates the model creating the image of a three-dimensional object. The appearance of the model depends on the chosen thresholds. SSD images can be very attractive and useful in evaluating complex anatomy[27].

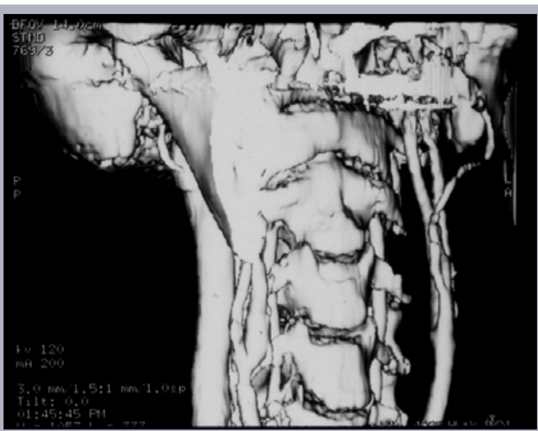


Figure 4.
SSD image of the unedited volume, RAO view, same patient as Fig. 1 and 2. The relation of the extracranial vessels and the cervical vertebrae are displayed, fine calcification of the arterial wall cannot be differentiated.

Volume rendering (VRT) preserves most density information. It does not require editing, but a powerful workstation, to generate images within reasonable time. By VRT the number, attenuation and opacity of the voxels can be adjusted separately to allow change in the transparency of selected volume.

VRT MIP

Figure 5.
Calcification of the plaque (arrow) that partially obscures the stenosis on the MIP image, is separately displayed on the VRT image.

The 3D appearance is maintained and thereby enables good analysis of the relationship between vascular structures[28].

Multiplanar reconstruction (MPR) is a two-dimensional reconstruction, by which any straight or curved imaging plane can be generated from the set of thin-slice images.

Figure 6.

MPR coronal reconstruction of the neck.

Although the introduction of spiral CT was revolutionary in the early nineties, it does have significant limitations, such as relatively long scanning time, and relatively small volume-coverage. With the introduction of multi-slice computed tomography, practically all disadvantages of single slice spiral CT have been eliminated. It can achieve – for instance - the solely arterial phase depiction of the whole limb, or the supraaortic vessels, or even larger regions[29].

4. ABOUT SELF-EXPANDING STENTS

The first publications about stent-protected balloon-dilatation of the carotid artery stenosis reported about periprocedural complication in 5,3-8,2%[30-34], which was mainly due to distal embolisation. The endovascular therapy gained more popularity in the late nineties, when the development of catheters and other equipment enabled the procedure to be carried out with far less complications[21, 35-37]. Self-expanding stents are much more suitable for treating carotid stenosis than the balloon mounted stents used before. There is no step between the tip of the delivery system and the double-over rolling membrane that constrains and covers the stent, which could work as a shovel and dislodge particles from the plaque. Because of this design, loss of stents is not any more a fear, either.

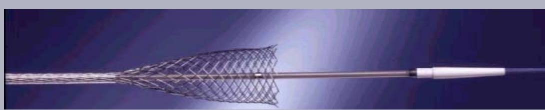


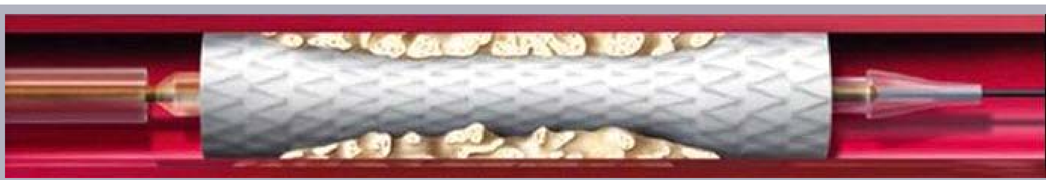
Figure 7.

Upper picture: opening of a self-expandable Wallstent.

Lower picture demonstrates the excellent flexibility of the same stent.

Because of these qualities they are able to cross narrower lesions without complications. Flexibility of the stent permits to adapt to tight vascular curves and kinking, avoiding modification of these curves and creation of disadvantageous haemodynamics. Stents with dense mesh of filaments cover and "protect" the plaque better, thereby lessen the risk of embolisation and stroke even before neoendothelisation occurs. The carotid arteries lay very superficially, having little protection by soft-tissues. Resistance to external compression is therefore also essential for long term patency. Self-expandable stents, especially the Wallstent with its braided stainless steel design, resist external compression better than balloon-mounted stents[38]. Self-expandable stent are manufactured mainly of stainless steel, or nitinol. The latter is a special metal that remembers its unconstrained shape when placed on human body temperature. They are therefore called memory-shape stents as well. They do not shorten, and have equal radial force alongside the whole stent. Because of their structure, each of their ring opens separately, holding their position firmly, but cannot be repositioned. To the contrary, Wallstent opens gradually, can therefore be repositioned, but may migrate in special cases. Radial force is smaller at the ends of the stent. It also shortens significantly; exact stent positioning requires practice.

Further technical development is expected to improve the above-mentioned qualities. Though bare self-expandable stents already have very advantageous properties for the endovascular therapy of carotid artery stenosis, the newest addition to the interventional radiologists armamentarium were the self-expandable stent-grafts, which by now became available with a delivery system delicate enough to trespass carotid plaques[39]. These are stents, with an inner cover of expanded polytetrafluoroethylene. Stent-grafts exclude side-braches, aneurysm, or fragile plaques from the circulation right after deployment, and do not depend on neoendothelisation[40].



a.

b.

c.

Figure 8.

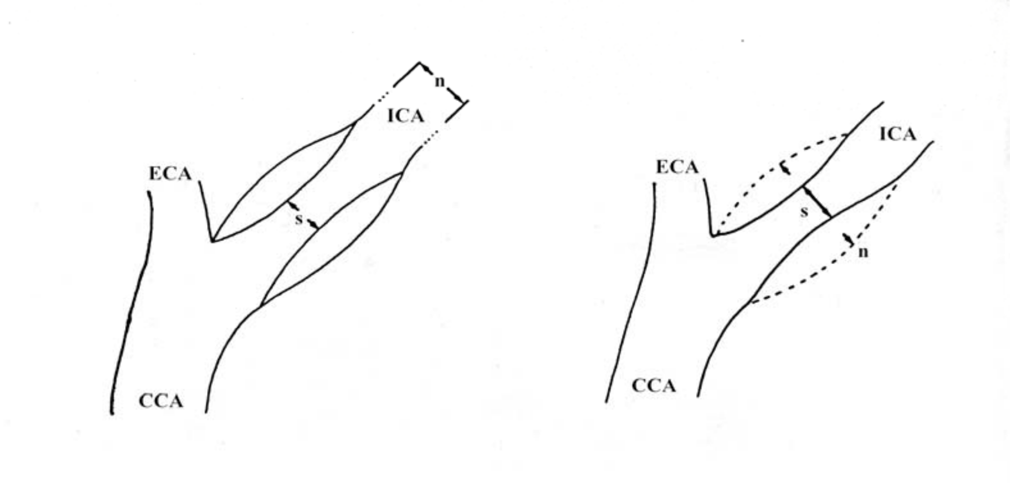
a. Stent graft after deployment. Plaque still causes some narrowing.
b. Postdilation with a balloon.
c. Final result, the plaque is safely excluded from the circulation, vessel lumen is restored.

OWN WORK

5. CT-ANGIOGRAPHY IN THE EVALUATION OF CAROTID BIFURCATION STENOSIS

5.1. Methods for measuring carotid artery stenosis

Standards of mathematical preciseness are very hard to implicate in the practice of medicine, due to the great – also anatomical - diversity of mankind. However, randomized trials, the basis of evidence-based medicine require such clear categories. The large surgical trials assigned treatment consisting of either best medical care alone available at their times, or best medical care combined with carotid endarterectomy to patients with recent symptoms judged to be due to severe degrees of stenosis as shown by biplane carotid arteriography. NASCET utilized the so called NASCET measurement, by which the diameter of the distal, undiseased ICA is used as denominator. It has received criticism because of the subjectivity of finding the first normal segment of distal ICA. It is also well known that the distal diameter of the vessel may diminish because of the stenosis, falsely resulting in lesser degree of stenosis measurement. Moreover, mild stenoses yield paradoxical negative numbers. (An artery with a stenosed lumen of 5 mm and a normal distal ICA diameter of 4 mm will give –25% stenosis.) Still, this type of measurement is used in North America in the every day practice, and in most papers regardless of their geographical origin. For the above reason, NASCET measurement is used throughout this work.



a. b.

Figure 9.

a. NASCET measurement: The reference is the normal, distal segment of the ICA (n). The maximal stenosis is labeled with s. Grading of stenosis has to be calculated as follows: (1-s/n) x 100

b. ECST measurement: The reference is the estimated original diameter of the carotid bulb (n). The maximal stenosis is labeled with s. Grading of stenosis has to be calculated as follows: (1-s/n) x 100

The European (ECST) measurement is based on the estimate of the original carotid bulb. It has received criticism because of the subjectivity of guessing the original diameter of the carotid bulb. It is, however, able to quantify minor degrees of stenosis.

The third best-known type of measurement is the carotid stenosis index, introduced in 1995 by Alexandrov, Bladin and co-workers from Toronto. Here the standard of reference is the proximal common carotid artery, which is presumingly free of disease. Unfortunately, wide variety of the diameter of CCA, as shown on a recent CT-angiography study, inhibits mathematical preciseness with this type of measurement as well.

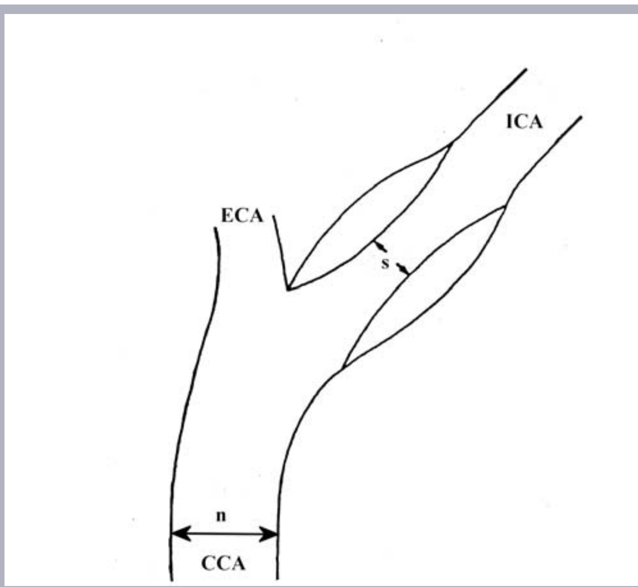


Figure 10.
Carotid stenosis index: The reference is the normal common carotid artery (n). The maximal stenosis is labeled with s. Grading of stenosis has to be calculated as follows: (1-s/n) x 100

5.2. ***Materials and Methods***

In our first group 62 consecutive patients (19 women, 43 men) who were 42-87 years old (mean age 65 years) were studied with CT-angiography and DSA. Thirty-two patients were examined in the Canadian and 30 patients in the Hungarian centre. All patients had symptomatic cerebrovascular disease in the form of transient ischemic attacks, amaurosis fugax or stroke. All were examined by Color Coded Duplex Sonography (CCDS) prior to CT-angiography and DSA, and were found to have an internal carotid artery stenosis >50%. Informed consent was obtained for both modalities. CT-angiography and digital subtraction angiography were performed within one month of each other.

5.2.1. ***Imaging***

DSA was done using the standard modified Seldinger femoral artery approach. An arch aortogram and subsequent selective carotid angiograms were obtained in anterior, 45-degree oblique and lateral projection. Typically a total of 120 ml of non-ionic contrast material was injected.

CT-angiography was performed on a Siemens Somatom Plus 4 Scanner (Siemens, Erlangen, Germany), or on a GE CTi scanner (General Electric, Milwaukee, USA). The following scanning parameters were used: beam collimation 3 mm (210 mA, 120 kV), pitch 1.5, reconstruction thickness 1 mm. A total of 120 ml of nonionic contrast material (Omnipaque, 300 mg I/ml, Nycomed) was injected at a rate of 3 ml/sec. The scan delay was determined using the scanners' bolus triggering software on the GE scanner, while because of lack of this software on the Siemens scanner a 20 second scan delay was used. Scanning began at the C5-C6 disk interspace and was terminated at the level of the sella. Single slice spiral CT scanners cannot cover a longer range with these imaging parameters. Axial CT images were filmed with a window level of 800/200 to differentiate between calcified plaque and contrast material in the vessels.

5.2.2. Postprocessing

3D reconstructions were done on separate standing workstations (Siemens MagicView workstation or GE Advantage Windows workstation). Regions of interest were placed around the carotid arteries on the axial images, and unwanted structures were removed using cutting functions. Background attenuation, which can result in loss of vessel definition on the MIP image, is kept to minimal with this technique[24]. Thresholding (the elimination of a chosen range of Hounsfield units from the images) was not used for editing in order to preserve all attenuation information. MIP images were created before and after calcification removal at increments of 30 degrees. Calcification that would obscure stenosis was removed manually on the axial source images, now placing regions of interest around the calcification. This allowed us not to remove adjacent vascular lumen signal[44]. The latter model without overlying calcification was used to create Surface Shaded Display (SSD) images to avoid underestimation of stenosis[44, 45]. On the MagicView workstation Volume Rendering Technique (VRT) images were also created. Orientation of projections for both SSD and VRT were the same as described above. The lower threshold for SSD and VRT images was determined interactively on the workstation on the re-edited axial images at the stenosed part of the vessel. The lower threshold varied between 120HU and 160HU according to the individual vascular enhancement of the patient.

5.2.3. Image analysis

Stenosis measurements (NASCET method) were done on the axial CT, the CT-angiography MIP, and the DSA images. The degree of stenosis was measured according to the NASCET method, and was categorized into one of the following categories: 0%-29%, 30%-49%, 50%-69%, 70%-99%, and 100% (occlusion). SSD and VRT images were not used for calculation of stenosis, as the density of the contrast material may be different at the stenosed part of the vessel and the distal part, resulting in erroneous calculation of the stenosis. SSD and VRT images were utilized for demonstration of vascular anatomy i.e. extreme tortuosity of the vessels. The results of the two centers were compared with One Way Analysis of Variance (ANOVA) on ranks test. Linear regression was used to determine correlation between the stenosis measurements on DSA & MIP images, and on DSA & axial CT images. Sensitivity, specificity, accuracy, positive and negative predictive values, and likelihood ratios were calculated to compare each test to DSA.

Calcification and the detectability of the soft components of the plaques were noted. Digital subtraction angiograms and CT angiograms were also evaluated for ulcerations. Ulcers within the plaque were defined to be present if they measured >2mm in depth. Abnormalities detected on DSA images that fell outside the range of CT-angiography were collected.

5.3. Results

The time required for editing and creation of the MIP and SSD images ranged between 20 to 30 minutes on the MagicView workstation and between 35 to 45 minutes on the Advantage Windows workstation. The time required was influenced by the degree of contrast enhancement of the internal jugular veins and by overlapping calcification.

Two cases had to be excluded because of severe motion artifact. In the remaining 120 arteries studied, no significant difference was found between the results of DSA, MIP or axial images in the two centers with ANOVA on ranks test.

Figure 11, 12.

Dunn, Thomas.

Linear regression showed high degree of correlation between DSA and axial images (R=0.937), the DSA and MIP images (R=0.946), and the MIP and axial CT images (R=0.955) in determination of stenosis at the carotid bifurcation.

The specificity of CT-angiography MIP images in detecting stenosis over 70% was 93.9%, the sensitivity 100%, negative predictive value 100%, positive predictive value 88.3%, accuracy 95.8%. The specificity of CT-angiography axial CT images in detecting disease that would require surgery was 93.9%, the sensitivity 94.7%, negative predictive value 97.4%, positive predictive value 87.8%, accuracy 94.1%. Results are displayed in Table 1.

Table 1. Comparison of CTA with DSA for Various Degrees of Carotid bifurcation Stenosis

Degree of Stenosis	Sensitivity	Specificity	PPV	NPV	+LR	-LR	Accuracy
<50%							
MIP	0.82	1.00	1.00	0.86	Infinity	0.18	0.92
Axial	0.85	1.00	1.00	0.88	Infinity	0.15	0.93
50-69%							
MIP	0.75	0.92	0.60	0.95	9.37	0.27	0.88
Axial	0.75	0.90	0.54	0.95	7.50	0.28	0.88
70-99%							
MIP	1.00	0.95	0.85	1.00	20.0	0	0.96
Axial	0.91	0.95	0.84	0.97	18.2	0.094	0.95

PPV and NPV indicate positive and negative predictive values, respectively; positive and negative likelihood ratios are noted as +LR and –LR, respectively. Occlusions were correctly identified in all cases.

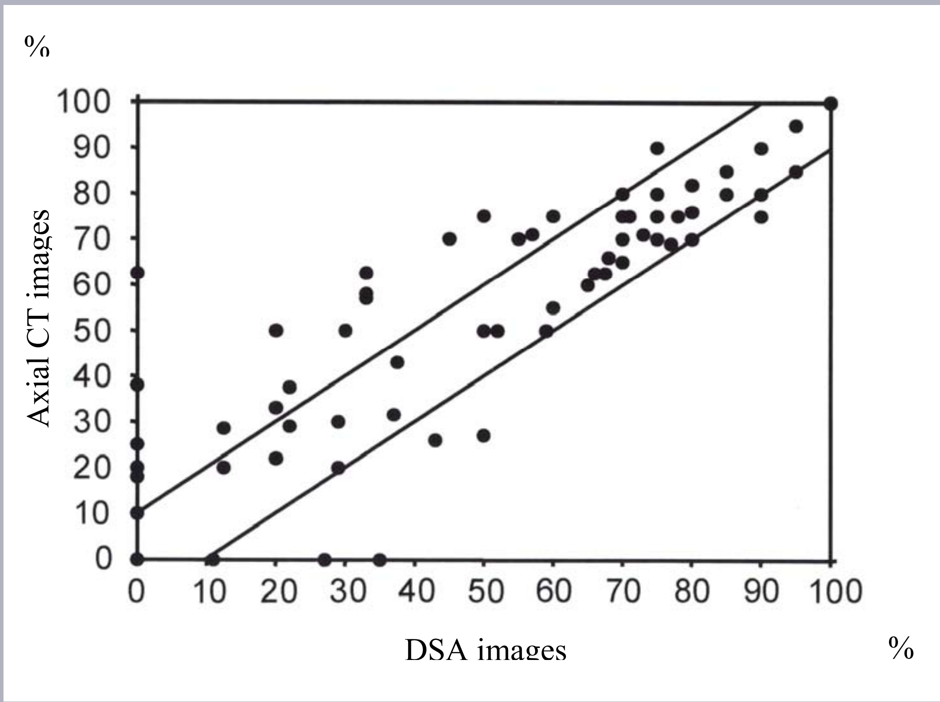


Figure 13. Stenosis measurement on DSA and axial CT-angiography images

A difference more than 10% in stenosis measurement was found in 29 arteries on axial CT images as compared to DSA. Overestimation occurred in 19 arteries, underestimation in 10 arteries. Mild irregularity or stenosis observed on DSA was entirely missed on the axial CT images in 3 cases. In most cases, however, axial CT images overestimated the degree of stenosis as compared to DSA (Fig.13). This overestimation was more marked when CT-angiography MIP images were compared to DSA images (Fig 14.).

Stenosis measurements on MIP images differed from the stenosis measurements on DSA by more than 10% in 29 cases. MIP images overestimated the stenosis by more than 10 % in 24 cases, and underestimated the stenosis in 5 cases.

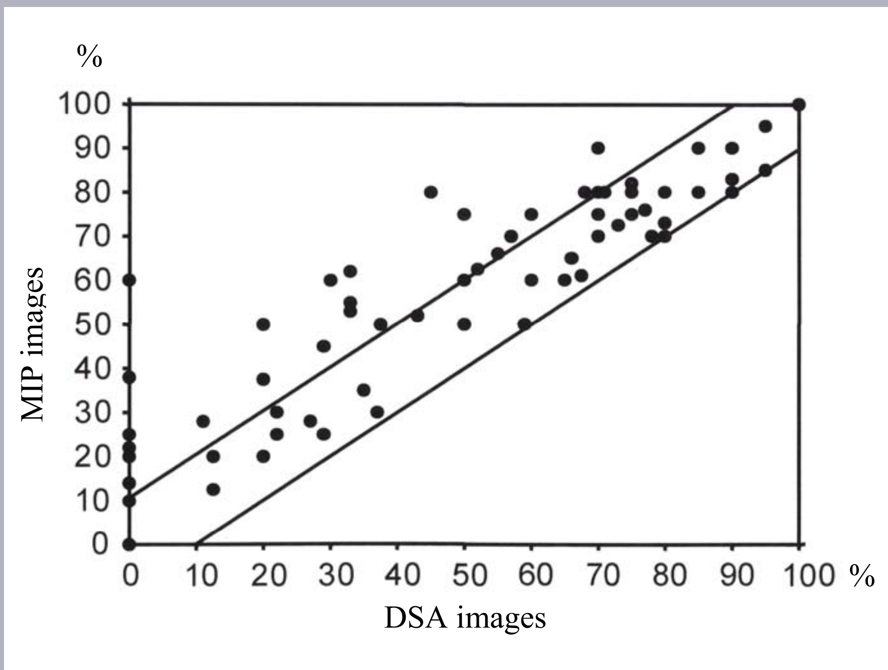


Figure 14. Stenosis measurement on DSA and CT-angiography MIP images

Overestimation on both the MIP and the axial CT images was the result of atheromatous, calcified plaques oriented oblique to the standard antero-posterior, 45 degree oblique, and lateral imaging planes of DSA (Fig. 15.) The high density of the plaque adding to the contrast material in the stenosed lumen also results in underestimation on DSA (Fig.16.).

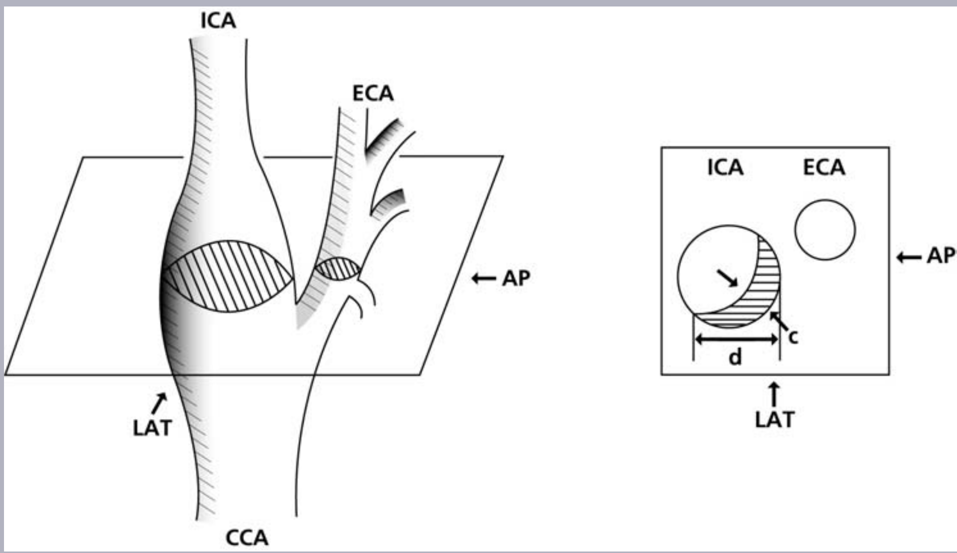


Figure 15. DSA can severely underestimate stenosis. Schematic drawing of an eccentric plaque aligned oblique to the standard antero-posterior (AP) or lateral (LAT) imaging planes of DSA. The free vessel lumen is striped on the drawing. The narrowest diameter measured on CTA images is indicated by „c". The narrowest diameter measured on DSA images is indicated by „d". The undiseased distal ICA being the denominator in both cases, DSA will indicate a milder stenosis, and the patient may falsely fall into the medical-therapy category.

MIP images largely underestimated the stenosis in one case. The web-like plaque was severely ulcerated and the MIP images failed to show the septa dividing the ulcers, giving the appearance of mild stenosis. The axial source images showed the narrowing and the ulcers accurately. Underestimations on the axial CT images occurred when DSA showed mild stenosis. Such mild stenoses were not detected due to lumen distortion in vessels oblique to the plane of CT scanning.

Figure 16,

Az 50 %-os

Subtotal occlusions with a diminished distal diameter were present in 9 arteries, each were correctly depicted by CT-angiography.

Calcification and the detectability of the soft components of the plaques were excellent, were well delineated in all cases. 18/20 ulcerations (90%) were correctly identified. In one case severe calcification, in another pulsation artifact inhibited the detection of small ulcerations. Following pathology fell outside the examination range of CT-angiography: One 95% stenosis at the origin of the left common carotid artery, two intracranial occlusions. In the case of tight stenosis at the origin of the common carotid artery, the common carotid artery was narrowed by approximately 50% on CT-angiography as compared to the contralateral CCA (Fig. 17).

SSD images were helpful in demonstrating vascular anatomy, but did not provide additional diagnostic information over the MIP images.

Figure 17.

5.4. Discussion

The accuracy of CT-angiography in the evaluation of the stenosis of the carotid artery bifurcation has been extensively discussed in the literature, but the correct place of this imaging method is not yet established in the preoperative decision-making. Scanning parameters and postprocessing techniques differ from site to site and consequently the results are different as well. A number of articles have dealt with significant effects of technical factors on the accuracy of CT-angiography. In spiral CT, slice sensitivity profiles are broadened with increased beam collimation. This results in image distortion along the z-axis (patient axis) and decreased contrast due to volume averaging[47, 48]. This becomes clinically important in stenosed vessels oblique to the z-axis, as is often the case at the origin of the internal carotid artery[22]. Beam collimation therefore has to be kept as narrow as possible by covering the volume that needs to be evaluated. The ratio of the table feed/tube rotation (pitch) also has to be smaller than two[22]. The reconstruction interval should be as small as possible to avoid generating step artifacts, which may resemble stenosis[24]. MIP images display the highest CT numbers along the casting parallel rays. Therefore, the elimination of unwanted structures with high CT numbers is essential. It is also important to reduce background attenuation, which can result in loss of vessel definition on the MIP image[24].

We found that the combined analysis of MIP images and the axial source images give correct information. The postprocessing technique can be standardized and it is relatively rapid. Some authors have used multiplanar reformatting for evaluation, and found it less time-consuming than the creation of MIP and SSD images. However, the random shape and alignment of the atherosclerotic plaque does not allow standardization of the multiplanar reformatting (MPR) [48]. Moreover, MPR only assures the inclusion of a short segment of the internal carotid artery into the image. For the evaluation of complex lesions more planes are needed, hence the postprocessing time comes close to that of creation of MIP images.

In our study SSD images did not have significant advantage over MIP images in the evaluation of the carotid bifurcation.

In our present study CT-angiography had a tendency to overestimate stenoses in comparison to DSA. However, the analysis of the axial CT images has clearly showed that DSA is less accurate in determining stenosis than CT-angiography due to the limited number of imaging planes and occasional overlap of the external carotid artery and internal carotid artery. Therefore, even a significant stenosis may be missed on conventional DSA performed in two or three projections. This has been already shown by studies using surgical specimen measurements[49, 50], and by recent rotational angiography studies[51].

CT-angiography, in contrast to ultrasound, is able to detect subtotal occlusion reliably.

Significant disease of the carotid arteries outside of the area that can be investigated by conventional CT-angiography may alter patient management. Patients with occlusion of the carotid siphon have no advantage to be gained from surgery; it is therefore of great importance to rule out the presence of occlusion.

Fortunately, the recently introduced multislice CT scanners are free of the disadvantages of single slice spiral CT. Multislice CT-angiography is potentially able to replace conventional DSA examinations, providing true arterial phase images of the entire carotid artery with high spatial resolution[52].

6. Endovascular therapy of the carotid artery bifurcation stenosis

6.1. History of stent-protected balloon-dilatation of the carotid artery stenosis

Percutaneous carotid angioplasty was first reported in 1981 for fibromuscular dysplasia[19, 20] and in 1983 for atherosclerotic disease[9]. The first results were not very encouraging, since elastic recoil, embolisation and restenosis were quite frequent complications. In 1995 Diethrich and coworkers from Phoenix, USA, reported about their plan for the future: about stent implantation into the carotids. They implanted a balloon-mounted Palmaz stent[53]. The patient treated was a 69-year-old symptomatic man who required a third intervention for recurrent carotid disease. They concluded: "…intraluminal stenting following balloon dilation for recurrent carotid disease may surpass redo CEA in long-term patency and may entail fewer procedural complications."

The first publications about stent-protected balloon-dilatation of the carotid artery stenosis reported about periprocedural complication in 5,3-8,2%[30-34], which was mainly due to distal embolisation. These results were highly criticized; stating that carotid angioplasty with stenting should only be preserved to high-risk surgical patients, symptomatic restenoses or distally positioned stenoses that are not suitable for endarterectomy[54-56]. The criticism was based on the results of the classical surgical trials (NASCET[10], ACAS[12]), which gave clear evidence, that endarterectomy is more effective for stroke prevention than medical therapy, if performed in low risk patients by experienced surgeons, in regional centers of surgical excellence. The endovascular therapy gained more popularity in the late nineties, when the development of catheters and other equipment enabled the procedure to be carried out with far less complications[21, 35-37]. Although stenting – this emerging technique – is often performed in high-risk patients with significant comorbidities, who would have been excluded from the previous surgical trials, it seems encouraging, that clinical outcomes lately approach that of endarterectomy.

It has been debated whether the risk of embolisation is greater with endovascular therapy or endarterectomy. Diffusion-weighted MR imaging has been used in many studies to detect new ischemic lesions[57-61]. However, fast fluid-attenuated inversion recovery MR images seem to be more sensitive to subtle signs of ischemic lesions[62-63]. The above authors suggest that endovascular therapy is associated with somewhat higher risk of embolisation then endarterectomy (20-22% as oppose to 4-5%), although Müller et coworkers[60] found new lesions in 34% of their endarterectomy patients.

Risks of anesthesia, wound infection, myocardial infarction, cranial nerve palsy and complications related to relatively long clamp-time are also avoided with stenting.

Evidence based medicine requires the result of randomized trials for decision about optimal choice of therapy. Such a trial is on its way for carotid stenting, the Carotid Revascularization Endarterectomy Versus Stent Trial (CREST). This US study began in late 2000. However, with an anticipated enrollment of 2500 patients and follow-up ranging to 4 years, it will be several years before randomized data are available to guide therapy selection in extracranial carotid artery stenosis. Until then, promising single center experiences are growing, which lead to further development and refinement of the technique to serve patients better.

6.2. Patients and methods

All patients were clinically evaluated and premedicated by a neurologist, neurosurgeon or vascular surgeon before the procedure. Pre- and postprocedural care was taken in the referring departments. Endovascular therapy was carried out in the DSA laboratory of our department, under the surveillance of an anesthesiologist. All patients gave informed consent.

Patients were selected for angiography on the basis of color coded duplex sonography. All patients had a stenosis over 70% based on the result of peak systolic velocity measurements. In cases of equivocal ultrasound results CT-angiography or MR-angiography was carried out. Stenosis measurements were done on the angiographic images according to NASCET criteria (Fig. 9.a.). Endovascular therapy was planned by stenoses >60%. Exclusion criteria were the following: Intracranial tumor, disabling stroke, stroke within 6 weeks, and occlusion of the internal carotid artery. Relative contraindication were severe kinking, and special haemodynamic situations caused by multiplex stenoses and/or occlusions. Both symptomatic and asymptomatic patients with primary atherosclerotic plaques or post-endarterectomy restenoses were candidates if they didn't meet our exclusion criteria.

In 15 of our patients MR examination was also carried out before and after the procedure, to assess the risk of embolisation of endovascular therapy in our hands.

The only selection criterion was that the patients had to live in-town, to be able to complete the both examinations. The examinations were done on a GE Signa 1.0T MR. Fast spin echo T_2 weighted axial, FLAIR sequential axial, and T_1 weighted coronal images were obtained.

6.2.1. Preprocedural patient preparation

Patients received combined platelet aggregation inhibitors 4 days before stent insertion (aspirin 100mg/day + ticlopidin 2x250mg/day or aspirin 100mg/day + clopidogrel 75mg/day). In emergency cases, when there was no possibility for combined therapy, 100 mg aspirin + 300 mg clopidrogel was administered in the morning of the intervention. All usual medication was continued except for antihypertensive drugs in cases of mild hypertension. Patients were fasting, but kept well hydrated.

6.2.2. Procedural patient care

Anesthesiologist was monitoring the patient during the procedure. Blood pressure, heart rate, general state of the patient was observed and corrected as necessary. 5000 units of heparin were administered into the common carotid artery before stent insertion, which could be repeated another time during the procedure. In case of alarming symptoms like neurological signs, and progressive headache, control angiography and acute CT examination of the head were carried out, and immediate treatment started according to the results.

6.2.3. Technical details of stent protected balloon dilatation of carotid bifurcation stenosis with "feasible passive protection"

The first step of endovascular treatment is the diagnostic angiography of the supraaortic vessels. Depending on the type of stent being used, 7F or 8F introducer is placed into the femoral artery. The appropriate size guiding catheter (7F or 8F) is then placed into the common carotid artery. We thrived to complete the procedure within the shortest timeframe caring for both the patient and the plaque as much as possible. The greatest risk of the endovascular procedure is distal embolisation, which may result in stroke and subsequent death. Therefore, we used the least traumatic, lowest profile stent and equipment available. This way the number of predilations before stent insertion could be reduced to avoid unprotected dilatation of the stenosis.

There have been attempts to decrease the risk of distal embolisation during stent placement with the use of protecting devices, which are designed to capture emboli during the procedure, or flow reversal in the internal carotid artery[64-67]. Although debris is almost always captured with these devices, they carry their own risks. They can only be used in fairly straight arteries, without significant kinking. Their use significantly lengthens the duration of the intervention, may cause severe spasm of the internal carotid artery resulting in prolonged ischemia. Naturally, none of the emboli released after the procedure are captured. Therefore, we did not use protecting device, either.

After the stent has been opened, postdilation was administered whenever necessary. Control angiograms were made during the procedure and for checking the final angiographic results. Intracranial vasculature was visualised as well to detect any complications that may have occurred. The procedure is illustrated in Figure 18.

Figure 18. stent procedure

6.2.4. Postprocedural care

Because of the use of relatively large diameter 7F or 8F introducers the checkup of the compression bandage of the puncture site after the procedure is crucial for avoiding false aneurysms. Severe hypotension may occur because of the compression of the baroreceptors located in the carotid bifurcation. Therefore, careful blood pressure monitoring is required for at least 24 hours. Hypotension is managed with omitting the hypotensive drugs, abundant administration of fluid, either orally or intravenously. The use of vasopressors may also be necessary.

6.2.5. Follow- up

All patients undergo clinical and color coded duplex sonography check-up at 1, 6 and 12 months.

6.2.6. Statistical evaluation

Data were collected on patient demographics, angiographic appearance of the lesions, rationale on equipment use, procedural and clinical outcome to evaluate our theory of passive protection. Atherosclerotic plaques were classified as smooth, irregular and ulcerated on the angiograms. Subtotal occlusions (stenoses over 95%) were noted. The necessity of pre- or postdilation and the types of stent used were registered. Procedural success- and periprocedural complication rates were noted. Restenosis rates were registered.

6.3 Results:

Patient characteristics, comorbidities are listed in Table 2. 149 patients (86 men, 63 women, 33 - 82 years old, mean age 57,5) were evaluated angiographically. 26,2% of the patients suffered from diabetes mellitus, 54,4% from hypertension, and 74,7% of the patients had a history of ipsilateral stroke or TIA. High risk patients (NASCET exclusion criteria) were also identified: 18,1% of our patients was older than 79 years old, had prior ipsilateral carotid endarterectomy, had organ failure likely to cause death within 5 years, had contralateral occlusion, or a more severe lesion cranial to the surgical lesion.

146 primary atherosclerotic lesions and 8 post-endarterectomy restenoses were considered for stent implantation. The procedure was not carried out in three patients. (Two patients had severe kinking with plaques extending above it. Both patients underwent carotid endarterectomy. One asymptomatic female patient with 80% stenosis of the left internal carotid artery had occlusion of the ipsilateral vertebral artery. The posterior fossa was mainly supplied by collaterals from the

left external carotid artery. The contralateral external artery has occluded previously as the result of carotid endarterectomy. Since the stent insertion may have resulted in occlusion of the left external artery as well, the patient was left on best medical therapy.)

Table 2. Patients characteristics

All patients	149	100%
Female	63	42, 30%
Male	86	57, 70%
Age	33-82, mean 57, 5	
Comorbidities		
Diabetes mellitus	39	26, 20%
Hypertension	81	54, 40%
Ipsilateral stroke or TIA in the history	111	74, 70%
NASCET exclusion criteria*	27	18, 10%
Restenosis after carotid endarterectomy	8	5, 37%
Contralateral occlusion	18	12,1%
Severe intracranial stenosis	2	1,34%
Organ failure likely to cause death within 5y	1	0,67%

*NASCET exclusions: age >79 y, prior ipsilateral carotid endarterectomy, unstable coronary syndrome, myocardial infarct in previous 6 mo, cardiac valvular or rhythm abnormality likely to cause embolic cerebrovascular symptoms, contralateral occlusion, a more severe lesion cranial to the surgical lesion, contralateral carotid endarterectomy within previous 4 mo, uncontrolled hypertension or diabetes, organ failure likely to cause death within 5 y, major surgical procedure in previous 30 d, prior severe cerebrovascular accident, progressing neurological syndrome, total carotid occlusion.

In the remaining 146 patients stent implantation was attempted into 151 arteries, in 150 cases successfully. In one case of heavily calcified plaque causing severe, ulcerated stenosis only the 0, 014" guide wire could be passed through the lesion. This patient underwent carotid endarterectomy as well.

The angiographic and procedural characteristics of the successfully treated 150 arteries are listed in Table 3. 142 primary atherosclerotic lesions and 8 post-endarterectomy restenoses were treated. Three patients had bilateral stent insertion, with a time interval of at least six weeks between the two sides. Subtotal occlusions (stenoses over 95%) were detected in 27,3% of the arteries that were successfully treated. Plaques were smooth in 23%, irregular in 51% and ulcerated in 26%.

Table 3. Carotid Stent Angiographic and Procedural Characteristics

	Number of arteries	**%**
All arteries treated:	150	100%
Stenosis over 95%	41	27,3%
Plaque surface morphology		
Smooth	34	23%
Irregular	77	51%
Ulcerated	39	26%

Figure 19. Avoidance of postdilation

Predilation was done in 5 cases; postdilation was not attempted in 12 cases (Figure 19.) Residual stenosis was always below 30%. The very first procedure in 2000 was carried out with a Smart stent, which had a diameter of 7F. The subsequent procedures were carried out in 86% with Monorail Carotid Wallstent, in 8,7% with Precise stent and in 4,7% with Symbiot stentgraft (Figure 20). Complications (listed in Table 4.) were the following: major stroke occurred in 1,3%, minor stroke or TIA 1,4%. One of the major strokes was caused by stent-thrombosis. This female patient was asymptomatic for two days after the procedure, when she underwent coronary bypass grafting. The reason for stent-thrombosis might have been the suspension of heparinization at the end of the operation.

Table 4. Hospital outcomes

Neurological complications		
Major ipsilateralis stroke	2	1, 3%
Minor stroke	1	0, 7%
TIA	1	0, 7%
Death (vascular origin)	0	0, 0%
Total neurological complications	4	2, 7%
Non-neurological complications		
Death (nonvascular)	1	0, 7%
Myocardial infarction	0	0, 0%
Bleeding or false aneurysm requiring surgery at puncture site	0	0, 0%
False aneurysm not requiring surgery at puncture site	3	2, 0%
Renal disfunction	0	0, 0%
Total non-neurological complications	4	2, 7%
Total complications	8	5, 3%

Figure 20. Symbiot

There was no procedure-related death. One patient with a previously undetected colonic cancer suffered hemorrhagic shock and subsequent death. In 3 patients were false aneurysms found at the puncture site, none of them required surgery.

None of the patients undergoing MR examination had any neurological events. The control MR examination was carried out 6 weeks ± 11 days after the stent insertion. Three of the 15 patients (20%) developed new ischemic lesions. One patient had a 2 mm size lesion in the contralateral hemisphere. The other two patients had ipsilateral lesions: one patient had one 3 mm diameter, while the other two new lesions; their size was 8 mm and 12 mm (Figure 21.)

50 patients have been followed up for more than one year, while 97 patients for more than 6 months. No new ipsilateral stroke was found so far. Significant restenosis occurred in two patients. The first patient underwent surgical graft insertion, and developed restenosis at the two ends of the graft. In the other case restenosis was successfully dilated with a high-pressure balloon.

Figure 21. MR

6.4 Discussion

Evidence based medicine requires the result of randomized trials for decision about optimal choice of therapy. The "Revascularization Endarterectomy Versus Stent Trial" (CREST), which began in late 2000, will need several years until randomized data will be available to guide therapy selection in extracranial carotid artery stenosis.

In the beginning of the nineties NASCET proved, that when operations are performed at regional centers of surgical excellence, by excellent surgeons, in low risk patient cohorts (any patient with contralateral carotid occlusion was already excluded from the NASCET), carotid endarterectomy is more effective in stroke prevention then medical therapy alone. However, several subsequent surveys of carotid endarterectomy have confirmed that rates of stroke and death are higher than reported in these trials[68], even at participating study institutions[69]. NASCET reported a perioperative death rate of 0,6%, while the Medicare study has found almost three times higher rate, 1,75%. Operators and hospitals with low volumes, as well as high-risk patients with significant comorbidities, both of which are commonly encountered in clinical settings, are specifically associated with greater rates of adverse outcomes. Endovascular therapy started with the treatment of patients with severe carotid artery stenosis, who were at high-risk to undergo carotid endarterectomy. Approximately 20% of our own patients would have been excluded from the NASCET. Almost 75% of our patients had previous TIA or stroke. Despite this, severe complications occurred in only 2% of our first 150 procedures, and there was no procedure-related death. In the Asymptomatic Carotid Atherosclerosis Study (ACAS), the perioperative stroke/death rate was somewhat higher, 2,3%[12]. Other authors report favorable results similar to ours. Severe complications were reported by Stankovic and coworkers[35] in 0% of 102 procedures, Yadav and coworkers[36] in 1,6% of 126 procedures, while Fox and his coworkers[37] found severe complications in 9,5% in NASCET high-risk patients. Wholey et al[21] have collected the data of 24 interventional centers. In their study major stroke occurred in 1,49%, death in 0,86% in 5210 arteries treated. Because of our unsuccessful experience with coronary bypass graft operation immediately after carotid stenting, if it is possible we wait 6 weeks with the operation, until neoendothelisation of the stent is completing and prevents stent-thrombosis.

Indulgence of endovascular treatment of the carotid arteries is probably best supported by the fact, that only one of our patients, who developed hemorrhagic shock because of his preprocedurally unknown colonic cancer, needed intensive care. Lack of need for intensive care heavily reduces the cost of treatment of these patients[70]. We surely avoid the risks related to anesthesia and surgical incision.

We believe that the use of passive protection in the endovascular therapy of carotid bifurcation stenosis (well prepared patient, best available equipment, fast procedure) is sufficient to achieve satisfactory complication rates, and obviates the need of costly protection devices. This observation is also supported by the results of the FLAIR examinations, as our silent embolisation rate is similar to the reports of other authors[57, 58], and is within the range of reports on microembolism related to endarterectomy[60, 71-72].

Limitation of this study is that more than 1 year of follow up is available only for 50 patients. Although the cumulative stroke results are favorable, 2 year cumulative stroke rate will have to be assessed for all cases. The cumulative stroke rate is 2,0% at present, which competes well with the 9,0% stroke rate reported in the surgical arm of NASCET[10].

Restenosis is reported in 1,9% to 16,8% in the first year after carotid endarterectomy[75], while of our above mentioned 50 patients two developed restenosis, resulting in 4,0% of restenosis rate.

Both the cumulative stroke rate and the restenosis rate support the idea that durability of the results of endovascular therapy seems to be adequate for stroke prevention and brain circulation.

In conclusion, these results demonstrate that stent-supported angioplasty of the carotid bifurcation is a reasonable alternative to endarterectomy, though we await the results of current randomized trials to further define the relationship between endarterectomy and stenting.

7. CONCLUSIONS

1. Single slice spiral CT-angiography is more accurate in determination of the degree of stenosis at the carotid bifurcation than DSA based on images obtained in two or three planes.

2. Plaque calcification is depicted by CT in all cases, and soft components of the plaque can be well differentiated from the calcification. Ulceration cannot be reliably detected in all cases.

3. Single slice spiral CT-angiography is unable to detect intracranial, or intrathoracic lesions. The examination provides accurate information about lesions in the cervical area.

4. Working in team based on strict protocol, with the best available equipment, stent supported endovascular treatment of the carotid bifurcation stenosis can be carried out even in NASCET high-risk patients with clinical complication rates as low as published in the ACAS.

5. Our periprocedural distal embolisation rate does not exceed the embolisation rate of big western-European centers, nor the embolisation rate related to endarterectomy.

6. Durability of the results of endovascular therapy seems to be adequate for long lasting stroke prevention and improved brain circulation.

8. Practical application of the results

Our results have shown that single slice CT-angiography is excellent for precise evaluation of the carotid bifurcation in case of ambiguous ultrasound results**.** This way the number of patients can be reduced who would unnecessarily undergo invasive DSA examination.

Based on the outcome of our single center series, we believe that stent supported angioplasty of primary atherosclerotic lesions of the carotid bifurcation is feasible even in high-risk patients, without protecting device, with favorable complication rates. The endovascular method is a reasonable alternative to endarterectomy. Good results require well-coordinated teamwork, utilization of best available endovascular equipments, and rigorous protocol designed for indulgence of the patients.

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RADIOLOGICAL DIAGNOSIS AND THERAPY OF THE EXTRACRANIAL CAROTID ARTERY STENOSIS

(Thesis)

1. Introduction

1.3 million people die in Europe each year because of stroke. Until the early nineties, the non-medical method of stroke prevention was the endarterectomy based on the diagnosis provided by catheter-based angiography. It is an old diagnostic thrive to substitute invasive diagnostic methods by less invasive ones. Nowadays, numerous vessel diseases can also be cured by interventional radiological procedures. We sought to assess the value of the minimal invasive, conventional CT-angiography to determine patient eligibility for carotid endarterectomy. We were also keen on proving that carotid artery stenting is effective in the treatment of primary atherosclerotic lesions, and it carries a low risk of complications.

2. Purpose

2.1. To determine, how accurate is the single slice spiral CT-angiography in grading of carotid stenosis.

2.2. To determine how reliable is CT-angiography in the plaque evaluation?

2.3. To determine, if single slice spiral CT-angiography is able to detect every abnormality that could alter the decision-making before carotid endarterectomy.

2.4. To determine if the endovascular therapy (stent placement) could be carried out with similar or lower perioperative complication rate as carotid endarterectomy.

2.5. To determine the impact of our own periprocedural distal embolisation rate by means of MR FLAIR imaging.

2.6. To determine the long-term efficacy of endovascular therapy in stroke prevention and brain perfusion.

3. Physics of CT-angiography

CT-angiography can be carried out on spiral-CT scanners, which are capable of depicting a complete anatomic region without any gap. Volume scanning was enabled by the simultaneous application of the slip-ring technology that replaced the power supply cables of the X-ray tube, and the continuous patient transportation. The X-ray tube and the detectors can be rotated in the same direction numerous times and a whole body volume can be depicted. Large volume of intravenous contrast material, administered with relatively high flow, after passing the pulmonary circulation, moves in bolus n the arteries. Timing the thin-slice scanning accurately to the arrival of the bolus, pictures of high quality can be obtained, which can be postprocessed by the computer, creating angiogramm-like pictures. Such postprocessing types are: multiplanar reconstruction (MPR), surface shaded display (SSD), volume rendering technique (VRT) and the maximum intensity projection (MIP).

4. About self-expanding stents

The stent-protected endovascular therapy of carotid artery stenosis gained more popularity in the late nineties, when the development of catheters and other equipment enabled the procedure to be carried out with far less complications. The self-expanding stents are much more suitable in treating carotid stenosis than the balloon mounted stents used before. Loss of stents is not any more a fear. Self-expanding stents have a lower profile (5F, app. 1.66 mm), a smoother outer surface, are much more flexible, and resist external compression better than balloon mounted stents. Further technical development is expected to improve these qualities.

7. CT- angiography in the evaluation of carotid bifurcation stenosis

Materials and Methods

62 consecutive patients (19 women, 43 men) who were 42-87 years old (mean 65 years) were studied with CT angiography and DSA. CT angiography was performed on a Siemens Somatom Plus 4 Scanner (Siemens, Erlangen, Germany), or a GE CTi scanner (General Electric, Milwaukee, USA). The following scanning parameters were used: beam collimation 3 mm (210 mA, 120 kV), pitch 1.5, and reconstruction thickness 1 mm. A total of 120 ml of nonionic contrast material (Omnipaque, 300 mg I/ml, Nycomed) was injected. Axial images and the MIP and SSD images created at increments of 30 degrees were

evaluated. Stenosis measurements were done on the axial CT, the CT angiography MIP, and the DSA images. The degree of stenosis was measured according to the NASCET method. The results of the two scanners were compared with One Way Analysis of Variance (ANOVA) on ranks test. Linear regression was used to determine correlation between the stenosis measurements on DSA & MIP images, and on DSA & axial CT images. Sensitivity, specificity, accuracy, positive and negative predictive values, and likelihood ratios were calculated to compare each test to DSA. Calcification and the detectability of the soft components of the plaques were noted. Digital subtraction angiogramms and CT angiogramms were also evaluated for ulcerations. Abnormalities detected on DSA images that fell outside the range of CT-angiography were collected.

Results

Two cases had to be excluded because of severe motion artefact. In the remaining 120 arteries studied, no significant difference was found between the results of DSA, MIP or axial images in the two centres with ANOVA on ranks test. Linear regression showed high degree of correlation between DSA and axial images (R=0.937), the DSA and MIP images (R=0.946), and the MIP and axial CT images (R=0.955) in determination of stenosis at the carotid bifurcation. The specificity of CT angiography MIP images in detecting disease that would require surgery was 93.9%, the sensitivity 100%, negative predictive value 100%, positive predictive value 88.3%, accuracy 95.8%. The specificity of CT angiography axial CT images in detecting disease that would require surgery was 93.9%, the sensitivity 94.7%, negative predictive value 97.4%, positive predictive value 87.8%, accuracy 94.1%. CT-angiography had a tendency to overestimate stenoses as compared to DSA. Overestimation on both the MIP and the axial CT images was the result of atheromatous, calcified plaques oriented oblique to the standard antero-posterior, 45 degree oblique, and lateral imaging planes of DSA. Because of geometric reasons, I found MIP images to be closest to reality. MIP images largely underestimated the stenosis in one case. Calcification and the detectability of the soft components of the plaques were excellent. Following pathology fell outside the examination range of CT-angiography: One 95% stenosis at the origin of the left common carotid artery, two intracranial occlusions.

8. Endovascular therapy of the carotid artery bifurcation stenosis

Patients and methods

149 patients (86 men, 63 women, 33 - 82 years old, mean age 57,5) were evaluated angiographically. 146 primary atherosclerotic lesions, and 8 post-

endarterectomy restenoses were considered for CAS. All patients had significant, over 60 % stenosis according to NASCET criteria. Exclusion criteria were the following: Intracranial tumor, disabling stroke, stroke within 6 weeks, occlusion of the interla carotid artery. Relative contraindication were severe kinking, and special haemodynamic situations caused by multiplex stenoses and/or occlusions. Both symptomatic and asymptomatic patients with primary atherosclerotic plaques or post-endarterectomy restenoses were candidates if they didn't meet our exclusion criteria. Atherosclerotic plaques were classified as smooth, irregular and ulcerated. Stenting was carried out in 86% with Monorail Carotid Wallstent. Predilation or use of protecting device was avoided in 96%. Procedural success- and periprocedural complication rates were noted. In 5 patients MR examination was carried out before and after the procedure. The only selection criteria was that they had to live in-town. Fast spin echo T_2 weighted axial, FLAIR sequential axial, and T_1 weighted coronal images were obtained. Follow-up consisted of color coded duplex sonography at 1, 6 and 12 months.

Results

26,2% of the patients suffered from diabetes mellitus, 54,4% from hypertonia, and 74,7% of the patients had a history of ipsilateral stroke or TIA. 18,1% of our patients was older than 79 years old, had organ failure likely to cause death within 5 years, had contralateral occlusion, or a more severe lesion cranial to the surgical lesion. All these patients would have been excluded from the NASCET study. 146 primary atherosclerotic lesions and 8 post-endarterectomy restenoses were considered for stent implantation. The procedure was not carried out in three patients because of morphological or haemodynamic reasons. In the remaining 146 patients stent implantation was attempted into 151 arteries, in 150 cases successfully. 142 primary atherosclerotic lesions and 8 post-endarterectomy restenoses were treated. Subtotal occlusions (stenoses over 95%) were detected in 27,3% of the lesions. Plaques were smooth in 23%, irregular in 51% and ulcerated in 26%. Predilation was donr in 5 cases, postdilation was avoided in 12 cases. Residual stenosis was always less than 30%. Complications were following: major stroke/death (nonvascular): 2,0%, minor stroke or TIA 1,4%. In 3 patients were false aneurysms found at the puncture site, none of them required surgery. None of the patients undergoing MR examination developod any neurological events. Two patients had new ischemic lesions. 50 patients have a follow-up longer than one year, while 97 patients have a follow-up longer than 6 months. No new ipsilateral stroke was found so far. Significant restenosis occurred in two patients. The first patient underwent surgical graft insertion, and developed restestenosis at the two ends of the graft. In the other case restenosis was successfully dilated with a high-pressure balloon.

9. Conclusions

1. Single slice spiral CT-angiography is more accurate in determination of the degree of stenosis at the carotid bifurcation than DSA based on images obtained in two or three planes.

2. Plaque calcification is depicted by CT in all cases, and soft components of the plaque can be well differentiated from the calcification. Ulceration cannot be reliably detected in all cases.

3. Single slice spiral CT-angiography is unable to detect intracranial, or intrathoracic lesions. The examination provides accurate information about lesions in the cervical area.

4. Working in team based on strict protocol, with the best available equipment, stent supported endovascular treatment of the carotid bifurcation stenosis can be carried out even in NASCET high-risk patients with clinical complication rates as low as published in the ACAS.

5. Our periprocedural distal embolisation rate does not exceed the embolisation rate of big western-European centers, nor the embolisation rate related to endarterectomy.

6. Durability of the results of endovascular therapy seems to be adequate for long lasting stroke prevention and improved brain circulation.

Tézisek

1. Bevezetés

Európában évente kb. 1,3 millió ember halálának okozója a stroke. megelőzésének nem-gyógyszeres módja a kilencvenes évekig kizárólagosan a katéteres angiographiával készített értérkép alapján elvégzett carotis endarterectomia volt. Régi diagnosztikus törekvés az invazív módszerek kevésbé invazívakkal történő helyettesítése. Ma már számos érbetegség gyógyítható is a betegeket a sebészi módszereknél lényegesen kevésbé terhelő intervenciós radiológiai módszerrel. Munkám során azt vizsgáltam, helyettesítheti-e a CT-angiographia a műtét előtti DSA vizsgálatot. Célom volt annak bizonyítása is, hogy a carotis arteria stentelése az atherosclerosis okozta primer szűkületek gyógyításának hatékony, alacsony rizikójú eszköze.

2. Célkitűzések

2.1. Tisztázni kívántam, hogy mennyire pontos a hagyományos spirál CT-angiographia az arteria carotis communis bifurcatiojában elhelyezkedő plaque okozta szűkület meghatározásában?

2.2. Tisztázni kívántam, hogy a plaque morfológiára vonatkozólag ad-e felvilágosítást a CT-angiographia?

2.3. Tisztázni kívántam, hogy a hagyományos spirál CT-angiographia kiszűr-e minden olyan elváltozást, mely a carotis endarterectomia elvégzését befolyásolja?

2.4. Tisztázni kívántam, hogy az endovaszkuláris terápia (stent behelyezés) elvégezhető-e hasonló perioperatív szövődmény rátával, mint az endarterectomia

2.5. Az intézetünkben végzett endovaszkuláris terápia kapcsán fellépő periprocedurális distalis embolisatio mértékének meghatározása MR FLAIR szekvenciával.

2.6. Az endovaszkuláris terápia eredményességének megítélése a stroke prevenció és az agy vérellátása szempontjából.

3. A CT-angiographia fizikai alapjai

CT-angiographiat ún. spirál-CT készülékekkel lehet végezni, melyek képesek egy teljes volument hiánytalanul leképezni. Ennek feltételét a röntgencső áramellátását biztosító kábelek ún. csúszógyűrűre cserélése, és a vizsgálóasztal egyidejű folyamatos mozgathatósága teremtette meg. Így a röntgencső és a vele szemben lévő detektorok folyamatosan, egyirányban forgathatók, és a teljes vizsgálandó volumen gyors leképezésre kerülhet. Nagy mennyiségű, nagy sebességgel beadott intravénás kontrasztanyag a kisvérkörön áthaladva az artériákban bólusban halad a keringéssel. A keringéshez megfelelően időzítve a vékonyrétegű scannelést, jó minőségű képek nyerhetők, melyeket a komputer utólagosan kezelni tud, s a hagyományos angiographiához hasonló képek nyerhetők. Ilyen utólagos rekonstrukciófajta a multiplanar reconstruction (MPR), a surface shaded display (SSD), a volume rendering technique (VRT) és a maximum intensity projection (MIP).

3. Az öntáguló stentek tulajdonságai

Az a. carotis interna stent védelmében végzett endovaszkuláris terápiája a kilencvenes évek végén virágzott fel, amikorra az eszközök fejlődése a korábbinál lényegesen kevesebb szövődménnyel tette lehetővé a beavatkozást. Az újabban kifejlesztett öntáguló stentek az a. carotis bifurcatio stenosisának ellátására jobban megfelelnek, mint a korábban alkalmazott ballonra applikált stentek. A felvivőrendszer csúcsa és a stentet borító burok között nincs lépcsőképződés, ami a plaque-ból embolusokat vájna le. A külső burok miatt a stent nem sodródhat le, mint korábban a ballonról. A felvivőrendszer lényegesen vékonyabb (jelenleg 5F, azaz kb. 1,66 mm a legvékonyabb carotis stent átmérője) és flexibilisebb, ami a stent biztonságos feljuttatását, és a szűkebb laesiókon történő kevésbé traumatikus átjuttatását teszi lehetővé. A flexibilisebb stent harmonikusabban idomul az érfalhoz, emiatt az éren kedvezőtlen haemodynamikai viszonyokat teremtő megtöretések kevésbé alakulnak ki. A nagy hálósűrűség a plaque-ok minél teljesebben történő lefedését szolgálja, így már a neointima képződése előtt is csökken az embolisatio és a stroke veszélye. A carotisokat kevés lágyrész fedi, emiatt hosszú távon az is lényeges, hogy ezek az öntáguló stentek a külső kompresszió ellen lényegesen rezisztensebbek, összenyomódásuk már nem jelent reális veszélyt. A további technikai fejlődés ezen tulajdonságok egyre kedvezőbbé válásától várható.

4. A CTA alkalmazása a. carotis communis bifurcatio stenosis esetén

Anyag és módszer

.

62 beteget (43 férfi, 19 nő, életkoruk 42 – 87 év, átlag 65 év) vizsgáltam CTA-val és DSA-val. A CT-angiographiák Siemens Somatom Plus 4-es vagy GE CTi berendezéssel, spirál üzemmódban készültek. A szeletvastagság 3 mm, a pitch 1.5, a rekonstrukció 1 mm volt. 120 ml nonionos kontrasztanyagot (Omnipaque 300) adtunk 3 ml/sec sebességgel. Az adatgyűjtés késleltetését a kontrasztanyag bedásához képest a GE scanneren a gép boluskövető programja automatikusan határozta meg, míg a Siemens scanneren ennek hiányában 20 secundummal késleltettük. Mind az axialis alapképek, mind a postprocessing során, 30 fokonként készült MIP és SSD rekonstrukciók kiértékelésre kerültek.

A szűkület mértékét a NASCET metódus alapján határoztam meg a MIP és az axialis alapképeken, valamint a DSA képeken. A két scanneren készült vizsgálatok adatainak összehasonlítását ANOVA-on-ranks teszttel végeztük. Lineáris regressioval hasonlitottam össze stenosis meghatározások közötti korrelációt a DSA vs. MIP és a DSA vs. axialis alapképeken. Meghatároztam, hogy a CTA mennyire képes a 70% fölötti stenosis kiszűrésére. Kiszámítottam a CTA szenzitivitását, specificitását, pontosságát, negatív és pozitív prediktív értékét a DSA-hoz képest. Regisztráltam a CTA képeken a plaque meszesedést, a lágy komponensek elkülöníthetőségét. Megnéztem, a CTA mennyire képes a DSA képeken ábrázolódó, 2 mm-nél mélyebb ulceratiok detektálására. Megvizsgáltam, milyen elváltozások ábrázolódtak a DSA képeken, melyeket a CT-angiographia vizsgálati volumenéből kimaradtak.

Eredmények

Két beteg CT-angiographiája mozgási műtermék miatt értékelhetetlen volt. A fennmaradó 120 arteria esetén ANOVA-on-ranks teszttel nem volt szignifikáns különbség a DSA/MIP/axialis képeken mért adatok, illetve a két scanneren készült vizsgálatok adatai között. A lineáris regressio jó egyezést talált a MIP/DSA (R=0,946), axialis képek/DSA (R=0,937) között. A CTA specificitása 93,9%, szenzitivitása 100%, negatív prediktív értéke 100%, pozitív prediktív értéke 87,8%, pontossága 94,1% volt a 70% fölötti szűkület meghatározásában a DSA-hoz képest. Mind a MIP, mind az axialis alapképek a DSA-hoz képest valamelyest túlbecsülték a stenosis mértékét, amikor a plaque okozta szűkület maximuma a DSA standard vizsgálati irányainak valamelyikével nem esett egybe. Mértani okokból a MIP képeket találtam a valósághoz legközelebb állónak. Egy bonyolult térszerkezetű plaque esetében a CTA becsülte jelentősen alul a stenosis mértékét, ennek oka a CTA rosszabb térbeli felbontóképessége volt. A plaque lágy komponensei minden esetben jól elkülönültek a calcificált részektől. 18/20 ulceratio ábrázolódott a CTA képeken isA következő, a CTA vizsgálati volumenéből kimaradó elváltozások ábrázolódtak a DSA képeken: egy bal a.

carotis communis eredésénél elhelyezkedő, 95%-os szűkület, két intracranialis a. carotis interna occlusio.

6. Az a. carotis communis bifurcatio stenosis endovaszkuláris terápiája

Betegek és módszerek

149 beteg (86 férfi, 63 nő, életkoruk 33 - 82 év, átlagéletkor 57,5 év) került DSA vizsgálatra. Az arteria carotis interna stentelését a NASCET és az ACAS tanulmányok ajánlása alapján 60%-os stenosis fölött végeztük el. A szűkület meghatározása az angiographiás képeken a NASCET kritériumok alapján történt. Kizárási kritériumaink a következők voltak: intracranialis tumor, nagyfokú demenciát vagy súlyos rokkantságot okozó stroke, hat héten belül bekövetkezett stroke, az arteria carotis interna teljes elzáródása. Relatív kontraindikációt jelentett a súlyos fokú kinking, illetve multiplex stenosisok, elzáródások miatti speciális haemodynamikai viszonyok. Mind symptomás, mind tünetmentes betegeken elvégeztük a beavatkozást, akár primer stenosissal, akár endarterectomia utáni restenosissal jelentkeztek, amennyiben a fenti kritériumoknak megfeleltek. Az atheroscleroticus plakkokat következőképp osztályoztam: sima felszínű, irreguláris, és ulcerált felszínű. A beavatkozást 86%-ban Monorail Carotid Wallstent-tel végeztük, 96%-ban előtágítás és distalis embolisatiot gátló eszköz használata nélkül. A beavatkozás sikerességét és a beavatkozás körüli szövődményeket regisztráltam. 15 betegnél mind a bevatkozás előtt, mind a beavatkozás után készült koponya MR vizsgálat. A szelekció alapját csupán a lakhely képezte, minden résztvevő beteg szegedi volt. Fast spin echo T_2 axiális, FLAIR sequentias axialis, T_1 súlyozott coronalis felvételek készültek. Utánkövetést Doppler ultrahang vizsgálattal végeztünk, 1-6-12 hónap elteltével.

Eredmények

A 149 beteg 26,2%-a szenvedett diabetes mellitusban, 54,4%-a hypertensioban, és betegeink 74,7%-nak anamnézisében szerepelt ipsilateralis stroke vagy TIA. Betegeink 18,1%-a volt 79 évesnél idősebb, szenvedett 5 éven belül valószínűleg halált okozó szervi elváltozásban, a contralateralis a. carotis internája korábban occludált, vagy a sebészi laesionál cranialisabban elhelyezkedő, annál súlyosabb laesioja is volt. Ezen betegek mindegyikét kizárták volna a NASCET tanulmányból. 146 primer atheroscleroticus szűkületet, és nyolc endarterectomia utáni restenosist ítéltük alkalmasnak stentbeültetésre. 3 betegnél morphológiai, illetve haemodynamikai okok miatt nem végeztük el a stentelést. A maradék 146 beteg 151 carotisát kíséreltük meg stentbehelyezéssel ellátni, 150 esetben sikerrel. 142 esetben primer atheroscleroticus stenosis, 8 esetben endarterectomia utáni restenosis miatt végeztük el a beavatkozást. A szűkületek 27,3%-a volt súlyos, 95% feletti szűkület. 23%-ban találtam sima, 51%-ban egyenetlen, 26%-ban ulcerált plaque-ot. Előtágítást 5 esetben végeztünk, utótágítástól 12 esetben tekintettünk el. Szövődményeink a következők voltak: Major stroke / halál (nonvascularis): 2,0%, minor stroke és TIA 1,4 %. 3 esetben észleltünk műtétet nem igénylő álaneurysmát a szúrás helyén. A 15 MR vizsgálaton is részt vett beteg mindegyike tünetmentes maradt. Két betegnél detektáltunk új ischaemiás laesiot. 50 betegünknél áll rendelkezésre egy éves, és 97 betegnél fél éves utánkövetés. Új ipsilateralis stroke nem jött létre. Szignifikáns restenosist eddig két esetben detektáltunk. Az első betegnél sebészi graftbehelyezésre került sor, mely után a graft két végénél alakult ki restenosis. A másik esetben a restenosist nagy nyomású ballonnal sikeresen tágítottam.

7. Következtetések

7.1 A hagyományos spirál CT-angiographia az arteria carotis communis bifurcatiojában elhelyezkedő plaque okozta szűkület meghatározásában pontosabb, mint a hagyományos DSA két- vagy háromirányú felvételeken alapuló szűkület-meghatározása.

7.2 A plaque meszesedése minden esetben kiválóan ábrázolódik, s a lágy komponensek jól elkülönülnek a calcificatiotól. Ulceratio nem minden esetben detektálható.

7.3 A hagyományos spirál CT-angiographiával az intracranialis, vagy intrathoracalis elváltozások nem detektálhatók. A vizsgálat a kóros nyaki szakasz pontos tisztázására szolgál.

7.4 Összehangolt teammunkában, a legjobb eszközökkel és szigorú protokoll alapján, az arteria carotis interna primer stenosisának stentbehelyezéssel történő endovaszkuláris kezelése nemcsak tünetmentes betegeken, hanem a NASCET tanulmány által túl nagy rizikójúnak ítélt betegeken is elvégezhető az ACAS tanulmányban talált szövődményrátánál kedvezőbb eredményekkel.

7.5 Az intézetünkben végzett endovaszkuláris terápia kapcsán fellépő periprocedurális distalis embolisatio mértéke nem haladja meg a nagy tapasztalatú nyugat-európai centrumok embolisatios arányát, és az endarterectomia kapcsán fellépő embolisatio mértékét.

7.6 Az endovaszkuláris terápia eredményének tartóssága eddigi tapasztalataink szerint a stroke prevenció és az agy vérellátása szempontjából megfelelő.

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