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Current results and future needs for carotid stenting

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Summary. We compared operative treatment and stenting on the carotid artery. Duplex findings and pathohostological examinations were done to judge, which patients are suitable for stenting or should be operated. We also looked for a correlation between the results of transcranial ultrasound and the histopathological findings as well as the clinical stage of cerebrovascular insufficiency during operative and stent procedure respectively. The results were discussed together with the results reported in the literature.

Key words: carotid stenosis, plaque morphology, transcranial doppler sonography, carotid endarterectomy, carotid stenting.

Method. In more than 400 patients who underwent carotid surgery and stenting, preoperative duplex sonography, intraoperative transcrabial ultrasound, and histological examination of the arteriosclerotic material were performed. In addition the operative treated patients (368) were compared to the Stent group (112 patients). A significant correlation between the number of HITS (high-intensity transient signals) and histologically verified plaque morphology was found. Irrespective of plaque morphology, up to ten times more HITS were detected during interventional treatment. Concerning the stages of cerebrovascular insufficiency, a statistically relevant accumulation of HITS was not seen. A significantly higher number of HITS was detected during carotid endarterectomy using a shunt. The risk for operative treated patients was 2.1 %, for the Stent group 6.4 % concerning stroke and death rate. The results are discussed with the published results in international studies and from other authors, especially for the need of carotid stenting.

State of carotid surgery. What are the achievements of vascular surgery during the last twenty years in the area of the carotid artery? Various surgical techniques of operating the carotid artery can be applied. Besides conventional endarterectomy numerous supporters of the eversion endarterectomy exist. According to some investigators, the eversion method has several advantages, mainly a reduced clamping time and a physiological reestablishment of blood flow without using prosthetic material. Most vascular surgeons favour intraoperative neuromonitoring (somatic evoked potentials) and transcranial doppler monitoring. In addition, angioscopic inspection of the vessel lumen before reanastomosis and - in case of doubt - intraoperative angiography is considered important [22]. This surgical procedure reduces the risk of therapy in such a way that according to results of the NASCET and ECST trials [36] at least for stage II of cerebrovascular insufficiency it is below the risk of spontaneous course of illness. For asymptomatic carotid stenoses it can be stated because of ACAS [3] and ACST trial that in case of high-grade stenoses a life expectancy of more than five years is considered a benefit for the patients [17; 49]. Probably the plaque morphology is as important as the degree of the stenosis.

Concerning complications many authors conclude that the risk of operation at stage I and II (asymptomatic stenosis, transient ischemic attacks) is significantly lower than at stage III and IV (acute stroke, completed stroke), which to a large extent influence the overall complication rate of carotid surgery [45]. After onset of an acute stroke most patients do not come to the hospital in time for an operative intervention even it is proven that it may be helpful [33]. Conventional staging of cerebrovascular insufficiency can be considered obsolete, since it is impossible to differentiate between stages II, III and IV at the beginning of neurologic symptoms prospectively. Neurologist Hennerici [40] demands a new classification, which especially accounts for the extent of cerebral defect, neurologic deficits, time passed since occurrence of stroke and age of patient in the case of acute carotid stenosis. To differentiate between symptomatic and asymptomatic patients is probably the best classification. Currently, a risk less than 3% in asymptomatic stage, 6% at stage of TIA and after minor stroke is accepted as standard. Of course a surgery and in particular a prophylactic intervention is not supposed to be more dangerous than spontaneous course of the disease (2; 41). What is acceptable for surgery should be valid for interventional procedures too.

State of Carotid Artery Stenting

From the historical standpoint, Mathias, Theron, and Kachel pioneered angioplasty for cervical carotid artery occlusive disease treatment in the early 1980s. With the advent of stent technology, interventional management of carotid artery disease began to develop as a practical technique, as shown by the early work of Diethrich Roubin, Wholey and Mathias [32; 51]. Stents provided significant improvements over conventional angioplasty, in addition to helping reduce the restenosis rates, prevents elastic recoil, and treat dissections.

During this early stage, there were primarily two peripheral stent systems available: the balloon-expandable Palmaz stent, and the self-expanding Wallstent. In 1999, a self-expanding stent made from the shape-memory nickel-titanium alloy became available. Since that time a great number of new Stent models, Protecting devices and catheter-systems were developed and improved, also the X-ray units especially for interventional treatment.

Data from clinical trials

A couple of randomised clinical trials comparing the efficacy of CAS and CEA have been conducted in conventional risk patients. Another clinical trial (SAPPHIRE) in high-risk patients has also now been completed. The results of the CAVATAS-study of the early 1990s, were only recently published on Phase I of the trial. Among 504 randomized patients primarily to angioplasty alone(only 25% received stents) and considered suitable candidates for CEA, the 30-day disabling stroke and death rates were comparable, 6.3% for CEA and 6.4% for the CAS group. In total the complication rate for carotid stenting and endarterectomy of 10% regarding mortality and stroke without taking into account transient and less severe neurologic deficits. This is according to the above mentioned criteria too high, and the study's data was not considered definitive for recommending CAS in most symptomatic or any asymptomatic stenosis patients [16]. In New York Ohki [56] found out that carotid stent implantation can cause embolization in all types of arteriosclerosis. A special filter is urgently recommended, since a lot of these embolizations can cause strokes. A smaller clinical trial was stopped prematurely because of a higher than expected complication rate in the CAS arm (Leicester trial) and in a trial performed by Alberts In February 2001 results of a multi-centre ISC study of Alberts [4] from Fort Lauderdale in 219 randomized symptomatic patients (stenoses 60-99%) were reported, consisting of a risk of 3.5% for operated patients and 12% for the stent-group. The conclusion was: "Carotid stenting is not as effective as endarterectomy". The study has been published only as an abstract and was stopped by the sponsoring industry (Boston Scientific). However, concerns have been raised as to the investigators' choice of a small sample size, inadequate credentialing of the interventionalists performing CAS, and unrealistic complications from CAS before the trial was halted. Results of Bergeron [14] in Marseille demonstrated the stent group, which only consisted of selected cases and no patients with random

risk factors or plaque-forms had a complication rate of 7.1%. The surgical group, however, had complications in 2.7% of the cases. So he did not see a justification of stenting in general and regards it as a supplementary method of vascular surgery.

Jordan [45] discovered a complication rate of 3% for operative therapy in general narcosis and 0.7% in local anaesthesia in his own case material. By performing transcranial doppler ultrasound he was able to detect eight times higher rate of microemboli during angioplasty and stenting than during operation. His recent study demonstrates embolism in almost 80% of the stent group and 7% of the operated patients. He also believes that procedure related complications are not being considered. We came in our investigations like other examiners to similar results [10; 11]. Also Koennecke [47] found that the Microembolisation is caused by the plaque morphology and research for detecting dangerous plaque morphology was done. Echolucent plaques without extensive calcification are more dangerous for embolization than a high grade stenosis with a smooth surface. But it is difficult to find out by means of Angiography [70], Duplex [10; 11; 30; 31] and CT scan or histopathological findings were able to detect calcification and emboligenic plaque morphology [29]. HITS (High intensity transient signals) can be observed in nearly every stented carotid artery and in most of the operative cases too, but the number for the stenting group of observed signals is 8 – 12 times higher and also the postinterventional NMR showed damaged brain tissue. So the Cochrane review in the year 2003 [17] couldn't show a significant advantage of carotid stenting. Randomized trials for comparing the endovascular treatment versus endarterectomy were performed. The CAVATAS II study was initiated in 2002. Most important was the EVA-3S trial in 2005 [49], which showed a significant difference in the non-protected stent arm, so the investigators stopped this arm of the trial. But in total the results for surgery were better than for stenting The German SPACE trial has included more than 1000 patients and was conducted by the German Society for Vascular Surgery [28; 34] which showed a small but certain advantage for the operative treatment. Also the CREST trial in which a high risk for octogenarians (12.1%) could be found in the lead in phase of the stenting group [42], the ICSS trial [43] and the CAPTURE registry were showing non acceptable complication rates for the carotid interventions, so until today the operation is the method of first choice for treating a carotid stenosis and the gold standard.

The SAPPHIRE investigators reported on the randomisation of 310 high-risk patients from a group of 334 eligible patients for CAS (n = 159) and CEA (n = 151. The sample included asymptomatic patients (68%) with stenoses >80% and symptomatic patients (32%) with stenoses >50%. The randomised patients included a high-risk group with one or more of the following criteria:

1. congestive heart failure with left ventricular ejection fractions of <30%.
2. cardiac surgical procedure needed within 6 weeks
3. recent myocardial infarction (>24 h and less than 4 weeks) and unstable angina
4. severe pulmonary disease
5. age <80 years.

Patients were also excluded if they had an ischemic stroke within 48 hours, total occlusion of the target lesion, or ostial lesions at the origin of the common carotid artery (CCA) at the aortic arch. Although the sample included these high-risk groups, nearly 30% of the randomised patients treated by CAS had restenosis after prior CEA as an indication for treatment. In the intention to treat analysis, the 1-year rate of major adverse events (any stroke, MI, or death from neurological causes) was 12.2% in the stenting arm and 20.1 in the endarterectomy arm. Excluding Mis, the adverse event rates were 5.5% in the stenting arm and 8.4% in the endarterectomy arm. Also the asymptomatic patients treated with CAS had a 30-day stroke and death rate of 5.8%. Most clinicians would regard these complications as excessive and exceed the AHA recommendation for procedural complications in an asymptomaticpopulation of <3%. The trial compares two strategies for the prevention of stroke. However, 30-day stroke and death rate were not significantly different (CAS 4.5%, CEA 6.6%) (p = 0.46). Although we may express reservations about the results of this clinical trial sponsored by the industry, approval for the devices by the FDA resulted in a recommendation for Pre-Market approval. This makes devices more readily available and interventionalists will liberize their indication for CAS.

Results of different stents

Current practice suggests consideration for CAS for several indications: high-risk patients with medical comorbidities, carotid restenosis following prior CEA, radiation induced carotid stenosis, and anatomically high stenoses of the carotid artery. But there are also some contraindications for CAS: Access site difficulties like tortuous iliac arteries, a difficult aortic arch, a sharp angled aortic access and lesion site difficulties like carotid aneurysms, fibromuscular dysplasia, kinked or tortuous ICA and heavily calcified vessels. Better an easy CEA than a suboptimal CAS! You have to be experienced to know when using which stent or device for what kind of anatomy and which protecting device for what kind of plaque morphological findings. There are no certain recommendations for this decision, but there is no rule "one type fits most". In contrary, we have to find out which device is the best for the individual patient, and also which patient should better be operated. So for a vulnerable plaque a proximal occlusion should be used, if the plaque has a high-grade stenosis a distal filter is appropriate. In any case and at all times avoid stressing the plaque. For ulcerated or thrombotic plaque formation if an interventional treatment is indicated, use a stent with closed cell structure (I.e. Wallstent), for calcified lesions and angled bifurcations with an open cell (i.e. Precise Rx Carotid).

Significance of plaque morphology with regard to transluminal dilatation and stenting the carotid artery

At the carotid bifurcation morphology of the artery can be very distinct. On the one hand there are smooth-walled, high-grade/severe stenoses with low risk of embolization, which can possibly occlude without neurological events. On the other hand low-grade, but ulcerous stenoses with atheromatous material are certainly correlated with high risk of embolism and can lead to massive strokes [1; 29; 30; 31]. Unfortunately, both duplex ultrasonography and radiographic imaging techniques fail to differentiate among the types of plaque morphology preoperatively. Clinical trials with prospective assessment of plaque morphology according to duplex-criteria in comparison with pathological-anatomical results demonstrated that those plaques with the highest embolic risk consisting of thrombotic depositions, atheromatous material, coral-reef like growth and freely-floating segments of intima are seldom defined preoperatively. In other cases a correspondence between preoperative finding and histopathological result was detected [10; 11; 30; 31] only at 66%. Classifying plaque morphology even postmortally with appropriate angiographic techniques is impossible. First of all, thrombotic depositions, atheromatous material and fractured calcified plaques can be hardly determined by duplex ultrasonography because it is localized in the non-echolucent part of the carotid artery. The dangerous plaque-forms are seen significantly more often at stages III and IV of cerebrovascular insufficiency and are associated with an increased operative risk, though the surgical intervention is often performed too late. A pathologist described the finding of a preparation-cylinder after endar-

terectomy as follows: "With such complex and variable morphology I feel dizzy at the thought that angioplasty and stenting in that area are being discussed seriously as a routine procedure. The morphology of arteries in the cervical section differs clearly from findings in other regions." The "Gray scale median" as described in the ICAROS-trial may be a measurement to determine plaque formations with a higher risk for neurological disorders. Below a GSM of 25 the risk for neurological disorders because of complications is 37% higher, also in restenoses.

In summary: prospective assessment of plaque morphology in the carotid region fails in most cases, particularly when mixed plaques with high embolic risk exist. In addition the potential of triggering massive embolization during carotid stenting [2; 5; 19] and to a much smaller extent during carotid endarterectomy [16; 17; 19; 27; 28; 35; 41; 46; 47] is proven. By performing transcranial doppler monitoring high intensity transient signals can be identified as embolic material. Based on our own case material pathomorphological findings, HITS were detected more frequently with atheromatous, ulcerous and thrombotic forms than smooth-walled calcified forms of arteriosclerosis. This difference is significant. During carotid endarterectomy the number of microemboli was between 5 and 25 compared to carotid stenting, where a mean number of HITS up to 180 per procedure irrespectively of plaque morphology was observed. In some cases during stent application HITS were detected even on the contralateral side.

Protection against embolism plays an important role in the development of catheter systems. In the USA carotid stenting without protective devices is prohibited. In Europe there are no clear recommendations to this special point, but in general in most publications the reduction of embolic events is related to the use of adequate protection devices. Carotid stenting can lead to protrusion of atheromatous material into the lumen, local thrombosis, stent-fractures, neointimal hyperplasia, recurrent plaques and stent-thrombosis, all of which are known to occur in other areas of the vascular system. A study on the occasion of operative therapy of carotid stenoses was conducted at our clinic. Carotid stents were implanted under these circumstances and the findings were inspected after the procedure. Angioscopic as well as pathohistologic examinations were applied to differentiate the findings. In case of smooth-walled stenosis it was possible to implant a stent without protrusion of the artery wall into the lumen. When placing stents into ulcerous, atheromatous or thrombotic stenoses, particles were literally cut off by the mesh of the stent, flushed into the lumen and subsequently into cerebral circulation after restoring blood flow. Despite using a protection device against embolization, atheromatous material will stay in place in the stent-mesh. A single case report demonstrates that weeks after carotid stenting the atheromatous regions did not heal. Therefore, one of the essential prerequisites for a surgery, the removal of arteriosclerotic material, is not given when stenting a carotid stenosis. Surgeons often observe neointimal hyperplasia induced by the use of suture material. Systems with non-penetrating clips were therefore developed, which do not traumatize the lumen. When atraumatic suture material can lead to such fatal results, what effect does a stent as a large metallic foreign body in the artery have? Until today studies about long-term effects have not been conducted, but pathohostological findings showed a high restenosis rate. Although based on vessel morphology, there are doubts about primary stent implantation. The indication of stenting recurrent stenoses is being repeatedly discussed. In principle it can be stated that, for restenosis as in primary stenosis, by means of duplex ultrasound and angiography, the various types of vessel morphology are difficult to determine.

Of course, if restenosis with smooth-walled neointimal hyperplasia is detected, angioplasty and implantation of carotid stent may be considered. Still a significant diagnostic uncertainty remains. In our findings including 25 carotid stent implantations the most severe complications consisted of one fatal cerebral embolization and one acute carotid occlusion with hemiparesis, which underwent immediate surgical intervention in order to prevent a major stroke. Furthermore we observed one asymptomatic stent-misplacement and one transient ischemic attack during the procedure. Protagonists [35; 39; 51] of the carotid stenting-method postulate the following prerequisites for the procedure:

1. smooth-walled stenoses
2. recurrent stenoses without atheromatous plaques
3. stenoses without thrombotic, ulcerous or calcified plaques

Even in the opinion of interventionalists stent implantation is not indicated, when dealing with thrombosis, severe ulcerations or calcifications and last but not least elongation of the artery. After all that has been said, we cannot know this for sure, because preoperative diagnosis of such lesions is less than satisfactory and preoperative classification is impossible in a lot of cases. Other forms of vessel-morphology, e.g. aneurysms, traumatic lesions, dissections and acute occlusions almost exceptionally require surgical treatment. So there will always be an imbalance for indication. The objective is to treat as little as possible and as much as necessary, which means lesser burdening for the patient should not automatically be correlated with poor results and an unfavourable prognosis. We know about recurrent stenoses and occasional strokes, but systematic follow-up examination has not been accomplished yet. Sporadic information demonstrates the relative simplicity of explanting a carotid stent days to weeks after the procedure. At a later time the stent can be integrated into the arterial wall as seen in other areas of the organism. Resection of the whole length of the artery with interposition of venous graft or (PTFE) prosthetic becomes necessary. These are individual cases based on verbal information. No paper dealing with this subject has been published yet. At our clinic we had to remove one stent in this manner. The patient was without complaints after implantation of a PTFE-graft. Permanent damage after explantation of a carotid stent has not been observed in our case finding.

In principal, questions concerning the interventional and operative therapy of the carotid stenosis have to be discussed. Is dilatation of the lumen a decisive factor for success of the therapy? Which role does the type of arteriosclerosis play for indication? How do long-term results look like? What information does the comparison between the risk of surgery and of carotid stenting bring? Let us not forget that in the best case of our own results, 75% of the procedures were performed on the wrong patients. That means, only 25% of our patients actually benefit from carotid endarterectomy. Until today the problem is the uncertainty which group the individual patient belongs to [6].

Statements in favour of the carotid stent in the Literature

Certain statements concerning the application of carotid stents should be discussed in more details:

1. The method has fewer complications

The SAPPHIRE-trial showed a non-inferiority for high-risk patients, if MI's are taken into consideration. But this is wrong according to current examination results [34; 42; 43]. Up to now beside the SAPPHIRE-trial patients with higher risk because of her pathomorphology for carotid stenting were excluded from the studies, which are therefore only partially comparable. Even based on publications, results as a rule do not reach those of international carotid trials. The procedure can be performed by puncture, which for itself can be considered as maximum invasive and brings all kinds of complications with it, even though they seldom occur. Colleagues, who are interventionally active, have to be prepared for that.

2. A stent can be applied ambulatory after an operation there

is no long hospitalization required, just a few days or even ambulatory.

3. No general anaesthesia is needed for stent implantation Carotid endarterectomy can also be carried out under local anaesthesia and in this way involves low risk.

4. Costs for stenting are lower than for surgery Of course the costs are much higher when the immense technical requirements especially protecting devices and the expensive equipment are taken into consideration.

5. Carotid stenting has a reduced rate of recurrent stenoses Long-term results of more than 5 years are rarely published. This statement is valid only for the previously practiced sole catheter-dilatation. This method certainly demonstrated an advantage in redo procedures.

Validation by trial and quality management

A prospective randomized trial with strict control and clear defined in- and exclusion-criteria and meeting those criteria is also required for asymptomatic patients and is running now in Germany under the name of "SPACE-2". We have to wait for the results in this first study only for asymptomatic patients and with the possibility of an arm with best medical treatment only. Until this day the gold standard of medical treatment is a surgery. Wild growth and uncontrolled application of stents should be rejected by scientific societies.

The mistakes made by surgeons in the past, which neurologists criticize until today, should not be repeated. Regarding quality management of carotid surgery, the German Society of Vascular Surgery is on the right track [33; 46]. A significantly lower complication rate, based on more than 50,000 documented patients, was reported compared with what was mentioned in international literature. One may criticize that the numbers are based on quality management and not on scientific trial, but the results of carotid angioplasty and stenting will be judged according to these criteria. Carotid angioplasty and stenting momentarily represents a method, the benefit of which has not been proven yet, neither for the patient nor for the health budget. Because a lot of patients will be unnecessarily harmed by its uncontrolled use, the method should be applied in clearly defined cases and under certain control only. The most important conclusion is: An operative or interventional treatment should not be more dangerous than the natural history of the disease.

Conclusion

A high risk of cerebral embolism was verified for patients with ulcerous carotid stenosis. The large amount of HITS during carotid stenting was striking

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Поточні результати та майбутні потреби в стентуванні сонних артерій

Резюме. Ми порівняли оперативне лікування і стентування сонної артерії. Одержали подвійні дані та провели гістопатологічне обстеження з метою встановити, в яких випадках доцільніше застосувати стентування, а в яких необхідно вдаватися до хірургічного втручання. Ми також виявили співвідношення між результатами застосування транскраніального ультразвуку з гістопатологічними даними, а також з клінічною стадією недостатності мозкового кровообігу під час хірургічного втручання і стентування відповідно. Одержані результати були зіставлені з результатами, описаними в літературі.

Ключові слова: стеноз сонної артерії, морфологі бляшки, транскраніальна доплерографія, каротидна ендартеректомія, стентування сонної артерії.

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