ICAS is a viable treatment option in the case of symptomatic intracranial atherosclerotic disease. Due to the high stroke risk under medical treatment, patients with high-grade (>70%) symptomatic intracranial stenosis represent the main target group for alternative endovascular treatment concepts such as ICAS. During follow-up, ISR seems to be a major target group for alternative endovascular treatment concepts. ISR was 31.2%, with 31.0% of the lesions being symptomatic. Especially younger patients with intracranial stenosis of the ICA or the M1 segment of the middle cerebral artery have shown a high risk of developing ISR, which may cause stroke in the first 12 months in ≤5% of the cases. Whether restenosis rates are relevant is still under discussion, but it remains undisputable that follow-up is necessary.

Conventional iaDSA is the current criterion standard follow-up examination after ICAS, and as such, it has been primarily used in studies evaluating ISR rates. Due to its invasive nature, iaDSA carries the risk of neurologic complications, especially in elderly patients with known cardiovascular disease and when fluoroscopic times are ≥10 minutes. Recent studies have shown that, within a high-volume neurointerventional department, the risk for neurologic complications during iaDSA is close to zero. Nevertheless, the accessibility of a high-volume institution is not always guaranteed for patients having their follow-up after ICAS, and even in high-volume centers, it is impossible to ensure that every iaDSA will be performed by an experienced operator. A new noninvasive technique for the depiction of intracranial vessels after ICAS is the ivACT. Buhk et al demonstrated, in a small series, that ivACT, in comparison with MDCTA, is a
feasible follow-up option for the delineation of in-stent pathologies or the exclusion of ISR. While MDCTA has been proved a reliable tool for screening intracranial artery stenosis, in vitro studies have shown that it is insufficient for the assessment of ISR. Trousback et al concluded that it is impossible to visualize the different stenoses subjectively—that is, without using image-analysis software—in a series of in vitro examinations delineating different grades of ISR in 3 and 4 mm stents for intracranial angioplasty. Similar conclusions have been drawn in studies evaluating MDCTA in the assessment of ISR in coronary stents. On the other hand, earlier studies have already presented the potential of ACT in the evaluation of small coronary stents. In their study, Mahnken et al noted that ACT proved to be superior to MDCT for in vitro visualization of coronary artery stents because the improved spatial resolution of ACT enabled better depiction of the stent lumen. This characteristic of ACT also allows the cross-sectional evaluation of normal or abnormal deployment of small intracranial stents, which is impossible with other imaging modalities such as MDCT, DSA, or MR imaging.

Other noninvasive techniques allowing the detection of ISR include transcranial duplex sonography and quantitative MR angiography. However, both of these lack the ability to provide anatomic data of the stent region, and especially duplex sonography is limited due to its dependence on operator experience and the anatomy of the temporal bone window.

The purpose of this study was the evaluation of ivACT in the detection of ISR and the comparison with iaDSA findings in the follow-up of 17 cases after ICAS.

Materials and Methods

Patients

Fourteen patients were treated with ICAS of a symptomatic intracranial artery stenosis from July 2006 to May 2009 (10 men, 4 women; mean age, 60 years; range, 45–75 years). One patient received 2 intracranial stents (petros ICA and M1), and in another patient, 3 follow-up examinations were performed in the time period mentioned above: the first, 3 months after ICAS; the second and third, 7 and 4 months after the first and second PTA of a recurrent high-grade ISR, respectively. Locations of stenoses, presenting symptoms, and applied stent systems are shown in On-line Table 1. All patients were admitted for standard follow-up within an average of 7 months (range, 3–12 months) after ICAS.

Approval of the local ethics committee and informed patient consent were obtained.

Image Acquisition

IvACT acquisitions and iaDSA examinations were performed on a biplane angiography system equipped with flat panel detectors (Axiom Artis dBA, Siemens, Erlangen, Germany). DSA data included only standard angiography series. For the acquisition of ivACT, we used the DynaCT program of our suite (Siemens) with the following parameters: 20 seconds of rotation; 538 projections; 220° total angle; CTDIv, approximately 35 mGy (manufacturer information); and a 30 × 40 cm detector, which allows the reconstruction of a nontruncated volume of approximately 22 cm (in-plane) and 16 cm (in the z-direction). While planning the DynaCT, we placed the stented segment near the center of the FOV, because a higher image quality is guaranteed near the central plane of the conebeam. However, we avoided placing the stented segment exactly in the center of the conebeam because ring artifacts can negatively affect the image quality.

Postprocessing of the rotational image data to a volume dataset was performed by using dedicated commercial software on a Leonardo medical workstation (InSpace 3D; Siemens). The software includes system-specific algorithms to correct beam-hardening, scattered radiation, truncated projections, and ring artifacts. Reconstruction resulted in a volume dataset of approximately 400 sections with a 512 × 512 matrix and an isotropic spatial resolution of approximately 0.1 × 0.1 × 0.1 mm³. The ivACT datasets were further processed to multiplanar reformations parallel and perpendicular to the stent region with a section thickness of 0.2–0.3 mm and maximum intensity projections of the other intracranial vessels. Before acquisition, 100 mL of iomeprol (Imeron 400; Bracco ALTANA Pharma, Konstanz, Germany) had been injected into a cubital vein at a flow rate of 5 mL/s by using a power injector. The start delay for rotational acquisition was 14–20 seconds, depending on the age and cardiopulmonary status of the patient. During ivACT, the patient was asked to close his or her eyes and to breath-hold during the 20 seconds of the C-arm rotation.

Image Analysis

Two neuroradiologists (M.-N.P., A.X.) independently performed the image viewing and rating on the above-mentioned Leonardo medical workstation by using the Warfarin-Aspirin Symptomatic Intracranial Disease study technique. As in the study of Albuquerque et al, ISR was defined as >50% stenosis within or adjacent (within 5 mm) to the stent as well as >20% absolute luminal loss at follow-up imaging. Moreover, all restenotic lesions, even those not fulfilling the criteria of ISR, were categorized by using the modified Mehran classification system. This system, originally developed to describe ISR after coronary PTA with stent placement, divides ISR into 4 subgroups: class I, a focal group with lesions involving <50% of the stented segment; class II, a diffuse intrastent group (>50% of the stented segment); class III, a proliferative group with lesions expanding beyond the confines of the stent; and class IV, a complete stent occlusion group.

Statistical Analysis

The mean value of each pair of measurements (rater 1, rater 2) was then calculated and used for further statistical analysis. The correlation between ISR percentage measures on ivACT and iaDSA examinations was assessed by the Pearson correlation coefficient r. Additionally, a simple linear regression of ivACT versus iaDSA was performed. Considering iaDSA as the criterion standard for the detection of ISR, we calculated empiric sensitivity and specificity, as well as the positive and negative predictive values for ivACT as a detection method. Statistical significance was assumed for P values < .05. All analyses were conducted with the free software R (version 2.8, http://www.r-project.org).

Results

Follow-up imaging with iaDSA and ivACT was obtained for 17 stenotic lesions. Measurements and descriptive results can be seen in On-line Table 2. Nine lesions had been treated with a self-expanding intracranial nitinol stent (Wingspan; Boston Scientific, Natick, Massachusetts), 4 with a relatively new balloon-mounted stent designed for intracranial use (Pharos; Micrus Endovascular, Renens, Switzerland), and another 4 le-
The cases presented in Fig 1 illustrate 2 examples in which ISR was excluded. In case 2, a Wingspan stent (2.5 mm) had been placed in a symptomatic stenosis of the right internal carotid artery (ICA) and had been successfully eliminated by a second PTA. The patient was admitted for standard follow-up imaging 7 months after ICAS of a symptomatic BA stenosis, the patient was admitted for standard follow-up imaging. Seven months after ICAS of a symptomatic BA stenosis, the patient was admitted for standard follow-up imaging.
2.5-mm Wingspan stent self-expanded to a diameter of 1.8 mm, as well as the streak artifacts near the confines of the stent (Fig 2).

Regarding the radiation dose, the use of a 20-second ACT protocol results in a CTDI value ~ 3.5 mGy, which is comparable with or even lower than the usual MDCTA or conven-
tional cranial CT protocols (~60 mGy).29,30 The dose could be further reduced with the application of a 5-second (CTDI<sub>w</sub> ~ 9 mGy) or an 8-second ACT protocol. However, longer rotating time is currently necessary to achieve sufficient contrast resolution for the depiction of ISR. Kyriakou et al.31 report in their publication that “the sampling artifacts, originating from the small number of projections in high speed (5 seconds), are quite distinct, and in high-speed protocols low tissue resolution is nearly nonexistent.” In contrast to other studies that have used a high-dose 20-second ACT protocol with a CTDI<sub>w</sub> ~ 75 mGy, we used the low-dose protocol solely in our study.23,31

The amount of contrast media used for ivACT in our study is higher than the amount being used in a conventional MDCTA (~60 mL in our department). The reason for this difference is the necessity of a longer acquisition time with the ACT protocol. To achieve an adequate contrast throughout the whole rotation, one must inject large amounts of contrast media continuously. We are currently using a modified protocol with 90 mL of contrast medium followed by 30 mL of saline flush, but a definite solution to the contrast dosage issue will be the deployment, in the future, of a shorter rotation protocol, with contrast and spatial resolution comparable with the currently used 20-second ACT.

The limitations of this study include its small sample size, the absence of bolus-tracking for ivACT, and the metal arti-
IvACT is a promising new noninvasive follow-up tool after ICAS. Although the first results are very promising, the absence of a bolus-tracking method after intravenous contrast medium administration could sometimes result in an insufficient depiction of intracranial vessels. This would mean repeated examinations and increased overall radiation and contrast dosage for the patient. We are currently working with the manufacturer on this issue, and we think that a viable method of bolus-tracking will be available in the months to come. Regarding the streak artifacts at the confines of the Wingspan stent, one should consider that an ISR that includes the confines of a stent is an infrequent one (modified Mehran IA). Moreover, with the development of new metal artifacts-reduction algorithms for ACT, even the marker region of the Wingspan stent may be visible without any streak artifacts in the near future.

Conclusions

IvACT is a promising new noninvasive follow-up tool after ICAS. In our sample, we could detect ISR on ivACT images with a high sensitivity and specificity. Further research is required to conclude that ivACT could replace iaDSA as a standard follow-up examination after ICAS.

Fig 4. Scatterplot of ivACT (%) versus iaDSA (%) plus an estimated regression line. facts around the markers of the Wingspan stent. Larger studies have to be conducted to verify the value of ivACT in the follow-up imaging after ICAS. Although the first results are very promising, the absence of a bolus-tracking method after intravenous contrast medium administration could sometimes result in an insufficient depiction of intracranial vessels. This would mean repeated examinations and increased overall radiation and contrast dosage for the patient. We are currently working with the manufacturer on this issue, and we think that a viable method of bolus-tracking will be available in the months to come. Regarding the streak artifacts at the confines of the Wingspan stent, one should consider that an ISR that includes the confines of a stent is an infrequent one (modified Mehran IA).

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