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Evaluation of the carotid and vertebral arteries: comparison of 3D SCTA and IA-DSA-work in progress

M. D. Seemann[1], K.-H. Englmeier[3], D. R. G. Schuhmann[3], C. Minx[1], H. Fürst[2], A. Heuck[1], M. F. Reiser[1]

[1] Department of Diagnostic Radiology, Klinikum Grosshadern, University of Munich, Marchioninistr. 15, D-81377 München, Germany
[2] Department of Surgery, Klinikum Grosshadern, University of Munich, Germany
[3] Department of Medical Informatics and Health System Research, GSF – National Research Center for Environment and Health, Neuherberg, Germany

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Abstract. *Objective:* The purpose of this study was to develop a method for three-dimensional (3D) visualization of the whole vascular system of the carotid and vertebral arteries using spiral computed tomographic angiography (SCTA), that allows accurate, qualitative and quantitative evaluation, of anatomical abnormalities, including detection of additional lesions, and estimation of degree of stenosis. *Materials and methods:* Fifteen patients with anatomical and pathological abnormalities of the arterial vascular system detected by color-coded duplex ultrasound were studied using intraarterial digital subtraction angiography (IA-DSA) with aortic arch injection, and SCTA. The carotid and vertebral arteries were segmented using an interactive threshold interval density volume-growing method and visualized with a color-coded shaded-surface display (SSD) rendering method. The adjacent bone structures were visualized using a transparent volume rendering method. *Results:* In all cases, the entire volume of the vascular system of the carotid and vertebral arteries could be visualized on SCTA, and the anatomical and pathological abnormalities on 3D SCTA correlated well with that seen on IA-DSA. *Conclusion:* Results of 3D SCTA had a high degree of correlation with results of IA-DSA in the evaluation of the vascular system of the carotid and vertebral arteries. The 3D SCTA with a subsecond spiral CT scanner is useful for the visualization of anatomical and pathological abnormalities in the circulation in the carotid and vertebral arteries and offer a promising minimally invasive alternative compared with other diagnostic procedures.

Key words: Computed tomography (CT), spiral technology – Carotid arteries, CT – Vertebral arteries, CT – Computed tomography (CT), image processing – Computed tomography (CT), threedimensional visualization – Computed tomography (CT), comparative studies

Correspondence to: M. D. Seemann

Introduction

Over the last 40 years, carotid endarterectomy has been shown to be beneficial to patients with symptomatic carotid teritory ischemia and more than 70 % stenosis of the internal carotid artery. The North American Symptomatic Carotid Endarterectomy Trial (NASCET) reported an absolute reduction of 17 % in the risk of ipsilateral stroke at two years in patients who were treated surgically compared with conservatively treated patients [1]. In order to identify patients who would benefit from endarterectomy, Masaryk et al. [2] suggested that the goals of carotid imaging must be to accurately quantify the degree of stenosis, to differentiate between high-grade stenosis and occlusion, and to detect any associated abnormalities such as tandem lesions that may affect the surgical procedure. In addition, in accomplishing these three goals, the imaging method should expose the patient to a minimal risk and the health care system to minimal costs.

Four imaging methods have been extensively evaluated in assessing carotid disease: (1) angiography (intravenous digital subtraction angiography and intraarterial digital subtraction angiography, performed as aortic arch injection angiography and selective carotid angiography); (2) ultrasound (US) of arteries (conventional doppler sonography (CDS) and color-coded duplex sonography (CCDS)); (3) magnetic resonance angiography (MRA); and (4) spiral computed tomographic angiography (SCTA). In recent years the noninvasive imaging methods of US, MRA and SCTA have been extensively evaluated and continuously developed in order to improve quality and reduce risks and costs in assessing carotid disease. Up to now none of these imaging methods have been able to supersede selective carotid arteriography, which is still regarded as the gold standard.

An important aspect of imaging that has revolutionized patient management is three-dimensional (3D) reconstruction of spatial image sequences. Therefore, in recent years great efforts have been made to increase the technical developments of independent workstations that allow rapid manipulation of imaging data sets and to improve postprocessing image quality of 3D visualization methods.

This study was performed in order to evaluate whether new technical developments in spiral computed tomography (SCT) and an automatic image analysis, synthesis and visualization system can improve the diagnostic performance of 3D visualization of spiral computed tomographic angiography (SCTA) in the assessment of anatomical and pathological abnormalities in the circulation in the carotid and vertebral arteries.

Materials and methods

Patients

The study was conducted in accordance with the ethical standards set forth in the Declaration of Helsinki (1989). Informed consent was obtained from all patients. Fifteen consecutive patients (8 women and 7 men) who ranged in age from 30 to 72 years (mean, 61 years) with anatomical and patholocial abnormalities in the circulation in the carotid and vertebral arteries detected by color-coded duplex sonography were examined by 3D SCTA and IA-DSA. All patients had suffered a cerebral transient ischemic attack with distinct focal neurologic dysfunction persisting less than 24 hours or a nondisabling stroke with persistence of symptoms for more than 24 hours within the previous 120 days. Exclusion criteria were a history of allergic reaction to contrast material and renal disease. In all cases, SCTA of the carotid and vertebral arteries was performed one day after IA-DSA.

Intraarterial Digital Subtraction Angiography (IA-DSA)

All examinations were performed with a Polytron 1000 (Siemens, Erlangen, Germany) as aortic arch injection angiography via the femoral approach and included three projections (posterior-anterior, 40° right and left oblique view). For each projection a contrast bolus of 30 ml nonionic contrast material iopromide 300 (Ultravist; Schering Pharmaceuticals, Berlin, Germany) was injected at a rate of 18 ml/sec automatically by a power injector (MCT Plus; Medrad, Pittsburgh, Pa) through a 5-F pigtail catheter.

Spiral Computed Tomographic Angiography (SCTA)

All examinations were performed with a subsecond spiral CT scanner (Somatom Plus 4A; Siemens, Erlangen, Germany). An anteroposterior scoutview was obtained and used for determining the acquisition volume extending from the level of the aortic arch to the level of the circle of Willis. Data acquisition was performed during a single breathhold in deep inspiration in a caudocranial direction. Patients were instructed not to move or to swallow during the data acquisition. SCTA scan parameters included a scan time of 0.75 second per 360° rotation, a slice collimation of 3 mm, a table feed of 6 mm, a reconstruction increment of 2 mm, a tube current of 233 mA, a tube voltage of 120 KV, a 14-cm field of view and a 512^2 matrix. Nonionic contrast material iopromide 300 (Ultravist; Schering Pharmaceuticals, Berlin, Germany) was injected automatically by a power injector (MCT Plus; Medrad, Pittsburgh, Pa) through a standard catheter placed into an antecubital fossa vein. A volume of 120 ml was injected at a rate of 3.5 ml/sec with a scan delay of 16 seconds. Data acquisition was completed after approximately 30 seconds and approximately 5 minutes were required to reconstruct the sections.

Three-Dimensional (3D) Reconstruction

The axial SCTA imaging data sets were transferred to an independent high performance graphic computer with two infinite reality engines (ONYX; Silicion Graphics, Mountain View, CA). An in-house developed software program was used. Resolution was a 512^2 matrix. The reconstructions were performed by one operator without knowledge of the results of the angiographic assessment.

The carotid and vertebral arteries were segmented using an interactive threshold interval density volume-growing method. In order to perform the volume-growing segmentation process, a segmentation range and minimum and maximum density levels had to be defined for a selected region. An objective method for the determination of the minimum Hounsfield unit for arterial vessel segmentation range was used in order to minimize operator dependence. The axial SCT images were viewed and the density of the vessel lumen (D_L) was measured by placing a region of interest in the central portion of the vascular lumen. Then the density of soft-tissue (D_{ST}) was determined by measuring the density of the ipsilateral sternocleidomastoid muscle. The minimum segmentation level (D_{MIN}) was then defined and set by increasing the density value from D_{ST} until the soft-tissue pixels were excluded from the segmentation range. The density of bone (D_{BT}) was determined by measuring the density of the cortex of the vertebral bodies. The maximum segmentation level (D_{MAX}) was then defined and set by decreasing from D_{BT} until the pixels of the bone-tissue and the central portion of any calcified plaque were excluded from the segmentation range.

After definition of a segmentation range, the carotid arteries and the vertebral arteries were segmented automatically using a volume-growing process with a seed placed in the lumen of the vessel. All contiguous pixels with a density in the segmentation range were included in the defined lumen. Employing a specific segmentation range is adequate for a longitudinal extension of several centimeters. As the arteries extend further in caudal and cranial direction, the segmentation range has to be redefined because the concentration of the contrast material within the vessels may change and beam hardening from the shoulders and base of the skull may affect density values.

In addition, manual image controlling and post-processing mechanisms may be used. If any unexpected findings were observed in the 3D image, the axial SCT images were reviewed to ensure that no mistake, such as inappropriate placement of the seed, has occured. After image editing and regardless of the segmentation range used, images of the vessels of interest from each axial scan can be magnified and manually modified if required. Here, the vessel surface can be separately outlined and the cross-sectional area can be filled seed by seed. Bone structures which fall within the segmentation range may be manually removed from the segmented lumen by drawing a boundary line.

After complete segmentation of the carotid and vertebral arteries they were coded with a color. A surface model is constructed using geometric primitires and the anatomical structures are displayed using a SSD rendering method.

The adjacent bone structures were visualized using a transparent volume rendering method and then coded with a separate color. The degree of transparency can be varied. All reconstructed anatomical structures can be combined in one figure. The entire 3D reconstruction process requires 30 minutes.

Image Analysis

The 3D SCTA and IA-DSA were interpreted by two separate observers who were blinded to the results of the other imaging study. The arteries were evaluated qualitatively for the presence of stenoses, tandem stenoses, occlusions, dissections, aneurysms or other anatomical abnormalities, and quantitatively for the degree of stenosis with both imaging techniques. The SCTA examinations were interpreted on a high performance graphic computer using

Table 1. Anatomical variations and pathological conditions of the vascular system of the carotid arteries. Comparison of 3D SCTA and IA-DSA: Consensus Readings (No. of cases)

IA-DSA	3D SCTA								
	Normal	Coiling	Stenosis Category			Tandem stenosis	Occlusion	Dissection	Aneurysm
			Mild	Moderate	Severe				
Normal			1						1
Coiling		1							
Stenosis Category									
Mild			1						
Moderate				3					
Severe					4				
Tandem stenosis						1			
Occlusion							5		
Dissection								2	
Aneurysm									1

Table 2. Anatomical variations and pathological conditions of the vascular system of the vertebral arteries. Comparison of 3D SCTA and IA-DSA: Consensus Readings (No. of cases)

IA-DSA	3D SCTA			
	Dominant Artery		Occlusion	Dissection
	Left	Right		
Dominant Artery				
Left	8			
Right		3		
Occlusion	1			
Dissection				1

Note: In three patients neither the vertebral artery on the left nor the right side was dominant

the color-coded 3D SSD images. The IA-DSA examinations were interpreted using hard copies of all relevant images from the whole DSA series. The severity of stenoses was determined by calculating the ratio of the narrowest diameter of the stenotic segment to the diameter of the disease-free artery distal to the stenosis (NASCET method) [3]. The stenoses were graded according to the following classification scheme: low-grade (mild) = 0 to 29 percent, medium-grade (moderate) = 30 to 69 percent, high-grade (severe) = 70 to 99 percent, and occlusion = 100 percent of diameter reduction [1]. Finally, the results of 3D SCTA were compared with the results of IA-DSA, which formed the standard of reference.

Results

The SCTA axial scans provided a high quality image of the vessel wall and a simultaneous depiction of surrounding soft-tissue structures. Due to the short scanning times artifacts resulting from swallowing and movemend did not occur in the neck area. Beam hardening from the bone structures of the shoulders and the base of the skull did not affect the image quality of the vessels in the respective regions. The choice of the threshold interval density facilitated a differentiation of the vessel lumen of the carotid and vertebral arteries and bony structures at the base of the skull and calcifications in the wall of vessel. Nevertheless, in SCTA we found some possible limitations. Streak artifacts from dental hardware represent a serious problem, because they lead to an unpreventable loss of data on the axial scans. Especially near the heart of the arterial vessels we found irregularities of the vessel lumen in the 3D reconstructions, that resulted from artifacts due to heart and arterial pulsations which simulated low-grade stenoses. However, in contrast to stenoses they occurred at regular distances along the vessels.

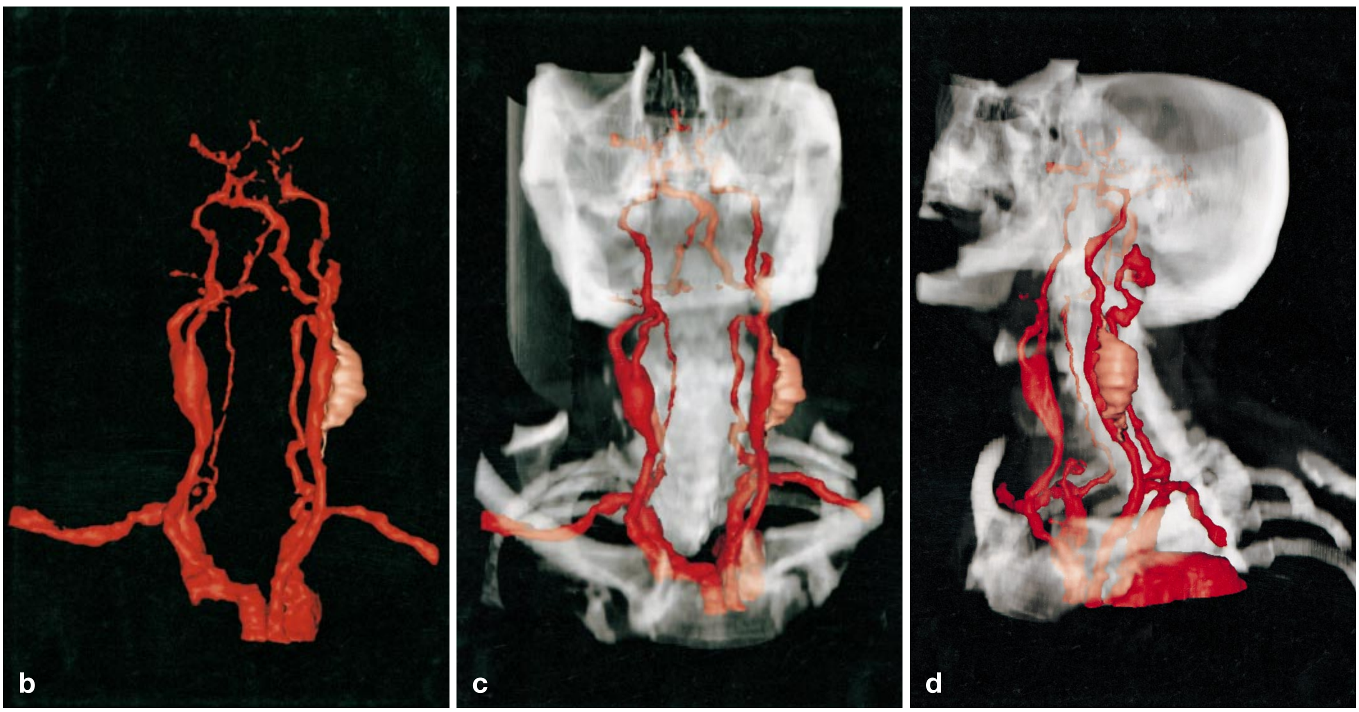
A total of 15 patients were studied with 3D SCTA and IA-DSA, and a wide range of arterial diseases were encountered. In all cases, the entire volume of the vascular system of the carotid and vertebral arteries from the level of the aortic arch to the level of the circle of Willis could be scanned with sufficiently thin slices to allow the reconstruction of images in arbitrarily fine increments from the volume data set. The entire volume of the common carotid arteries (CCA), the internal carotid arteries (ICA) and the vertebral arteries (VA) could always be assessed. The external carotid arteries (ECA) could be adequately assessed as far as the base of the skull. Findings on 3D SCTA had a high degree of correlation with those on IA-DSA. In 3D SCTA in the vascular system of the carotid arteries the following anatomical variations including coiling of the internal carotid artery (ICA) ($n = 1$) and pathological conditions such as stenosis of the common carotid artery (CCA) ($n = 1$) (medium-grade ($n = 1$)), stenoses of the ICA ($n = 6$) (low-grade ($n = 1$), medium-grade ($n = 2$) and high-grade ($n = 3$)), stenoses of the external carotid artery (ECA) ($n = 2$) (low-grade ($n = 1$) and high-grade ($n = 1$)), occlusion of the CCA ($n = 1$), occlusions of the ICA ($n = 3$), occlusion of the ECA ($n = 1$), dissections of the ICA ($n = 2$), aneurysms of the CCA ($n = 2$) and tandem stenosis of the carotid arteries ($n = 1$) were detected. The diagnosis of all observers in consensus obtained from 3D SCTA evaluation agreed in all but two cases with the diagnosis obtained from IA-DSA. In one case, a low-grade stenosis of the ECA was described without pathological finding in IA-DSA but was detected in 3D SCTA. In one case, a thrombosed aneurysm of the CCA was described only as a irregularity of the vessel wall in IA-DSA but was detected in 3D SCTA. In all other cases, there was no additional information to be gained from IA-DSA or a loss of information using 3D SCTA (Table 1). In 3D SCTA in the vascular system of the vertebral arteries were detected a dissection of the vertebral artery ($n = 1$), in nine patients a dominant left vertebral artery (LVA), in three patients a dominant right vertebral artery (RVA) and in three patients neither side was dominant. The diagnosis of all observers in consensus obtained from 3D SCTA evaluation agreed in all but one case with the diagnosis obtained from IA-DSA. In one case, a RVA was described as occluded in IA-DSA but was detected as a thin non-dominant artery in 3D SCTA. In all other cases, there was no additional information to be gained from IA-DSA or a loss of information using 3D SCTA (Table 2).

Using the segmentation process described above, the carotid and vertebral arteries could also be visualized at the base of the skull despite adjacent bony structures. The computer supported automatic image analysis, synthesis and visualization system resulted in a superior diagnostic performance of SCTA (Fig. 1).

Discussion

An imaging method for the carotid and vertebral arteries should be judged on its ability to enable pathological conditions to be accurately assessed, for example, the degree of stenosis and the differentiation of high-grade stenosis from occlusion and its ability to allow detection of associated anatomical abnormalities such as tandem

Fig. 1 a–d. A 70-year-old patient after thrombendarterectomy, on both sides of the carotid arteries ten years ago. **a** Anteroposterior view, IA-DSA, aortic arch angiography, early arterial phase, shows dilatation of the right common carotid artery, an irregularity of the vessel wall of the left common carotid artery and only a left vertebral artery. **b** Anteroposterior view, color-coded 3D SSD reconstruction of the arterial vascular system *(red)* shows dilatation of the right common carotid artery, a thrombosed aneurysm of the left common carotid artery *(bright red),* a left dominant vertebral artery and a thin right vertebral artery. **c** Anteroposterior view, color-coded 3D SSD reconstruction of the arterial vascular system *(red)* and transparent volume rendering of the adjacent bone structures *(white).* **d** Left side lateral view



lesions that may affect the surgical procedure [2]. The purpose of this study was to ascertain whether or not 3D SCTA could be used to accomplish these diagnostic objectives. This study differs from previous studies as the carotid and vertebral arteries were visualized in their entire volume from the level of the aortic arch to the level of the circle of Willis and different vascular abnormalities and pathological conditions were examined. The results of this study suggest that 3D SCTA is able to provide all the relevant information required for the planning of surgery and can potentially detect additional lesions such as tandem stenosis. In this trial, the time interval between SCTA and IA-DSA was short, both studies were performed within 24 hours.

Intraarterial digital subtraction angiography (IA-DSA) is a relatively invasive procedure bearing the risk of severe and potentially life-threatening neurological complications in addition to adverse drug reactions (ADRs) to contrast material and damage to the arteries, e. g. at the puncture site [4, 5]. To evaluate the local, systemic and neurological complications following IA-DSA with selective catheterisation of the carotid arteries, Davies et al. [4] studied 200 patients who were referred for the assessment of cerebral ischemia. They reported transient neurological complications (resolved within 24 hours) in 5 %, reversible (resolved within seven days) in 1 % and permanent in 4 % of cases. Two patients died after a stroke and two other patients suffered a disabling stroke. The incidence of total neurological complications and post angiographic strokes was higher in patients with greater than 90 % stenosis of the symptomatic internal carotid artery [4]. Every IA-DSA projection requires a bolus injection of contrast medium, thus limiting the number of projections possible. Therefore complex vascular structures or pathological alterations can sometimes be visualized only insufficiently [6]. Even angiography does not yield 100 % accuracy in the differentiation of high-grade stenosis from occlusion and may lead to false-positive diagnoses of occlusion by failing to depict slow flow in high-grade stenosis [7].

SCTA is a relative new technique and initial results regarding its possible application in the evaluation of vascular diseases of the carotid artery have been reported [8–13]. In 1984, Heinz et al. [8, 9] described the use of thin-section dynamic CT for the direct visualization of carotid atheroma and thrombi and showed 3D reconstructions of the carotid artery. In 1992, Schwartz et al. [10] reported an accuracy of 100 % for the differentiation of high-grade stenoses from occlusion using CTA. In 1994, Cumming and Morrow [12] described the usefulness of SCTA for the detection of very small ulcerations and plaque irregularity. In 1996, Link et al. [13] reported the usefulness of SCTA for the detection of proximal internal carotid stenoses that are greater than 30 % and for the detection of calcified plaques. The literature [8–13] showed a good overall agreement between SCTA and DSA for evaluation of internal carotid artery stenosis. Nevertheless, quantification of stenosis is only one important factor in the diagnosis of cerebrovascular disease [13]. The length of carotid artery imaged was small. The technique used in the literature did not allow an evaluation from the carotid origin to the carotid siphon, the two locations at which tandem stenoses occur most frequently [14]. Therefore, Link et al. [13] suggested that a major disadvantage of SCTA as compared with angiography is the lack of information about tandem lesions caused by the limited coverage. The surgical importance of tandem lesions has been the subject of recent debate. Masaryk et al. [2] argue that detection of these lesions is crucial before performing carotid endarterectomy, since patients with such lesions are at greater risk from intra- and perioperative strokes and significant cardiac complications. Polak [15] argues that such lesions are uncommon and that, in any case, detection of such a lesion would probably not result in postponement of surgery. The surgical relevance of tandem lesions is not yet clearly defined and may require further research.

The technical equipment for SCT facilitates the acquisition of data from large areas of the human body within one breathhold and during a defined period following contrast medium injection. Timing of data acquisition can be adjusted so that either the arterial or venous vessel show maximum contrast after venous contrast bolus injection. The technical developments of slip-ring computed tomography and of independent workstations for 3D reconstruction that allow rapid manipulation of data have increased the interest in the use of contrast material-enhanced SCT for vascular imaging [10, 16, 17]. Advances in SCT can be expected as the capabilities of commercially available scanners and workstations are expanded. In particular, development of x-ray tubes with higher heat capacity and x-ray detectors with improved sensitivity may allow longer data acquisitions, which would enable for coverage of the same area with thinner sections, thus producing a better quality of the 3D anatomy of the vessels with fewer partial volume effects. The subsecond spiral CT scanner and the scanning parameters used in this study allowed a continuous scanning of a length of 468 mm over a period of 60 seconds. Subtraction techniques may allow SCT angiograms without the need for segmentation on each individual SCT image by enabling subtraction of calcified plaques adjacent to the vessel lumen [18, 19].

The advantages of SCTA are the short examination times, its independence of operator experience, it is not sensitive to flow artifacts, has relatively low costs, and its low effective dose rates are typically in the order of 2–10 mSv. The CT examination of vessels, with spiral data acquisition, is a robust, simple, reliable, powerful and promising diagnostic imaging technique with a low failure rate and low invasiveness and with simultaneous registration and visualization of vessels (including morphology of the plaques). It also offers simultaneous depiction of surrounding soft-tissue structures. With a tailored examination technique, pathological changes in vessels as small as 2 mm can be visualized [6]. In some cases with complex vascular anatomy, SCTA has proved to be superior to intraarterial angiography [6]. The basis of this approach, filling a vascular lumen with contrast material, is similar to conventional angiography and provides anatomic detail that is not available with conventional angiography, MR angiography or sonography. The degree of stenosis can be underestimated with conventional angiography because of the limited number of imaging planes and the inability to differentiate contrast material from densely calcified atherosclerotic plaques [12]. On the CT angiograms, contrast material can be differentiated from calcified plaques, and the lumen of the artery can be viewed in multiples planes, allowing better determination of the site of maximal stenosis [12]. The ability to allow detection of slight differences in contrast is one of the major advantages of SCTA. CT angiography with 3D and multiplanar reconstructions can show plaque morphology better and can show calcified stenotic lesions not visible on conventional angiograms [12]. Both, multiplanar reconstruction (MPR) or maximum intensity projection (MIP) would provide a more rapid view of the vascular structures, but both have disadvantages and therefore were not used by us. Sagittal, coronal, or curved plane MPR allows visualization of the volume of the carotid artery in many cases but Dillon et al. [11] indicated that MPR might lead to confusion in the interpretation of tortuous arteries or to identification of the external carotid artery as the internal carotid artery. It is suggested that MIP volume rendering, offers some improvement over shaded-surface display (SSD) rendering when one is dealing with calcified plaques [12]. However, errors in interpretation will occur in cases with dense or large circumferential plaques, and problems with overlying vascular structures (especially the internal jugular vein) remain. MIPs are less dependent on the skills of the operator, but such projections do result in some difficulty in "seeing through" calcified plaques [17]. Dillon et al. [11] suggested that segmentation and connectivity algorithms can be helpful in removing unwanted structures (bones, veins, and calcified plaque) but these procedures currently add significantly to the processing time, require further "massaging" of the image data, and do not show plaque morphology. In this study, the carotid and vertebral arteries were segmented using an interactive threshold interval density volume-growing method and visualized with a color-coded SSD rendering method. In our opinion, this is a real intraluminal visualization similar to IA-DSA. Nevertheless, the most reproducible and accurate technique for the visualization of SCTA data remains to be established.

As a new technique, SCTA must be compared with the other currently available methods, such as ultrasound (US), conventional Doppler sonography (CDS) and above all color-coded duplex sonography (CCDS). The introduction of CCDS facilitated for the first time the simultaneous depiction of the soft-tissue structures and the morphology of the vessels and the noninvasive assessment of the blood flow velocity and the direction of blood flow in real-time. US uses no contrast material and is widely used as a screening method. The sensitivity of US in detecting high-grade stenoses is as high as 90 % [20, 21]. Many surgeons prefer confirmation of the US diagnosis before performing endarterectomy, since the surgical procedure itself is associated with a total perioperative complication rate of 5.8 %–7.6 % [1]. The echogenic signals of the blood can be improved by the injection of a contrast medium and low volume flow rates and flows in poststenotic high-grade areas can be clearly better shown and therefore the risk of false diagnosis of a vessel occlusion will be reduced. Presumably the most relevant disadvantages of US are the great dependence on the experience of the operator and the quality of the ultrasound unit for accurate and reliable results. In addition, it fails to provide an adequate overview of the carotid circulation, which would allow detection and evaluation of the more distal abnormalities such as tandem stenotic lesions or distal loops or coils of the internal carotid artery, that may affect the surgical procedure [14]. The ultrasound diagnostics are not appropriate postoperatively after carotid endarterectomy because of the extensive soft-tissue swelling at the operation site and the necessary aseptic requirements in the wound area.

MRA provides an overview of the carotid circulation, but its accuracy in diagnosing stenoses of the bifurcation may be hampered by signal loss in areas of turbulent flow [22–26]. However, studies by Heiserman et al. [27] and Huston et al. [28] using state-of-the-art 2D time-of-flight MR projection angiography have reported improvements over previous studies in the accuracy of MRA. Recent reports indicate a sensitivity of over 90 % in detecting high-grade stenoses [27, 28]. However, the persistent tendency to overestimate stenoses with MRA results in positive predictive values for high-grade stenoses as low as 39 % [28]. Owing to the overestimation of stenosis that may occur with MRA, the predictive value of a positive MRA (ie, surgical disease in present) can be much less than that of a positive SCTA. The negative predictive value (ie, surgical disease is not present) is very high for both methods. As compared to MRA, SCTA is a robust method with a low failure rate. The failure rate is related to the period of time required for data acquisition during which the patient must not move: a maximum of 30 seconds for SCTA versus 10–15 minutes for time-of-flight and phase contrast MRA. One advantage of spiral CT angiography may be its good differentiation between moderate and severe stenoses, which is a problem with MR angiography along with attendant flow artifacts [13]. In addition, SCTA can be performed on patients with cardiac pacemakers and on claustrophobic patients. First experience with MRA using 3D gradient-echo sequences with ultrashort echo and repetition times seems to be a promising new technique, because of relatively independence of complex flow effects and short examination times of 30–50 seconds [29]. Both US and MRA, on the other hand, have been reported to yield false-positive and false-negative results in differentiating high-grade carotid stenoses from occlusions, a differentiation that is crucial to surgical planning [20–22, 30].

SCTA, on the other hand, has also various limitations. In the neck area, artifacts may result from swallowing, movements and tooth filling material. In our study, artifacts from swallowing and movement did not occur, probably due to the short scanning times employed. Artifacts from tooth filling material represent a serious problem, because they lead to an unpreventable loss of data on the CT scans. SCTA has various disadvantages that are inherent to the technique. In contrast to US and time-of-flight and phase contrast MRA, bolus administration of iodinated contrast material is required. The use of contrast material subjects the patients to the risks of nephrotoxicity and allergic reaction. Increased use of nonionic contrast agents will reduce the risk of contrast material reactions and may decrease the occurrence of inadvertent swallowing by the patients as the contrast material is administered. In patients with diminished cardiac output, contrast enhancement within the arteries is diminished and protracted. On the other hand, the total volume and rate of injection of contrast material used in this study were essentially the same as those used for routine CT applications and thus subject the patient to no more risk than any other contrast-enhanced CT study.

Link et al. [13] suggested that the main advantage of cerebral angiography is its ability to display the whole vessel, which at present cannot be achieved with any other imaging technique. In this study we have shown, that 3D SCTA using a subsecond spiral CT scanner is useful for the visualization of anatomical and pathological abnormalities in the entire volume of the vascular system of the carotid and vertebral arteries and offer a promising minimally invasive alternative compared with other diagnostic procedures like ultrasound (US) and magnetic resonance angiography (MRA). The increased use of minimally invasive or noninvasive diagnostic imaging methods, alone or in conjunction, will reduce the absolute number of patients put at risk by intraarterial angiography, yet the rate of post angiographic complications is likely to increase since patients with high-grade stenosis of the symptomatic internal carotid artery are probably most at risk from complications although they have most to gain from carotid endarterectomy. The axial SCT scans are sufficient for the diagnosis of anatomical and pathological abnormalities in the circulation in the carotid and vertebral arteries and surrounding soft-tissue structures. However, the documentation of findings with 3D SSD image reconstructions of the vessels is an important application for SCTA. Obtaining additional information of the 3D anatomy of the vessels results in better assessment of morphology of the complex vessel anatomy and better orientation allowing viewing from any direction. The different diagnostic imaging methods have different advantages and disadvantages which should be considered in order to employ them correctly. 3D SCTA can provide most of the information needed and is a valuable alternative to IA-DSA, especially in high-risk patients. Improvements in image processing and the merging of this technology with other diagnostic procedures will lead to further development of the technology. DSA remains the standard for diagnosis of symptomatic patients with suspected stenosis of the internal carotid artery [13]. The diagnostic value of 3D SCTA will be shown by increasing the number of patients and by careful analysis and evaluating of the cost-effectiveness of the diagnostic procedures, that will in the future become an additional criterion. Using desktop workstations to simulate medical procedures, the information gained by 3D SCTA enables an efficient diagnosis and complements and supports preoperative planning [31].

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Book reviews

European Radiology

Byrne J. V., Guglielmi G.: Endovascular Treatment of Intracranial Aneurysms. Berlin, Heidelberg, New York, Springer, 1998, 248 pages, 98 illustrations in 188 parts, ISBN 3-540-62764-2, DM 178.00

Endovascular treatment of intracranial aneurysms with detachable coils is a new promising technique which has been used now in selected patients for more than 5 years. Thus, there was a need for a book written by experts giving information on the background, indication, technique, problems and future developments of this treatment. Guglielmi and Byrne have tried to meet this need with their well-written 248-page work. The authors point out that the management of patients with aneurysms and subarachnoid hemorrhage involves much more than occluding mechanically an aneurysmal lumen with metallic coils. As a result, the first 100 pages of the book deal with the etiology, symptomatology, natural history, and complications of cerebral aneurysms and subarachnoidal hemorrhage, completed by a summary of the modern imaging procedures. This propedeutic part of the book is well structured and informative, not only for neuro-interventionalists. Even neurologists, neurosurgeons and general radiologists will profit from this. One drawback is the lack of detailed information on the surgical management of aneurysms and especially on the results of the large neurosurgical series, which may be helpful in estimating the current value of the endovascular method. The literature added for each chapter is remarkable; however, references which are not cited and presented on internal workshops (e. g. reference No. 112 on page 102) should not be included.

The fourth of the eight chapters starts with the endovascular treatment of aneurysms, presenting an overview of the historical situation, and descibing the general indications for the use of balloons and coils. Chapter 5 on page 133 then starts with the description and technical management of the endosaccular packing of aneurysms using the electrically detachable coils. Chapter 6 continues with a description of the management of aneurysms at specific sites. Chapter 7 gives an overview of the results of the endovascular method based on the results of the worldwide data collection of interventional centers. The authors point out that long-term results are unknown and that the technique – today an alternative for patients with high surgical risk or inoperable aneurysms – is still at an early stage and needs further development. A future outlook is given in the last chapter. The price of the book is in relation to the contents and the good quality of the illustrations is acceptable. It is written primarily by experts for experts. Nevertheless, I can recommend it to every radiologist, neurologist and neurosurgeon who is in contact with patients suffering from aneurysmal disease.

J. Reul, Bonn

Swischuk L. E.: Imaging of the newborn, infant and young child, 4th edition. Baltimore: Williams and Wilkins, 1997, 1088 pages, £ 162.00, ISBN 0-683-08051-2

This is a book which should find a place in every department of radiology which deals with young children, and in the library of every children's hospital. Most specialist paediatric radiologists will wish to have their own copy. In its fourth edition, Leonard Swischuk's classic textbook is larger than ever, giving a balanced coverage of plain radiography, contrast studies, ultrasound, CT and MRI. Over 1000 pages of text are presented in a lucid and readable format. Although now a large text, it retains its single-volume format, making it a practical working reference or bench book. As a single volume dealing specifically with the radiology of neonates and infants, it fills its particular niche superbly.

The chapters are laid out in a conventional systems approach (respiratory, cardiovascular, alimentary, genitourinary, skeletal and soft tissues, head and brain, spine and spinal cord). Each chapter is divided into short sections, which are separately referenced, making the book easy to use either as a reference source or for more extensive reading. Key points in the text are highlighted in bold print. In each section, the radiological manifestations of different conditions are covered comprehensively, with good clinical correlation and discussion of differential diagnosis. Normal variants and major syndromes are well described and illustrated. Plain radiography, contrast studies and ultrasound are given prominence, but angiography, CT and MRI are all well covered. Nuclear medicine and scintigraphy are included where appropriate, but are generally covered in less detail.

The references are generally comprehensive and up to date, although many references of purely historic interest are also included. The illustrations are of high quality; some are printed in rather small format, but in general the clarity of reproduction is good enough to compensate. In particular, the reproduction of ultrasound images is outstandingly good. The index is accurate, comprehensive and useful.

In conclusion, the fourth edition of *Imaging of the Newborn, Infant and Young Child* remains the definitive textbook of radiology of the early years of childhood, which can be recommended without reservation. It represents good value for money and will be an essential purchase for departments of paediatric radiology.

L. Abernethy, Liverpool