CT Angiography of Intracranial Aneurysms: A Focus on Postprocessing

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Computed tomographic (CT) angiography is a well-known tool for detection of intracranial aneurysms and the planning of therapeutic intervention. Despite a wealth of existing studies and an increase in image quality due to use of multisection CT and increasingly sophisticated postprocessing tools such as direct volume rendering, CT angiography has still not replaced digital subtraction angiography as the standard of reference for detection of intracranial aneurysms. One reason may be that CT angiography is still not a uniformly standardized method, particularly with regard to image postprocessing. Several methods for two- and three-dimensional visualization can be used: multiplanar reformation, maximum intensity projection, shaded surface display, and direct volume rendering. Pitfalls of CT angiography include lack of visibility of small arteries, difficulty differentiating the infundibular dilatation at the origin of an artery from an aneurysm, the kissing vessel artifact, demonstration of venous structures that can simulate aneurysms, inability to identify thrombosis and calcification on three-dimensional images, and beam hardening artifacts produced by aneurysm clips. Finally, an algorithm for the safe and useful application of CT angiography in patients with subarachnoid hemorrhage has been developed, which takes into account the varying quality of equipment and software at different imaging centers.

Abbreviations: DSA = digital subtraction angiography, dVR = direct volume rendering, FOV = field of view, ICA = internal carotid artery, MCA = middle cerebral artery, MIP = maximum intensity projection, MPR = multiplanar reformation, PICA = posterior inferior cerebellar artery, SAH = subarachnoid hemorrhage, SSD = shaded surface display, 3D = three-dimensional, 2D = two-dimensional

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Introduction
Sudden onset of vigorous headache typically is the leading symptom in patients with subarachnoid hemorrhage (SAH) caused by the rupture of an intracranial aneurysm. Computed tomography (CT) is the first step in the examination of these patients. Once SAH is confirmed, it is paramount to detect the source of bleeding in order to initiate therapy. Digital subtraction angiography (DSA) is still the most sensitive tool for the detection of intracranial aneurysms. The selective intraarterial injection of contrast medium ensures optimal enhancement of the intracranial arteries with superior resolution compared with that of CT or magnetic resonance (MR) angiography. However, DSA has the disadvantage of being an invasive method. The risk of acquiring a permanent neurological deficit with cerebral angiography in patients with SAH is below 0.1% (1). Despite this relatively low risk, a noninvasive method yielding three-dimensional (3D) information for the planning of therapeutic intervention is desirable.

The reported sensitivity of CT angiography lies in the range of 80%–97% (2–8) depending on the size and location of an aneurysm (3). In all of these studies, some kind of 3D visualization was used to analyze the CT angiography data. Little is known about the influence of postprocessing methods like maximum intensity projection (MIP), shaded surface display (SSD), and direct volume rendering (dVR) on the detection rate of intracranial aneurysms. However, it can be assumed that the same CT angiography data may lead to varying detection rates when different visualization strategies, computer platforms, and graphics hardware are used (9–12).

In the first section of this article, technical aspects of CT angiography with a focus on data acquisition are discussed. In the second section, different methods for the postprocessing of CT data are presented, including the analysis of source images and the methods currently available for two-dimensional (2D) and 3D postprocessing, such as high-resolution dVR. Then, typical pitfalls encountered while working with CT angiography data are demonstrated. Finally, we propose a reasonable paradigm for the use of CT angiography in patients with SAH, taking into account that this method is still not a standardized procedure.

Technique of Intracranial CT Angiography
CT angiography can be defined as a fast thin-section volumetric spiral (helical) CT examination performed with a time-optimized bolus of contrast medium in order to enhance the cerebral arteries (13). In order to visualize the intracranial arteries, the examination includes the region from the first vertebral body up to the vertex. It is important to include the atlas in the study to ensure incorporation of the posterior inferior cerebellar artery (PICA), which has an extracranial origin from the vertebral arteries in about 18% of cases (14).

On our four-row multissection scanner (Somatom 4 Volume Zoom; Siemens Medical Solutions, Erlangen, Germany), we used the following parameters: 120 kVp, 200 mAs, collimation of 4 × 1 mm, table feed of 2.7 mm per rotation, and rotation time of 0.5 seconds. Image reconstruction parameters were as follows: section thickness of 1.25 mm, overlapping steps of 0.5 mm, and field of view (FOV) of 120 mm². The applied narrow FOV of 120 mm² leads to an excellent in-plane resolution (0.23 × 0.23 mm²) and reproduces all relevant information (Fig 1). In addition, lateral parts of the skull are already eliminated, which simplifies the postprocessing of source data. It is possible to perform reconstructions in steps of 0.23 mm to produce isotropic data (15), thus yielding voxels of equal extent in all three dimensions. In our experience, this does not noticeably increase image quality while doubling the number of source images, thus leading to an extension of time spent on postprocessing source data.

For enhancement of intracranial arteries, 100 mL of contrast medium (Ultravist 300; Schering, Berlin, Germany) was injected intravenously at a flow rate of 4 mL/sec by using a power injector (EnVision CT injector; Medrad, Indianola, Pa). A bolus tracking method (16) was used routinely to achieve optimal synchronization of contrast medium flow and scanning. Once the injection is started, the bolus tracking software measures attenuation values within one internal carotid artery (ICA), and the spiral scan is automatically started as soon as a threshold of 100 HU is exceeded.

If bolus tracking is not available, the test bolus method should be applied to calibrate timing of the data acquisition (17): Ten seconds after bolus injection of 20 mL of contrast medium, a dynamic single-axial-section study (one scan every
2 seconds) at the level of the first cervical vertebral body is started until the contrast material appears as hyperattenuating spots in the ICAs. By using this technique, the time interval between bolus administration and the beginning of data acquisition can also be determined individually.

Analysis of CT Angiograms

The examples shown in this article were created with the regular software of the workstation supplied with a Somatom Volume Zoom CT scanner (Syngo Wizard version VA 40C; Siemens Medical Solutions). The dVR images were created on a separate workstation (Syngo Leonardo 2002B; Siemens Medical Solutions).

Prior to any kind of postprocessing, such as 3D visualization, a detailed review of the source images that are the basis of CT angiography is mandatory (18). These source images contain the entire information that is available from the data. Even the most sophisticated methods for 3D imaging will lead to a distinct loss of data and, thus, potentially important information. Partial thrombosis or calcification of an aneurysm will be missed if the source images are not reviewed in a meticulous way. The interactive analysis of the source images should be done on a workstation rather than by looking at hard copies in order to develop a better perception of the course and the relationships of the intracranial arteries of interest. A wide window setting is necessary to enable differentiation between arteries filled with contrast medium, bone, and calcifications (Fig 2).
Figure 2. Importance of an adequate window setting to demonstrate the intracranial arteries within the skull base. CT image obtained with a window width of 500 HU and a center of 150 HU. Both ICAs can be clearly differentiated within the carotid canals (arrows).

Figure 3. Preparation of the volume for analysis. (a) Posterosuperior image shows large veins (arrowheads), which are typically also visible in CT angiography of intracranial vessels and preclude an unobstructed view of the circle of Willis and the basilar artery (arrow). (b) Left lateroposterior image shows easy elimination of the most obscuring venous structures by using a clip plane (dotted white line) parallel to the clivus. (c) Posterosuperior image obtained after application of the clip plane (dotted white line) shows that the basilar artery is demonstrated completely (arrowheads).
Many aneurysms can already be detected by analyzing the source images. Smaller aneurysms below 5 mm in diameter are often difficult to detect on the basis of source images alone. Therefore, several methods for 2D and 3D postprocessing have been developed that allow more detailed analysis and in addition an "angiographic" representation of CT angiography data.

**Postprocessing of CT Angiography Data**

The basic principle of 2D and 3D postprocessing is to input cross-sectional images into a computer and thereby to create a so-called volume. One can imagine that this procedure is like putting back together the pieces of a sliced potato. Once a volume is created, several methods for 2D and 3D visualization exist (19). The easiest way to analyze a volumetric data set is multiplanar reforma-
tion (MPR), in which from a given angle of view a plane is reconstructed in a defined depth of the volume. This way it is possible to create coronal, axial, sagittal, as well as any kind of oblique sections. The quality of the reconstructions depends on the voxel size. With the use of isometric data (ie, voxels have the same depth, length, and height), all images are of the same quality as the basic source images (20). In contrast to MIP and the 3D methods discussed later, the reconstructed planes contain all information that is contained in the source images. Therefore, MPR should always be the method of first choice for the further examination of CT angiography data (21).

To create useful "angiographic" representations from CT angiography data, it is always necessary to eliminate disturbing structures from the volume in order to ensure an unobstructed view of the circle of Willis and its related arteries. For this purpose, several graphical tools exist that vary depending on the software of the workstation used. To eliminate the straight sinus and other veins that always prohibit an unobstructed view of the basilar artery, a so-called clip plane can be applied parallel to the clivus (Fig 3). This kind of data manipulation is always necessary when MIP or 3D visualization of CT angiography data is performed by using one of the following methods.

**Maximum Intensity Projection**

The term maximum intensity projection (MIP) means that from any given angle of view only the brightest voxels of a volume are collected and used to create an image (22). Therefore, MIP is not a 3D method, as it creates 2D images in which voxels from different locations within the volume are collapsed into one plane. Thus, depth information is lost and it is not possible to tell whether a structure is located in the front or back on the basis of a single MIP image. Because calcifications and bone are brighter than contrast material–filled arteries, it is possible to differentiate levels of attenuation (eg, to recognize a calcified artery).

The use of MIP as a method to create CT angiograms is limited due to the fact that the skull base has a much higher attenuation than the intracranial arteries and therefore has to be eliminated when MIP is used for image reconstruction (23). When dealing with intracranial aneurysms, it is often not possible to clearly depict the relations of the aneurysm to its adjacent arteries. Furthermore, with the use of MIP, small aneurysms will often be missed as they are eclipsed by the signal of their parent vessels averaged into the same 2D plane (Fig 4).
Figure 5. Analysis of CT angiography data with MPR and thin-section MIP. (a–c) Sagittal (a), coronal (b), and axial (c) MPR images show a small aneurysm at the bifurcation of the right MCA (arrow). Note the large intracerebral hematoma (arrowheads in a), which is usually not demonstrated on threshold-based 3D images. (d–f) Sagittal (d), coronal (e), and axial (f) MIP images obtained with thin sections of 20 mm show the aneurysm more clearly (arrow) and show the intracerebral hematoma as well (arrowheads in d).
In contrast to the two methods for 3D visualization described later, MIP is not threshold dependent and therefore is relatively easy to use. It has to be kept in mind that MIP uses only about 10% of the information contained in a given volume. In our experience, MIP is of minor use for the creation of CT angiograms in order to search for and analyze aneurysms but is often very helpful when used interactively on the workstation in thin sections of about 10–20 mm in addition to MPR (24) (Fig 5). In contrast to threshold-dependent methods, smaller arteries are displayed without user interaction (22).

Threshold-dependent Methods for 3D Visualization

Shaded surface display (SSD) and direct volume rendering (dVR) are more difficult to use than MIP. They require the user to define thresholds for the selection of voxels on the basis of their attenuation (measured in Hounsfield units). For SSD, typically upper and lower thresholds are defined and from a chosen angle of view the first layer of voxels with an attenuation within the defined parameters is displayed. Therefore, the images show the surface of these structures and provide valuable information about the 3D shape of an object (25). On the other hand, all structures are shown in the same color and information about the attenuation of a structure is lost completely. For example, it is not possible to see calcifications within an artery on SSD images. Since MIP retains information about the attenuation of objects yet does not allow the depth perception provided by SSD, both methods may be used to complement one another.

The definition of the thresholds is performed interactively by the user and significantly influences the appearance of the vascular structures (7) (Fig 6). Setting the lower threshold to a low value (eg, 100 HU) will result in an image showing many vascular structures, including the veins and small arteries. When the lower threshold is increased (eg, to 200 HU), structures of low attenuation such as intracranial veins and small arteries will disappear completely and the major arteries will appear smaller. The “ideal” threshold to depict intracranial arteries has to be found interactively and depends on several parameters, including the injection rate of the contrast medium and cardiac output, both of which influence the attenuation of the contrast material–filled vasculature (26).
From the point of view of a computer scientist, MIP and SSD are types of “volume rendering” in which only one layer of voxels is used for visualization. In the medical literature, the term volume rendering is reserved for the technique described next, in which all voxels of a volume are considered for visualization (27).

Direct volume rendering (dVR) is the most sophisticated method for 3D visualization. The basic principle is to select several groups of voxels according to their attenuation in Hounsfield units and to assign them a color and a so-called opacity (28,29) (Fig 7). When dVR is used to create CT angiograms, the voxels of high attenuation containing information about bony structures are selected separately from those voxels with a attenuation between 100 and 300 HU containing information about contrast-enhanced vascular structures. This selection allows the creation of 3D images showing red arteries and white bone. A high opacity will lead to images that look similar to those produced by SSD. Use of a low opacity can result in the creation of transparent objects (eg, it is possible to make intracranial arteries visible beneath a layer of skull bone) (Fig 8). Selecting only a small group of voxels with a high opacity allows creation of a “virtual endoscopic” view in which the thin layer of voxels resembles the vessel wall (Fig 8e) (30).

There are so many possibilities to create images that it is impossible to compare studies of CT angiography with volume rendering from different institutions. As with SSD, the appearance of the intracranial arteries strongly depends on the selected thresholds. Lower values will show

Figure 7. Basic principles of volume rendering. Groups of voxels are selected according to their Hounsfield unit values. Every group has its own color and opacity. A low opacity makes the objects transparent. dVR image (superior view) of a patient with two aneurysm clips (a) and photograph of the workstation screen (b). The voxels representing the metal clips (arrows in a) are colored blue with a high opacity. Bone (voxels between 200 and 2,000 HU) is colored white with an opacity of 49%. Finally, the voxels between 90 and 300 HU that contain the vascular information are colored red with a 50% opacity.

Figure 8. Different possibilities for examining an aneurysm of the left MCA with dVR. (a) Frontal image obtained without shading. (b) Frontal image obtained with shading (addition of an artificial light source), which gives the objects more depth. (c) Frontal image obtained by selecting only a small group of voxels with a low opacity. The vessels appear transparent, thus allowing visualization of a branch of the MCA running behind the aneurysm (arrow). (d) Left frontolateral transparent image allows the orifice of the feeding artery to be seen through the aneurysm (arrow). (e) Frontal “virtual endoscopic” image, obtained by selecting only a small group of voxels with a high opacity, shows a pseudocconnection between the aneurysm and an adjacent artery (arrow). This “kissing vessel” artifact is a partial volume problem that is often seen on CT angiograms of intracranial aneurysms. (f) Anterocaudal image obtained with high opacity shows the close relationship of the aneurysm to the lower branch of the MCA (arrow).
Figure 9. Standard 3D projections obtained by using dVR interactively on the workstation (left) and diagrams of the corresponding arterial anatomy (right). This systematic analysis is of extreme importance, especially when an aneurysm is detected at first glance, to ensure that additional aneurysms are not missed. ACA = anterior cerebral artery, PCA = posterior cerebral artery, PCom = posterior communicating artery, VA = vertebral artery. (a) Superior view of all of the intracranial arteries. In many cases, larger aneurysms are immediately visible on this overview. (b) Posterior view of the basilar and vertebral arteries. Aneurysms of the PICA and the basilar artery tip can be detected on this view. AICA = anterior inferior cerebellar artery. (c) Lateral view of the intracranial part of the ICA. Note that the ICA is partially obscured by osseous structures, making detection of aneurysms in this area difficult with 3D images alone. (d) Unobstructed view of the MCA bifurcation obtained from a superior angle. (e) Unobstructed view of the anterior communicating artery (ACom) obtained from a superior angle. (f) Unobstructed view of the anterior communicating artery (ACom) and the bifurcation of the left MCA obtained from an inferior angle after elimination of the skull base by using a clip plane (Fig 3).
more vessels including venous structures and thus lead to a more complex image. It very much depends on the experience of an individual user to select these thresholds in an efficient way. To ensure a good detection rate for aneurysms, it is mandatory to evaluate the 3D models in a standardized way (Fig 9). The areas where aneurysms are most likely to occur have to be inspected in particular detail. This is extremely important because there is more than one aneurysm in about 20% of patients with SAH (31). Although it is customary to use red for the group of voxels containing the vascular structures, it is not clear whether the colors have an influence on aneurysm detection (Fig 10).

Unfortunately, the quality of dVR highly depends on many factors like the quality of the workstation and the applied rendering algorithm (29). Therefore, dVR is not a unique method and available studies are still not comparable.

**Detection of Intracranial Aneurysms with CT Angiography**

In a systematic review of studies published between 1988 and 1998, the average sensitivity of CT angiography for the detection of intracranial aneurysms was about 90%. Aneurysms with a size of 3 mm or below were detected in 61% of cases, whereas the sensitivity for aneurysms with a larger diameter was 96% (32). More recent studies found even higher overall detection rates of up to 97%, and some authors already solely rely on the findings of CT angiography in patients with SAH (21,33,34). Because the detection rate depends on technical requisites and user-dependent post-processing techniques, this is not yet accepted practice in most radiology departments.

For the increasing number of aneurysms treated by using an endovascular approach, CT angiography may be used as a tool for therapeutic decision making and therapy planning: A major advantage of CT angiography compared with DSA is the generation of 3D information on the exact anatomy of the intracranial arteries. In addition to the mere detection of aneurysms, these 3D models can be most helpful for therapy planning as well (21). When intravascular coiling is the therapy chosen on the basis of the CT angiographic findings, additional pretherapeutic DSA is not necessary, as it is part of the coiling procedure. In addition, CT angiography can help predict the ideal angle for the endovascular approach. Information on the exact dimensions of an aneurysm provided by CT angiography can be used to determine the diameter of the first coil (Fig 11). For the neurosurgeon, information about adjacent vascular structures and the possibility of simulating the intraoperative view prior to surgery are often helpful (Fig 12) (35).

**Figure 10.** Visualization of the intracranial arteries with 3D dVR performed by using different colors. Superior views show the arteries colored red (a) and blue (b). It is not known whether the colors affect the detection rate of intracranial aneurysms with CT angiography.
Figures 11, 12.  (11) Use of CT angiography for planning endovascular therapy. (a) Anterior 3D dVR image obtained with a high opacity shows an irregular aneurysm of the left intracranial carotid bifurcation (arrow). (b) Anterior transparent dVR image obtained with a low opacity shows the measured diameters of the dome and neck of the aneurysm (arrow). The maximal diameter of the dome was almost 7 mm. (c) Posteroanterior DSA image of the left ICA obtained after placement of the first coil. Because the exact measurements of the aneurysm (arrow) were determined with CT angiography, a 7-mm-diameter platinum coil was used first. (12) Use of CT angiography for planning surgical therapy in a patient with two small aneurysms at the bifurcation of the right MCA. Arrows = aneurysms. (a) Three-dimensional dVR image obtained with a high opacity shows anatomic information nearly identical to the intraoperative findings (c). (b) Transparent dVR image obtained with a low opacity shows the orifice of the main stem of the MCA (arrowhead). Such images are often helpful in demonstrating the anatomy behind the vascular structures. (c) Photograph shows the intraoperative findings.
Perimesencephalic hemorrhage is a distinct entity characterized by subarachnoid bleeding that is confined to the peripontine and perimesencephalic cisterns. A source of bleeding will be found in only 5% of these patients (36). Although the cause remains unclear in the other patients, their prognosis is usually excellent and rebleeding is uncommon. It has been proposed that these patients should be investigated with CT angiography alone (37). As CT angiography does not allow exclusion of nonaneurysmal lesions such as dural arteriovenous fistulas or small angiomas, this management would lead to patients being subjected to both CT angiography and DSA in 95% of cases (38). Therefore, we would perform DSA as the primary and only study in these patients.

**Shortcomings and Pitfalls of CT Angiography**

When performing CT angiography for the detection and therapy planning of intracranial aneurysms, knowledge about several potential pitfalls is essential. The in-plane resolution of CT is relatively high depending on the FOV that is used for source image reconstruction; for example, a FOV of 120 mm² combined with a 512 matrix results in an in-plane pixel size of 0.23 × 0.23 mm². The through-plane resolution, which is defined by the section thickness, typically lies around 1 mm. In order to produce more homogeneous reconstructions, the section images are usually reconstructed in overlapping steps of 0.5 mm or less. Therefore, small perforating arteries with a diameter below 0.5 mm are not visible on CT angiograms (39). It is often difficult or even impossible to differentiate the infundibular dilatation of the origin of an artery from an aneurysm, which can lead to false-positive results (7,40) (Fig 13a). This problem frequently occurs concerning the origin of the posterior communicating artery from the ICA. Often, the situation can be clarified by lowering the thresholds on the 3D images (Fig 13b) or by careful inspection of the source images.

In about 10% of cases, it will not be possible to see a clear margin between an aneurysm and adjacent arteries, which results in the erroneous impression that a connection between these vascular structures might exist. This “kissing vessel” artifact (41) is more likely to appear with larger aneurysms (Fig 14). During daily clinical work, this...
Figure 14. Kissing vessel artifact. (a) CT angiogram (superior view) shows an aneurysm of the left anterior communicating artery (arrowhead) adjacent to the right ICA (arrow). An aneurysm at the bifurcation of the left MCA is also seen. (b) Right frontal dVR image shows a large connection (arrow) between the right ICA and the aneurysm (arrowhead). (c) Transparent dVR image clearly shows the connection (arrow). Arrowhead = aneurysm. (d, e) Transparent (d) and virtual endoscopic (e) dVR images show a hole (arrow) between the right ICA and the aneurysm. (f) DSA image shows no connection between the right ICA and the aneurysm (arrow). A separate angiogram was obtained for each carotid artery, and the images were combined manually. To demonstrate the lack of a connection, the space between the right ICA and the aneurysm is shown as larger than it actually was.
artifact is easily recognized by following the course of an artery adjacent to an aneurysm and should not cause problems in most cases when high-opacity dVR or SSD is used for display. When transparent low-opacity dVR images are used and even more so when “virtual endoscopy” is performed (42), the closely related vascular structures will show “holes” that can easily be misinterpreted as connections. Therefore, virtual endoscopy is of minor use for both investigation and therapy planning of intracranial aneurysms.

The time that elapses between the arterial and the venous phase of a contrast material bolus flowing through the intracranial circulation is about 5–6 seconds. Therefore, even with four-row multissection scanners, it is not possible to produce pure arterial phase CT angiography. Thus, the depiction of venous structures cannot be avoided, and when they appear adjacent to arteries they can sometimes be mistaken for aneurysms (Fig 15). On the other hand, information about the location of intracranial veins may be of interest for surgical treatment planning (43). The latest scanner prototypes, which are equipped with up to 16 detector rows, accomplish data acquisition even faster, and pure arterial phase CT angiography of the intracranial vasculature will soon become possible (44).

Aneurysms involving the skull base often do not show very well on 3D images. Analysis is more easily performed by using the section images. This is especially true when there is intraaneurysmal thrombosis or calcification of the aneurysm wall. These important findings are easily recognized on the section images but are often not seen even when dVR is used for 3D visualization (Fig 16).
Patients with clipped aneurysms represent a specific problem. Beam hardening artifacts produced by the aneurysm clips preclude a clear depiction of nearby intracranial arteries depending on which material the clips are made of (39). Therefore, CT angiography is of minor value for the postoperative follow-up of patients after aneurysm surgery in most cases. When CT angiography is used for this purpose, it is mandatory to carefully inspect the source images prior to 3D visualization to check for the occurrence of artifacts around the clip (Fig 17).

Discussion
The increasing quality of CT provides excellent source images, and there are already reports of cases where CT angiography showed aneurysms that were not seen at standard DSA (Fig 18) (7). Since methods for standardized and reproducible 3D visualization are not available as yet, the real value of CT angiography for the detection and evaluation of intracranial aneurysms remains unclear despite the wealth of studies focusing on this topic. The use of any commercially available workstation for postprocessing requires intensive familiarization with both the techniques of 3D visualization as well as the different manipulation tools available on the workstation used. Their actual value strongly depends on the individual experience of the investigator (19). For a meaningful delineation of the target structures, correct adjustment of transfer functions as well as efficient interactive manipulation of volume data are necessary to make the aneurysms clearly visible. Therefore, studies performed so far evaluate specific systems and the results depend on the experience of individual users. Thus, the results from these different studies cannot be readily compared.

In order to allow a comparison of scientific studies, it is essential to eliminate external influences and to reduce the number of uncontrolled variables as much as possible. A model for a standardized postprocessing algorithm has been proposed by our research group (45). Our approach is based on an automated 3D image reconstruction generated by a remote high-end workstation. CT data are transferred to the remote system via the Internet, and standardized video sequences are returned. The idea to produce standardized videos based on high-quality volume rendering could also be realized locally on modern workstations. Such a software tool would be a useful addition to widely used CT angiography equipment by allowing the reproduction of studies within a department and the comparison of results between different institutions.
The example of the aneurysm involving the skull base (Fig 16) demonstrates that although the CT angiography data contained information about thrombosis and calcification, the visualization strategy applied was not sufficient to depict the lesion accurately. Thus, it would be useful to find methods for improved depiction of aneurysms located within the cavernous sinus and near the skull base that are clinically applicable. For this purpose, special postprocessing techniques aiming at the suppression of irrelevant bony structures are required. So far, two solutions for this problem have been proposed. The first is based on the acquisition of two separate sets of data—one before and one after the administration of contrast media—which then allow digital subtraction of the images, resulting in “CT-DSA” (4,46). Patients have to lie absolutely still during scanning and are exposed to a greater amount of radiation. The second relies on the automated separation of bony and vascular structures (47). This approach is technically even more challenging, since threshold-based elimination of the bone is difficult due to partial volume effects.

MR angiography is another possibility for the noninvasive investigation of intracranial aneurysms. Its main advantage when compared to CT angiography is that the bone does not disturb the images. The reported sensitivity of MR angiography for the detection of intracranial aneurysms is comparable to that of CT angiography for aneurysms with a diameter greater than 3 mm but is significantly lower for smaller aneurysms (32). In contrast to CT angiography, for which at least data acquisition is carried out with relative consistency throughout the published studies, the protocols for MR angiography show a wide variability. An interesting application for MR angiography is the follow-up investigation of patients who have been treated with platinum coils (48). Whereas CT angiography is not useful in these patients due to severe beam hardening artifacts, MR angiograms are not degraded by the coils (49).

In 2002, the results of the International Subarachnoid Aneurysm Trial (ISAT) (50) showed that for patients with a ruptured intracranial aneurysm for which both endovascular coiling and neurosurgical clipping were therapeutic options, after 1 year the outcome in terms of survival without disability was significantly better with endovascular coiling. This will lead to an increasing number of aneurysms being treated with an endovascular approach.

CT angiography can be performed immediately following the confirmation of SAH with nonenhanced CT. Three-dimensional information on the aneurysm that caused the bleeding can be obtained within a few minutes and used for therapy planning. The findings and therapeutic options can then be discussed among neurosurgeons and endovascular neurointerventionalists. Once coiling is the therapeutic option chosen, additional DSA is not necessary as it is part of the procedure. If endovascular treatment is not pursued, DSA may be necessary in addition to CT angiography, depending on the experience of a specific institution.
The resulting algorithm is shown in Figure 19. It takes into account the fact that the quality of CT angiography may vary even within a department, depending on the experience of the investigator. Negative CT angiography findings in a patient with SAH must always be corroborated with DSA.

Conclusions

CT angiography is a promising method for both detection and therapy planning of intracranial aneurysms. Recent technical developments such as the introduction of multissection CT and high-resolution dVR provide CT angiographic images of increasing quality. For institutions with ample experience using state-of-the-art equipment, it may be safe to rely on the findings provided by CT angiography alone for both therapeutic decisions and therapy planning. As long as CT angiography is not a standardized method with regard to postprocessing and 3D visualization, it is not yet possible to clearly define the real value of CT angiography with respect to the detection rate of intracranial aneurysms. Future developments should focus on standardized 3D visualization based on workstations that are widely used. Only then will reliable comparative studies concerning the sensitivity and specificity of the method be possible.

References


Figure 19. Algorithm for use of CT angiography in patients with SAH.