Computed tomographic angiography in intracranial vascular diseases
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**Background.** The development of spiral computed tomography (CT) introduced more precise imaging of the vessels also with computed tomographic angiography (CTA). Because it is minimally invasive method, it was widely accepted by radiologists and clinicians. In early 90 ties CTA also accompanied conventional angiography and magnetic resonance angiography (MRA) in imaging of intracranial vascular diseases. CTA is used for detection and evaluation of intracranial aneurysms, vascular malformations, stenoocclusive diseases of intracranial arteries and pathological changes of venous sinuses. Comparing to conventional angiography as the «gold standard», CTA has high specificity, sensibility and diagnostic accuracy concerning detections of intracranial aneurysms. Regarding vascular malformations, CTA is used for diagnostics and pre and postoperative evaluation of it. CTA can show good results in imaging of venous angiomas, and so invasive conventional angiography can be avoided in this pathology. Stenoses and occlusions of arteries can be diagnosed and evaluated in patients with cerebral vasospasm, patients with acute stroke, and patients with chronical arterial stenoses and occlusions.

**Conclusion.** CTA is usefull for demonstration of occlusive and stenosing changes of intracranial venous sinuses. With CTA it is possible to generate threedimensional reconstructed images, which give more accurate determination of anatomical relations in intracranial vascular diseases. The main disadvantage of CTA in comparison to intraarterial angiography is the lower spatial resolution of CTA, but is constantly improving with the developement of better scanners and workstations, so that there are great possibilities for further developement and wider use of CTA in the diagnosis of intracranial vascular diseases.

**Key words:** computed tomographic angiography; tomography , x-ray computed; intracranial vascular diseases; cerebral aneurysm –diagnosis

**Introduction**
Since its introdution in clinical practice in early 1970s, computed tomography has gone throught a lot of important refinements and became more accurate and much faster from its beginnings till today. Progresive reduction in scan times and improved spatiultaneous moving of the patient through the gantry while X-ray sources rotates.\(^1,2\) Because this proces is contiuonos rather then stepwise as in conventional CT scanning, examination time is reduced. Besides advantages like increased patients throughtput I and contrast resolution made CT imaging a workhorse for many years. In early 1990s computed tomography has been revolutionazed by technical advantages of spiral CT. Spiral CT scanning involves continous data aquisition throughtout the volume of interest by sim and reduction of motion artifacts, spiral CT also offers additional properties, which are not possible with conventional step by step CT scanning. Because of short acquisition time, scanning can be timed with peak opacification of arterial or venous phase, after peripheral intravenous application of contrast media. The resultant images (raw data) are processed with various computed rendering techniques, such as multiplanar reformatting (MPR), shaded surface display (SSD), maximum intensity projection (MIP) and volume rendering technique (VRT) to generate two or three-dimensional images of the vessels. As a result, CT angiography is performed less invasively, faster and at a lower cost then conventional intraarterial angiography (3,4).

In neuroradiology, the diagnostics of cerebrovascular diseases represents one of its major fields of activity. It has progressed a lot during the last decade with advent of MR imaging and spiral computed tomographic technology. CTA was increasingly used for detection and evaluation of intracranial aneurysms, intracranial vascular malformations, intracranial vascular stenoses and occlusions and pathological changes on intracranial venous sinuses.

The purpose of this paper is to review the value of CTA in detection and evaluation of vascular intracranial diseases.

**Intracranial aneurysms**
Aneurysms are circumscribed dilatations of arteries that communicate directly with the vessel lumen.
They may be saccular (berry) or fusiform (5).

**Intracranial saccular aneurysms**

Saccular aneurysms are found in 1% to 5.6% of population (5,6). 15% to 20% of patients have multiple aneurysms (7). Saccular aneurysms are important part of vascular pathology, because subarachnoid haemorrhage (SAH) is in 80%-90% caused by rupture of a saccular aneurysm. In 15% SAH may be caused by arteriovenous malformation, and 5% by diverse causes (8). SAH resulting from a ruptured aneurysm of intracranial arteries carries a poor prognosis and the mortality in untreated patients may be as high as 45% (8).

For many years intraarterial cerebral angiography has been a technique of choice for demonstration the intracranial aneurysms, but it is invasive, expensive and has 1% of complications, while 0.5% develop permanent neurological deficits (9,10). Therefore non-invasive MRA and minimally invasive CTA have been increasingly used over the past few years (11,12). Although MRA is capable of showing an accurate anatomy of intracranial vessels and vascular pathology, there are some difficulties in detection and demonstration of aneurysms with turbulent or slow blood flow (13-17). MRA is contraindicated in patients with ferromagnetic clips, pacemakers or life-support devices (18). CTA is insensitive to turbulent blood flow artifacts and in contrary to MRA, it can be performed in patients with ferromagnetic implants (19-21). In patients with SAH CTA demands little additional time and is easily performed immediately after conventional CT (22). CTA is highly accurate, sensitive and specific as compared to DSA (gold standard)(20, 23-27).

Because of its minimal invasiveness the indications for CTA in diagnostics of cerebral aneurysms are broader than for DSA and can be divided into six groups:

1. **Patients with acute SAH.** The patients are usually critically ill and clinically unstable. On time diagnosis of the etiology of bleeding is essential for planning an early surgery or other intervention. Intraarterial conventional angiography performed within the first 6 hours after initial bleeding is associated with an increased rebleeding rate (28). CTA is very suitable in the acute stage after SAH because it does not require intraarterial catheterization, scanning time is only 50 seconds and it can be performed on the same scanner immediately after the demonstration of SAH by conventional CT scan (23-25, 29).

2. **Patients with proven history of SAH, but with negative or indeterminate first angiography.** In a number of patients, no underlying cause is identified despite complete neuroradiological investigation. In the literature this proportion varies between 3.8% (30) and 46% (31) with accepted mean of 15% (32). The etiology of angiogram-negative SAH remains elusive. Numerous theories have been proposed. One theory postulated that SAH may be due to leakage from the lenticulostriate and thalamoperforating vessels (33). Another theory suggested a venous or capillary source for the patients with perimesencephalic SAH (34). The most popular theory attributes bleeding to an aneurysm that undergoes thrombosis or is destroyed at the time of haemorrhage (35). CTA performed about 3 weeks later, can demonstrate partially or completely recanalized aneurysm.

3. **Patients with a suggestive but uncertain history of SAH.** In these patients, instead of invasive DSA as first imaging modality, CTA or MRA can often make the diagnosis (36,37). For example, we found an aneurysm at the bifurcation of the left middle cerebral artery in 37 years old woman suffered a sudden strong headache two weeks before and did not seek medical help at that time (Figure 1).

4. **Patients without SAH, but with suspicious clinical signs of an intracranial aneurysm or an aneurysm-like lesion on conventional CT images or MR images.** In this group we have an example of 68 years old woman suffering from paresis of the right third nerve, where we detected a large right internal carotid artery aneurysm (Figure 2).

5. **Screening in “high risk population”.** The existence of families with a history of intracranial aneurysms is well recognized. In large epidemiologic studies, the prevalence of familial intracranial aneurysms is higher then in general population (7% to 9%) (38-44). Even in situation of sporadic case, relatives of the patients are often worried that they may also harbor an aneurysm. In screening we use CTA as an additional or alternative method to MRA in patients with a family history of aneurysmal disease and patients with predisposing hereditary disease, such as autosomal polycystic renal disease.

6. **Follow up of treated or non-treated aneurysms.** Once the aneurysm is detected and clipped,
question may arise as to the proper placement of the clip. One potential problem is to only partially clip the neck of the aneurysm and allow continued filling of the aneurysm. Another is possible occlusion of vital arteries after improper placement. Postoperative evaluation has traditionally been done with conventional angiography (45). In few cases we have had used CTA in order to clarify such dilemmas. Depending on the size and orientation of the clip, a starshaped artifact in the immediate vicinity of the clip is seen. In most cases we have been able to demonstrate both clip and eventually residual aneurism as well as patency of vessels despite this artifact (Figure 3). Inspite of this, CTA in its present form cannot replace DSA in all situations of evaluation of aneurysm clip placement (46).

Finally, since CTA and DSA are in most cases complementary examinations, their combination often provides more data in the preoperative evaluation of intracranial saccular aneurysms than would be obtained with each of them separately. CTA could be considered useful technique in the preoperative evaluation due to their three-dimensional representation of outer and inner vessel surfaces. The so called endovascular view of both the neck and sack of the aneurysm can demonstrate the relationship between the aneurysm and arterial branches (47,48). CTA also allows the display of adjacent bone structures (Figure 4) and allow surgeons to plan a craniotomy with the best approach to the neck of the aneurysm (26).

**Intracranial fusiform aneurysms**

Fusiform aneurysms are dilated and elongated atherosclerotic vessels. They commonly affect supraclinoid segment of internal carotid artery and vertebrobasilar arteries. Mural thrombus is common. Hemorrhage is rare (5). Surgical therapy is not possible in majority of the cases. CTA is able to clearly demonstrate this type of aneurysm and so to avoid DSA (Figure 5).

**Intracranial vascular malformations**

Intracranial vascular malformations are a diverse group of congenital lesions of blood vessels. These lesions are usually classified as arteriovenous malformations (AVM), venous angiomas, cavernous angiomas and capillary teleangiectasias (5).

**Intracranial arteriovenous malformations**

Pathologically, the AVMs show clusters of abnormal arteries and veins. The vessel walls are typically thickened and contain elastin and smooth muscle. AVMs are subdivided into pial AVMs, dural AVMs and dural arteriovenous fistulas.

**Pial AVMs** consist of an plexus of arterial feeders, nidus and dilated draining veins. Because there is no intervening capillars blood shunts directly from arteries to veins. These vessels are pathological and are prone to rupture. The risk of hemorrhage is 2% to 4% per year. For each episode of hemorrhage there is a 29% chance of death and 23% chance of long term morbidity (49). The therapy of AVMs can be surgical, radiosurgical or interventional. A pre-therapeutical neuroradiological evaluation requires a diversity of anatomical and hemodynamic information. From the morphological point of view, neuroradiological studies identify feeding arteries and draining veins and evaluate angioarchitecture of the nidus. From hemodynamic point of view, flow velocities in the different vascular compartments should be evaluated. Conventional angiography still represents the gold standard for evaluating feeding arteries, draining veins and the angioarchitecture of the nidus. It is also mandatory for hemodynamic evaluation of AVMs. The experience in the last few years showed that MRA and CTA can be useful in diagnostics of AVMs (50-52).

CTA can have important role in following situations:
1. **Detection of AVM.** CTA can be useful in diagnosis, excluding or confirming the presence of AVM in a suggestive clinical context.
2. **Pre-therapeutical evaluation of AVM.** In conjunction with conventional angiography, conventional MR and CT images CTA can be used to obtain three-dimensional images of AVM. Reconstructed three-dimensional CTA images can be viewed from any perspective, which can be used for exact localisation of feeding arteries, nidus and draining veins (Figure 6).
3. **Post-therapeutical evaluation of AVM.** Analysis of AVM reduction after treatment can be performed with CTA images. This technique offer suitable method for minimaly invasive and reproducible follow up.

In dural AVMs and dural arteriovenous fistulas neither CTA nor conventional MR or MRA can
substitute or complement conventional angiography in diagnosis and pre-treatment evaluation (27,53,54).

**Venous angiomas**

Venous angiomas are congenital anomalies of intracranial venous drainage. They represent anatomic variants resulting from arrested embryological venous development causing persistence of primitive medulary veins (55). They are described as a local network of small medulary veins, resembling caput medusae, which converge centrally into a large transmedullary vein that courses toward the cortical surface or the deep venous system (56,57). Venous angiomas are most common incidental vascular malformations detected radiologically and at autopsy (58). They are also designed «developmental venous anomalies» to emphasize their frequency and their benign nature. Usually they cause no symptoms but may rarely be associated with headache, seizure, or focal neurologic deficit (58,59) and even more rarely with acute symtomatic hemorrhage (60). In most cases surgical therapy is not necessery or possible (58-60).

Today the technique of chioce in neuroradiological diagnosis of venous angiomas is MRA and conventional MRI with administration of gadolinium. A stellate appearence on MR is said to be patognomonic of venous angiomas (61). Only in rare circumstances, when diagnosis is not certain conventional angiography needs to be performed. With conventional angiography, a venous phase abnormality characterized by multiple dilated medulary veins converging on a larger trancortical vein, giving a «caput medusa» appearance is diagnostic (58-61).

Instead conventional angiography CTA also can be used (62). CTA demonstrate findings characteristic for venous angiomas: small vascular structures in deep white matter converging to a more dilated trancortical draining vein (Figure 7). The use of CTA in diagnosis of venous angiomas shows good preliminary results and could obviate the need for conventional angiography in most cases.

**Cavernous angiomas and capillary telangiectasias**

In cavernous angiomas and capillary telangiectasias, both conventional and non or minimaly invasive angiographic techniques fail to revel the majority of lesions, wheras conventional MRI still remains the technique of choce (5,27).

**Intracranial vascular stenoses and occlusions**

Intracranial stenotic and occlusive vascular patology can be divided in cerebral vasospasm in patients with SAH, acute arterial occlusion in patients with acute ischemic stroke and chronic stenoticocclusive diaseases of arteries.

**Cerebral vasospasm**

The most debilating complication of acute SAH is cerebral vasospasm, acounting for 14% of deaths or severe disability in patients with SAH (63). Onset of spasm occurs 4 to 11 days after hemorrhage in approximately 30% of patients (64). Current therapy includes hypervolemic and pharmacologic therapy and its efficacy is well documented (64).

Conventional angiography is one diagnostic method for this complication, but the risk of preforming this procedure in the critically ill patient can limit its application. Transcranial Doppler sonography is noninvasive and rapidly performed, but does not provide anatomic information and is limited to a small acoustic window (65,66). MR angiography is restricted in the evaluation of these patients due to reduced intracranial blood flow.

CTA offers the potential for rapid, minimally invasive method of diagnosing and monitoring this complication (67) (Figure 8).

**Acute ischemic stroke**

Strokes are a major public health problem. Stroke is the third most common cause of death since one third of the patients die and another third are rendered permanently disabled (68). In Slovenia the incidence of stroke is 190,5/100000 people. Mortality in the first 30 days is 21 % (69). Ischemic infarction of brain tissue, because of acute arterial occlusion is the major causative factor. The majority of infarctions are caused by thrombembolism from underlying atherosclerotic disease (70,71). The majority of stroke patients are treated conservatively (72). Sistemic intravenous or local intraarterial thrombolysis has recently shown promise of improving patient outcome (73,74). However, thrombosis must be identified and treated promptly for optimal results. Because trombolytic drugs produce intracranial hemorrhage in 6% to 20% of cases , the potential for salvaging the ischemic brain must be defined (74,75). The reversibility of ischemic process not only depends on the time
after ictus, but is primarily a function of the degree of persistent collateral flow to the affected tissues. Brain without sufficient collateral flow will die within minutes, whereas tissue with good collateral flow will remain viable. In the latter circumstances thrombolytic therapy can be effective. Patients with acute stroke are examined with unenhanced CT of the brain to exclude intracranial hemorrhage or other rare causes for stroke. CT is also useful in assessing early signs of cerebral ischemia, such as parenchimal hypodensity and focal brain swelling (76,77). But conventional CT does not show the extent of disturbed cerebral perfusion, which is determined by the site of occlusion and collateral blood supply and is not capable of showing volume of viable tissue at risk from low perfusion, which is the target of thrombolytic treatment (78). Recently MRA and MR imaging with hemodynamic and diffusion weighted pulse sequences are increasingly used in patients with acute stroke. Diffusion and perfusion images are highly sensitive to early infarction and an extent of infarcted brain tissue (79,80).

In acutely ill stroke patients CTA is more practical and faster than MR imaging and can be performed immediately after conventional unenhanced CT of the brain. Because of these considerations, few authors studied whether CTA is capable of showing the site of arterial occlusion, estimating collateral circulation, and determining the extent of severe parenchimal perfusion deficit. Preliminary results of these studies showed that CTA is safe in cases of acute stroke and can add an important diagnostic information to those obtained by conventional CT and may provide a rational basis for optimal treatments of patients with acute stroke. (78,81,82).

Chronic stenoocclusive diseases
Chronic stenoocclusive diseases of intracranial arteries are most commonly caused by atherosclerosis (5,83), less often by nonatheromatous causes, like fibromuscular dysplasia, vasculitides and idiopathic progressive arteriopathy (moyamoya) (5,84). Stenoocclusive diseases of intracranial arteries impairs the blood supply of the brain and increase the possibility of ischaemic stroke. Early diagnosis and treatment of this pathologies has an important role in stroke prevention. In nonatherosclerotic stenoocclusive diseases conventional angiography still plays a primary role, due to mainly changes on arteries of second and third order (84). Spatial resolution of MRA and CTA is too low for precise imaging of these arteries, which measure less than 1 mm in diameter (85). Because atherosclerosis affects mostly larger intracranial arteries, like internal carotid artery, middle cerebral artery, basilar and vertebral arteries, useful and reliable diagnostic method is MRA (86,87) and nowadays also CTA (88). CTA most reliably demonstrates calcifications in atherosclerotic lesion, which can have an important impact concerning further therapy (Figure 9).

Venous sinus compression and trombosis.
External compression of venous sinuses can cause their narrowing or obstruction. It is most commonly caused by the tumor or bone fragment with impression fracture. Sinus thrombosis is a partial or complete obstruction of sinus lumen due to intraluminal clot and usually affects superior sagittal sinus, than transversal, sigmoid and cavernous sinus (5). Thrombosis can spread into cortical veins, straight sinus and internal cerebral veins. Interruption of venous outflow can cause local or diffuse cerebral edema and cortical venous infarctions, which are often hemorrhagical (89). In the past, the prognosis in patients with venous thrombosis has been poor, with the mortality rate between 30% and 80%, but has been improved in the later years by effective systemic heparin anticoagulation, fibrinolytic therapy and anti-edema therapy (90,91). The availability of successful treatment has increased the need for prompt and accurate diagnosis. Besides conventional angiography, conventional CT (95), MR and MRA (91-93) have increased the ability to detect this condition. Conventional contrast enhanced CT has low sensibility in the diagnosis of dural sinus thrombosis (94). MRA, the present examination of choice for evaluation of dural sinuses, is limited by motion artifacts and patient’s contraindications (95). Recently developed CTA with another name CT venography offers greater sensitivity and specificity than routine contrast-enhanced CT in the diagnosis of dural sinus thrombosis (95,96). On CT venography, dural sinus thrombosis is seen as the absence of opacification of the affected dural sinus on reconstructed images (Figure 10) and as a filling defect in the dural sinus on source images (95,96). Also, in cases of external venous compression, CTA can reliably demonstrate venous sinuses and cortical veins, important for preoperative planning (Figure 11).

Conclusion
CTA is the youngest angiographic imaging modality which has been quickly accepted especially for detection and evaluation of intracranial saccular aneurysms, so far mostly diagnosed by conventional intraarterial angiography.
Important part of CTA are post-processing techniques. Because three-dimensional reconstructions of intracranial vessels offers anatomical imaging in the similar way as perceived with human vision, we can better understand the morphology of pathological processes and its relations to surrounding structures.

Minimal invasiveness of CTA represents an important advantage to conventional intraarterial angiography. The main disadvantage of CTA, has been and in some regard still is a lower spatial resolution compared to conventional angiography. Inspite of this, the balance between advantages and limitations still supports CTA in many clinical issues.

Quick development of spiral CT scanners and image processing software enables further development and improvement of CTA. Recent innovation of CT scanners with multiple detectors makes scanning of larger volumes with higher spatial resolution possible. Further improvement represent new software with volume rendering techniques and fast workstations, so that it is now possible to process larger quantity of data in much shorter time.

In conclusion, CTA, if combined with three-dimensional techniques, has excellent possibilities to become reliable and acceptable method for the evaluation of not only intracranial saccular aneurysms, but also of most intracranial vascular diseases.

References


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**Figure 1.** CT angiogram, volume rendering technique, anteroposterior view, demonstrates an aneurysm at the bifurcation of the middle cerebral artery and its relationship to the middle cerebral artery branches (arrows).
**Figure 2.** CT angiogram, volume rendering technique, right anterior oblique view, demonstrates a longish aneurysm coming out from the right internal carotid artery and spreading backwards and downwards in the area of the third nerve (arrows).

**Figure 3.** CT angiogram, volume rendering technique, superior view, performed after basilar artery aneurysm clipping, demonstrates the clip (arrows), patent basilar artery and its branches (arrowheads) and no residual aneurysm.

**Figure 4.** CT angiogram, volume rendering technique, anterosuperior view, demonstrates a large right middle cerebral artery aneurysm. The relationship of this aneurysm to the inner table of the skull is well shown (arrows).
Figure 5. CT angiogram, volume rendering technique, posterosuperior view, demonstrates fusiformly dilated and elongated right vertebral artery and basilar artery (arrows). On the basis of this examination, it was decided that the patient was not an operative candidate. DSA was avoided in this case.

Figure 6. CT angiogram, volume rendering technique, anteroposterior view, shows pial arteriovenous malformation of the right hemisphere. Two main feeding arteries (arrows), nidus (arrowheads) and draining vein (open arrow) are well demonstrated.
Figure 7. CT angiogram, volume rendering technique, anterosuperior view, shows venous angioma in left cerebellar hemisphere (arrows). The lesion has characteristic «caput medusa» configuration.

Figure 8. CT angiogram, volume rendering technique, superior view, shows vasospasm of intracranial arteries (arrowheads) after subarachnoidal haemorrhage and an anterior communicating aneurysm (arrow).
Figure 9. CT angiogram, maximum intensity projection, left anterior oblique view, demonstrates atherosclerotic stenosis of supraclinoid segment of left internal carotid artery (arrow) and extensive calcifications in this atherosclerotic lesion (arrowheads). Because of calcifications, angioplasty is contraindicated in this case.

Figure 10. CT angiogram, multiplanar reconstruction, sagital reconstruction, shows absence of opacification in posterior and middle portion of superior sagittal sinus because of thrombosis (arrows).
Figure 11. CT angiogram, volume rendering technique, left posterior oblique view (a) and inferior view (b) clearly demonstrates parasagittal meningioma (arrows) and its relationship to the superior sagittal sinus (open arrows) and cortical veins, which is important in preoperative planning.