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# CT angiography for the detection of cerebral aneurysms – an analysis of 436 verified cases

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## Summary

**Background:** The aim of the study was to evaluate the clinical value of computed tomography angiography (CTA) in patients suspected of cerebral aneurysms based on 436 verified cases, which is the largest CTA series in the world literature apart from multicenter studies.

**Material/Methods:** The authors analyzed retrospectively the results of CTA performed with the use of a single-slice CT unit in 436 consecutive patients with suspicion of cerebral aneurysms during five years and compared them with cerebral angiography and/or surgical findings.

**Results:** CTA revealed 369 cerebral aneurysms in 309 patients. There were 21 (4.8%) false negative and 14 (3.2%) false positive results. The false positives involved unclear cases (small aneurysms vs. vascular loop) and the false negatives concerned small aneurysms (≤3 mm), mostly on the internal carotid artery and multiple aneurysms. The overall efficiency results were: sensitivity 94.4%, specificity 97.3%, accuracy 96.1%, positive predictive value 96.2%, and negative predictive value 96.0%. The highest accuracy was found for middle cerebral artery aneurysms (97.6%), followed by the vertebro-basilar system (96.6%), anterior communicating artery complex (96.5%), and internal carotid artery (93.6%) aneurysms. The sensitivity was 100% for aneurysms >5 mm, 96.7% for aneurysms 3-5 mm, and 77.8% for aneurysms ≤3 mm. Among 316 patients who were treated surgically, an operation was performed only on the basis of CTA in 264 cases (83.5%).

**Conclusions:** CTA is a minimally invasive neuroimaging method of high diagnostic efficiency and should be a primary vascular examination in patients with suspicion of aneurysm allowing, in most cases, avoidance of invasive cerebral angiography.

**Key words:** **CT angiography • cerebral angiography • cerebral aneurysms**

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## Background

Intracranial aneurysms are the most frequent causes of spontaneous subarachnoid hemorrhage (SAH) [1]. Hemorrhage from ruptured aneurysms leads to death in nearly half of patients [2], while one third of the survivors develop permanent neurological deficits [3]. The treatment modality of choice is surgical or endovascular occlusion of the aneurysm.

The role of neuroimaging is efficient and safe detection and characterization of the aneurysm in order to reach the optimal treatment decisions. In patients with SAH, the diagnosis and treatment should be made as quickly as possible to prevent rebleeding and vasospasm [4]. The gold standard in diagnosing intracranial aneurysms is cerebral angiography [5], which is, however, an invasive study potentially resulting in complications [6–8], including rebleeding [9–12]. Therefore, in the last decade there has been great interest in non-invasive vascular imaging methods, such as computed tomography angiography (CTA) and magnetic resonance angiography (MRA).

MRA has limited value for patients with SAH [13–17] due to difficulties in monitoring the patients [18] and artifacts from the extravasated blood. Therefore many authors claim that CTA, which can be performed directly after plain CT and regardless of the patient's clinical state, may become the primary tool in imaging intracranial aneurysms, especially in the acute phase [19–22]. For many years, CTA was considered a supplementary method to cerebral angiography. However, due to advances in hardware and software, as well as growing experience of radiologists, the efficiency of CTA has increased and it is assessed by some authors as even more valuable than cerebral angiography [23,24].

In spite of multiple papers concerning the usefulness of CTA in diagnosing intracranial aneurysms, the literature still lacks studies assessing its value on the basis of a large body of material, especially material verified surgically. The relatively low numbers of cases which are analyzed in most publications do not allow establishing the role of CTA in patients with a suspicion of intracranial aneurysm or its potential to replace cerebral angiography.

The aim of the present study is to establish the diagnostic value of CTA as a single vascular imaging method in patients suspected for intracranial aneurysms on the basis of 436 cases verified angiographically and/or surgically. To our knowledge, this is the largest sampling of CTA material in the world literature apart from multicenter studies.

## Material and Methods

We analyzed retrospectively the cases of 436 patients (255 females and 181 males), aged 10–81 years (mean: 50.0 yrs) who underwent CTA examinations due to suspicion of cerebral aneurysm during five years (1999–2003) which were verified by either angiography or operation. Most of the patients (371, 85.3%) presented with intracranial hemorrhage, usually SAH; the other symptoms included headache, third cranial nerve palsy, or epilepsy. There were 309 (70.9%) emergency studies, the remaining 127 (29.1%) CTA examinations being scheduled. In unquiet or unconscious patients, sedation or general anesthesia were applied.

CTA studies were performed with a single-slice spiral CT unit (Somatom Plus 4, Siemens). The gantry was tilted parallel to the meatosupraorbital line. The examination covered the intracranial space from the lower border of the foramen magnum to the level of the ventricular bodies. The CTA protocol was as follows: angio-head algorithm, 140 kV, 159 mA, collimation 2 mm, pitch 1, reconstruction distance 1 mm, acquisition time about 30 s, matrix 512×512 with field of view (FOV) tailored individually depending on the head size.

Nonionic contrast medium (Iopromidum/Ultravist 300/370 mg I/ml or Iohexol/Omnipaque 300/350 mg I/ml) was injected intravenously into the antecubital vein via a wide-lumen venflon using an automatic injector. The amount of the contrast medium was 1.5–2 ml/kg body weight (100–150 ml in adults), the injection speed was 5 ml/s. The delay between the onset of the injection and the acquisition was calculated individually on the basis of the initial dynamic CT study at the Willis's circle level after injection of 15–20 ml of the contrast medium.

Postprocessing and detailed analysis of CTA were performed on the Magic View workstation (Siemens). The final diagnosis was based on the analysis of both source scans (partitions) and reconstructions. In all cases, 2D maximal intensity projection (MIP) reconstructions were used with 12 images in each of the main planes (axial, sagittal, and coronal) and a 15° distance between the views (36 images overall). In some cases the MIP reconstructions of a selected volume (VOI ) and 3D reconstructions, such as surface-shaded display (SSD) and volume rendering technique (VRT), or multiplanar reconstructions (MPR) were additionally performed. In the acute cases, the preliminary assessment of CTA was performed immediately after completing the study only on the basis of the partitions.

A five-grade scale of aneurysm detection probability in the CTA study was used: 1 – certain, 2 – probable, 3 – ambiguous, 4 – probable exclusion, and 5 – certain exclusion. The diagnosis was considered certain if the visible focus of opacification was undoubtedly connected with a parent vessel and had the same degree of contrast enhancement on both partitions and reconstructions. Probable diagnoses concerned the cases of minimal doubts in the interpretation of the opacified focus, e.g. due to its small size. The results were qualified as ambiguous if the opacified focus was visible only on either partitions or reconstructions, or was difficult to assess due to atheromatosis, vessel tortuosity, vessel anomalies, bone artifacts, or the poor quality of the study. The probable or certain exclusion of the aneurysm meant minimally doubtful or undoubtedly negative CTA results, respectively. In evaluating the diagnostic efficiency of CTA, every certain, probable, and ambiguous diagnoses were considered as positive CTA results, while probable or certain exclusion diagnoses were classified as negative CTA results.

Apart from CTA, 172 patients (40%) underwent cerebral angiography, 138 cases (80%) after and 34 cases (20%) before CTA. Three hundred and sixteen patients (72.5%) underwent 324 surgical procedures, most of them during the first three days after CTA. In 264 cases (83.5%) surgery was planned only on the basis of the CTA results.

To assess the diagnostic efficiency of CTA, we compared retrospectively its results with angiographic and surgical appearances, analyzing such parameters as aneurysm detection, localization (parent vessel), and size (the greatest diameter in mm) in four typical areas of aneurysm occurrence: the intracranial portions of both internal carotid arteries (ICAs), middle cerebral arteries (MCAs) with their divisions, anterior cerebral arteries (ACAs) with anterior communicating arteries (ACoAs) complex, and the vertebrobasilar system (VBS), including the intracranial portions of both vertebral arteries (VAs), both posterior cerebral arteries (PICAs), and the basilar artery (BA) with its branches. Because of the possibility of *"de novo"* aneurysm, both angiography and surgical result were used as verifying methods only if they were performed no later than six months after CTA. Surgical verification was based on reports from the operations performed in the Department of Neurosurgery at Wroclaw Medical University.

In order to establish the value of CTA as a method of detecting cerebral aneurysms, the following parameters were calculated: sensitivity, specificity, accuracy, positive predic-

**Table 1.** Diagnostic efficiency parameters of CTA in the whole group and depending on the location of the aneurysm.

| Location | Number of results | | | | CTA efficiency parameters [%] | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | TP | TN | FP | FN | SN | SP | ACC | PPV | NPV |
| ACA-ACoA | 131 | 144 | 3 | 7 | 94.9 | 97.9 | 96.5 | 97.8 | 95.4 |
| MCA | 99 | 143 | 2 | 4 | 96.1 | 98. 6 | 97. 6 | 98.0 | 97.3 |
| ICA | 95 | 127 | 5 | 10 | 90.4 | 96.2 | 93.6 | 95.0 | 92.7 |
| VBS | 30 | 86 | 4 | 0 | 100.0 | 95. 5 | 96.6 | 88.2 | 100.0 |
| Any location | 355 | 500 | 14 | 21 | 94.4 | 97.3 | 96.1 | 96.2 | 96.0 |

CTA – computed tomography angiography; ACA-ACoA – anterior cerebral artery – anterior communicating artery complex; MCA – middle cerebral artery; ICA – internal carotid artery; VBS – vertebro-basilar system; TP – true positive; TN – true negative; FP – false positive; FN – false negative; PPV – positive predictive value; NPV – negative predictive value; SN – sensitivity; SP – specificity; ACC – accuracy.

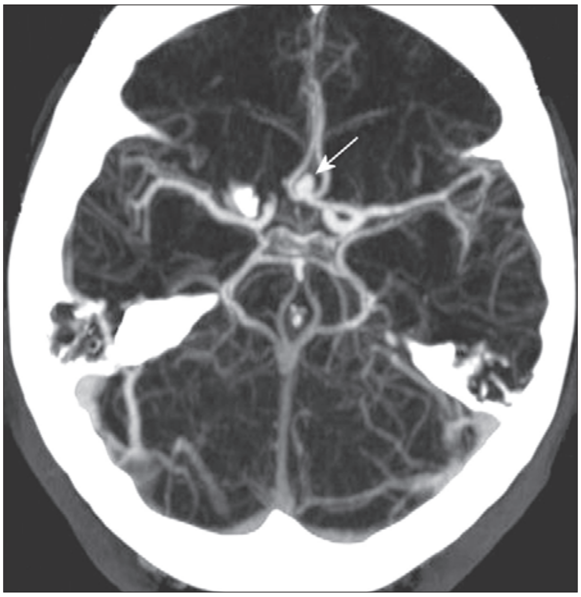

**Figure 1.** ACoA aneurysm directed anteriorly (arrow).

tive value, (PPV), and negative predictive value (NPV). They were also calculated separately for different aneurysm locations and sizes.

Taking into account the marked frequency of multiple aneurysms, which is estimated in the literature as 15–30% [25] and in our material as 25%, the authors decided that analysis of the efficiency of CTA would be referred to the aneurysm or to the area and not to the CTA study. Therefore, each assessed CTA study could be the source of one or several positive or negative results.

## Results

In the analyzed group of 436 patients, no aneurysms were detected by CTA in 127 cases (29.1%), while 369 aneurysms were suspected in 309 patients (70.9%). Among the patients with suspected aneurysms, 230 (74.4%) had a single aneurysm and 79 (25.6%) multiple aneurysms. The size of the suspected aneurysms ranged from 2 to 47 mm. The majority of the suspected aneurysms (335, 90.8%) were located in the ICA distribution (ACA-ACoA complex, MCA, and ICA) and only 34 (9.2%) were located in the vertebro-basilar system (mainly on BA).

Overall, among the 369 suspected aneurysms on the basis of the CTA studies, 355 were confirmed to be diagnosed correctly, while 14 foci of opacification were verified negatively (sensitivity 94.4%). In all 14 cases of the false positives, the CTA studies were considered ambiguous, with only a suspicion of an aneurysm but, according to the established criteria, they were classified as false positive results. On the other hand, none of the aneurysms assessed in CTA as certain or probable were the source of a false positive result. The negative CTA results in the whole group were verified in 521 "areas". There were 500 true negative results and 21 false negative results (specificity 97.3%).

The value of the diagnostic efficiency of CTA (including sensitivity, specificity, accuracy, positive and negative predictive values) for the whole group as well as for particular localizations are presented in the Table 1.

*Diagnostic efficiency of CTA depending on the location of the aneurysms*

Among the CTA studies of the ACA-ACoA complex, 134 aneurysms in 131 patients were found (Figures 1,2AB). In this group, 131 aneurysms were confirmed (true positive results), while 3 foci of opacification were verified negatively (false positive results). In one of the false positive cases two ACoA aneurysms were suspected, but only one irregular aneurysm was found intraoperatively and two other suspected small aneurysms turned out to be a dilated proximal A2 segment of an additional pericallosal artery and a vascular loop.

In 151 patients with a suspicion of an aneurysm in the ACA-ACoA area, CTA did not reveal any vascular malformation. Among these, negative CTA results were confirmed in 144 patients (true negative results). There were 7 false negative results, 6 of them involving the ACA-ACoA complex and 1 a pericallosal artery. Only in two of the six cases was the overlooked ACA-ACoA aneurysm a single one. In one of them the assessment was difficult due to the vasospasm; however, the aneurysm was visualized in a follow-up CTA. In the four other cases, the patients had two aneurysms, one of which was overlooked while the second was diagnosed correctly. The last overlooked 3-mm aneurysm on a pericallosal artery was found intraoperatively in a patient with SAH. CTA did not reveal it because it was located beyond the range of the performed

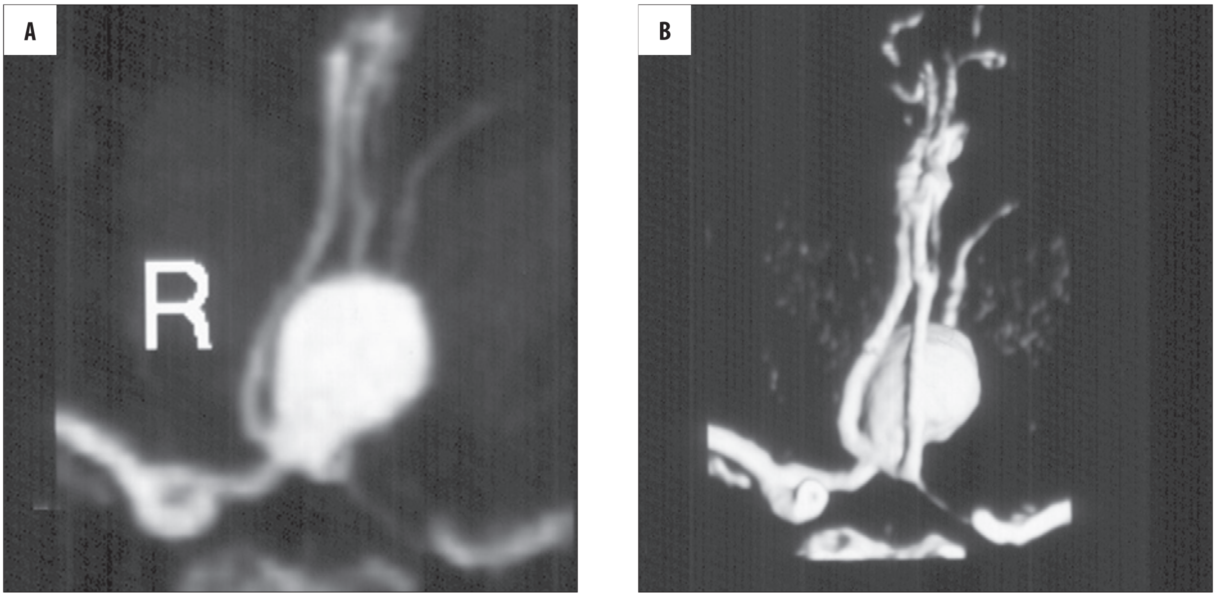

**Figure 2.** Large ACoA aneurysm, MIP (A) and VRT (B) reconstructions. VRT clearly shows the neck of the aneurysm.

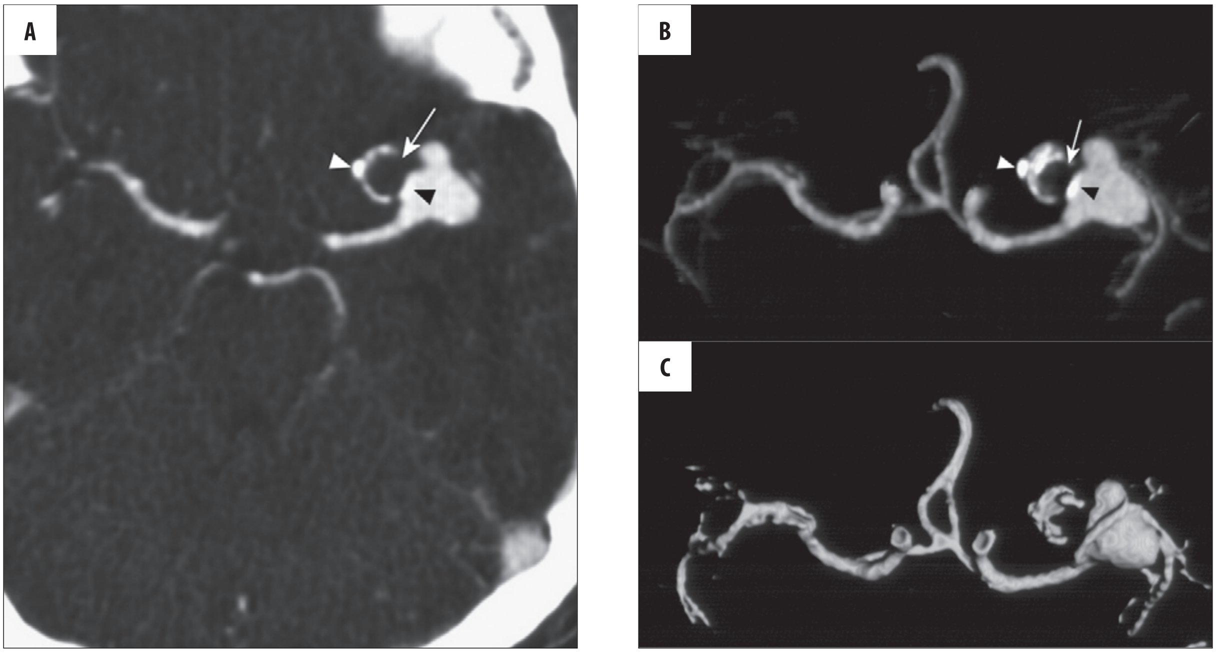

**Figure 3.** CTA: source image (**A**), MIP (**B**), and SSD (**C**) reconstructions. Large partially thrombosed (arrow) and calcified (arrow heads) aneurysm at the bifurcation of the left MCA. Thrombosis and calcifications can be best assessed on source and MIP images, while SSD reconstruction provides a good evaluation of the relationship between the aneurysm and the adjacent vessels.

study. In two cases, CTA revealed small (2- and 3-mm) ACoA aneurysms which were not visualized by angiography, but confirmed surgically. One of these cases involved the patient with the developmental variant of three pericallosal arteries.

Among the CTA studies of the MCA area, 101 aneurysms in 80 patients were suspected (Figures 3A–C,4AB). Ninety-nine of them were verified to be true findings (true positive results) and 2 foci of opacification suspected for aneurysms were not confirmed (false positive results). The latter involved patients with tortuous arteries and suspected aneurysms proved to be vascular loops. In one case it was verified angiographically (this patient also had one large aneurysm in the second division of the same artery which was correctly diagnosed in CTA). In the second case, the small focus of opacification in the division of MCA was also interpreted as an aneurysm by angiography, but intraoperatively it proved to be a vascular loop (this patient had three other aneurysms correctly diagnosed in CTA which were clipped during one operation).

One hundred and forty-seven negative CTA results of the MCA area were verified and 143 of them proved to be diagnosed correctly (true negative results) while there were 4 false negative results. Among the 4 overlooked MCA aneu-

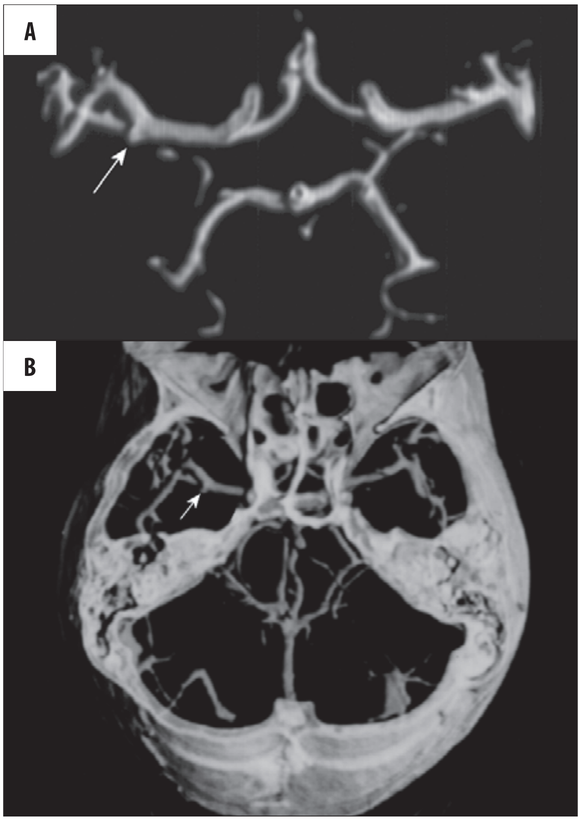

**Figure 4.** Small aneurysm (arrow) at the bifurcation of the right MCA on VRT images without (**A**) and with (**B**) bone structures. The latter view provides important information for the neurosurgeon concerning the relationship between the aneurysm and bone structures.

rysms, 2 were located atypically on the proximal part of the M1 segment (including one in the patient with severe atheromatic changes) and the two remaining ones were incidental aneurysms which accompanied other bleeding aneurysms (on ipsilateral MCA and ICA).

On the basis of the CTA studies, 100 aneurysms of the ICA area were suspected (Figures 5AB,6A–C). In this group, 95 aneurysms were confirmed (true positive results) and 5 foci of opacification were verified negatively (false positive results). In two patients the false positives concerned 4- and 2-mm foci of opacification which were located in the cavernous part of the ICA on the C4 and the border of the C4 and C5 segments. These foci were not confirmed angiographically as aneurysms and were probably part of the cavernous sinus. In two other patients the suspected ICA/PCoA aneurysms were proved angiographically to be dilated origins of the PCoA. The last false positive regarded the female patient with a proved ICA/PCoA aneurysm who was suspected to have a second aneurysm in the ICA bifurcation which, however, was not found during angiography.

Negative CTA results from 137 ICA areas were verified. In 127 cases they were confirmed (true negative results), while there were 10 false negative results (10 aneurysms in 10 patients). Eight of them concerned aneurysms located at the PCoA origin. In 3 cases a dilated origin of the PCoA was suspected instead of aneurysms. In 2 other cases, small additional aneurysms located adjacent to a larger, correctly diagnosed aneurysm were overlooked, and 3 remaining cases concerned small (<4 mm) aneurysms coexisting with correctly diagnosed bleeding aneurysms in other locations. In one patient the aneurysm at the origin of the ophthalmic artery with atheromatous changes (one of two in this location) was overlooked and in one case an ICA bifurcation aneurysm was not detected while another aneurysm at the PCoA origin was diagnosed correctly.

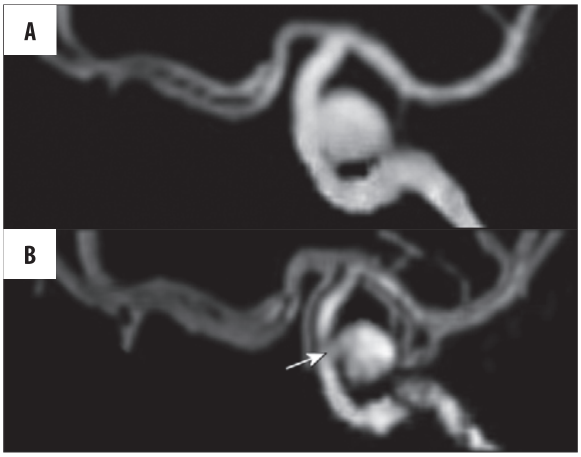

**Figure 5.** Large ICA/PCoA aneurysm on MIP (**A**) and VRT (**B**) images. The neck of the aneurysm (arrow) is very well delineated on the VRT image.

In one patient with extensive atheromatous changes, the CTA study revealed a 6-mm ICA/PCoA aneurysm which was not detected during angiography but confirmed surgically.

Thirty-four vertebro-basilar system aneurysms were suspected by CTA in 34 patients (Figure 7). Of this group, 30 aneurysms were confirmed (true positive results), while 4 foci of opacification were verified negatively (false positive results). All false results involved atheromatous vessels. Three foci of opacification wrongly diagnosed as aneurysms were located at the BA bifurcation. In the fourth false positive case, a 2-mm VA/PICA aneurysm was suspected in a patient with a large cerebellar hematoma, but intraoperatively it proved to be a tortuous vessel. Negative CTA results from the vertebro-basilar system were obtained in 86 patients, and all of them proved to be diagnosed correctly (86 true negatives, no false negatives).

*Diagnostic accuracy of CTA depending on the size of the aneurysm*

In the analyzed material there were no false results in the subgroup of 240 verified aneurysms larger than 5 mm. In the size subgroups of 1–3 mm and 4–5 mm, the numbers of positively verified aneurysms (true positive results) were 35 and 80, respectively. In those subgroups the numbers of aneurysms not detected by CTA (false negative results) were 10 and 11, respectively (Table 2). Therefore the sensitivity of CTA in the size subgroups 1–3, 4–5, and >5 mm was 73.8%, 87.9%, and 100%, respectively. The analysis of all factors which influenced the false results in our material are presented in the table (Table 3).

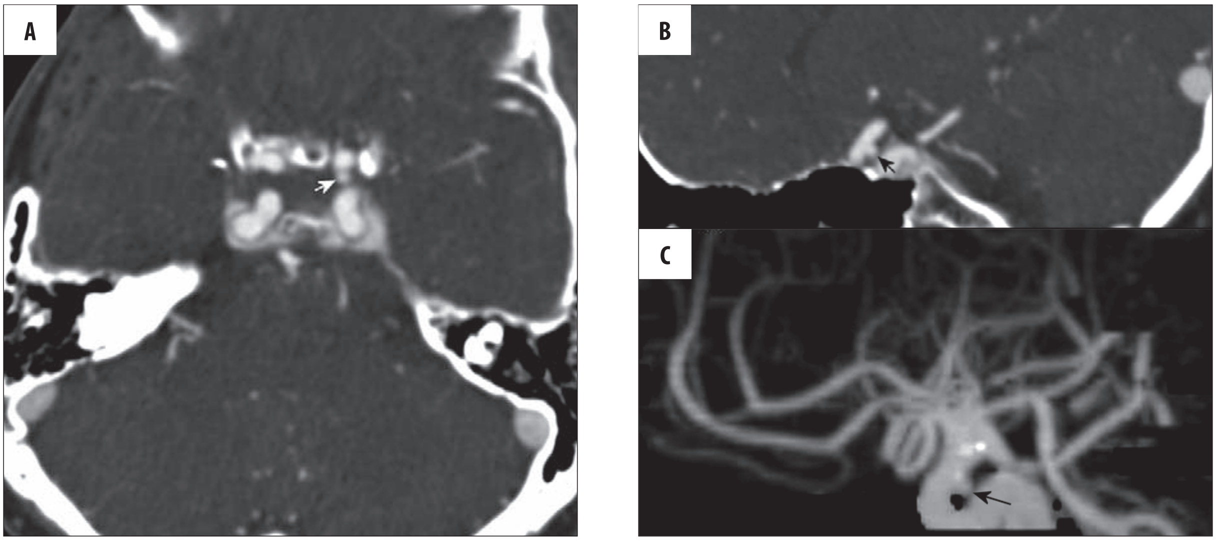

**Figure 6.** Small ICA aneurysm (arrow) on the source (**A**), MPR (**B**), and MIP (**C**) images.

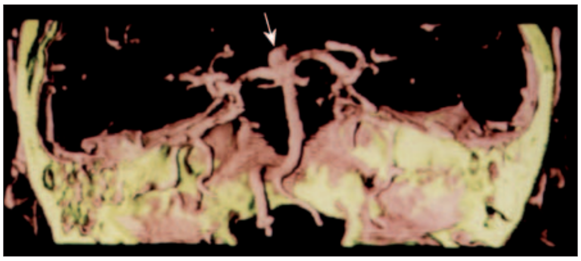

**Figure 7.** Basilar tip aneurysm (arrow). Colour-coded VRT reconstruction of vessels and bone structures, coronal view.

## Discussion

The first reports on the application of CT in detecting cerebral aneurysms originate from the late 1980s and were based on results from sequential CT units [26–28]. The long acquisition times of those studies did not enable sufficient opacification of the intracranial vessels, so they could not be used as an alternative to intra-arterial angiography. After introducing spiral CT units in the early nineties, CTA became a new method of diagnosing cerebral aneurysms [29,30]. However, due to the limited value of the first-generation CT units, lack of experience, and the small groups of patients, CTA was considered by most authors at that time only as a supplementary method to conventional angiography [31–34]. Only a few authors claimed satisfactory results with CTA and considered it a possible independent method, with a sensitivity of 97% and specificity of 86% [35]. Increasing availability and upgrading of the spiral CT scanners and their software caused a rapid development of the CTA technique in the late nineties [21,36,37]. Many authors concluded that in cases of obvious CTA appearances, conventional angiography may be abandoned, especially when the location of the detected aneurysm corresponds with the SAH distribution [21,38–40]. In some reports, CTA sensitivity in detecting aneurysms was close to that provided by DSA [22,41].

In the present study, the diagnostic efficiency parameters for all aneurysms, regardless of their size and location, are about 95%, with sensitivity exceeding 94% and specificity, accuracy, and positive and negative predictive values ranging from 96.0% to 97.3%. Our results are close to the highest values presented by other authors also using one-slice CT scanners [21,35,42]. The sensitivity of CTA in our material is higher than in the prospective meta-analysis published in 2003 by Chappel who, on the basis of the overall material of 1251 patients, calculated the sensitivity of CTA as 93.3% and specificity as 87.8% [43]. The obtained results are comparable with those published by Young et al. [35] who, to our knowledge, have evaluated the greatest number of patients examined in one institution (2000 patients in the period of 1993–1998) until now. In recent papers evaluating CTA studies performed on the new-generation multi-slice CT scanners [44–47], the results of efficiency parameters are approximately 95% [47,48], which are similar to our results. We are currently analyzing a new series of patients examined on a multislice scanner which will be published later.

Our results of PPV and NPV (96.2% and 96.0%, respectively) indicate high specificity in both detecting and excluding aneurysms. From the clinical point of view it is essential that CTA not only has a high sensitivity in detecting aneurysms, but also that it is not the source of many false positive results. In our study, the specificity of detecting aneurysms was 97.3%, but it would have reached 100% if we had not qualified the uncertain results to the positives. On the other hand, the uncertain results were always verified in the follow-up CTA or angiography, and thus did not result in unnecessary neurosurgical procedures. Only in two cases the uncertain results of CTA were negatively verified intraoperatively, but the decisions to conduct the operations were based on the patients' clinical state due to massive hemorrhages and not on the CTA results. There were no false positive results in patients with certain CTA diagnoses, and the PPV for this subgroup was 100%.

Our material of 436 patients who underwent CTA studies, including 309 patients with 355 aneurysms, enabled independent evaluation of efficiency for different areas of the intracranial arterial system. CTA had the highest diagnostic efficiency in detecting MCA aneurysms. The obtained

**Table 2.** Diagnostic efficiency parameters of CTA depending on the size of the aneurysm.

| Size of aneurysm [mm] | Number of results | | | Sensitivity of CTA [%] | PPV of CTA [%] |
|---|---|---|---|---|---|
| | TP | FP | FN | | |
| 1–3 | 35 | 8 | 10 | 77.8 | 81.4 |
| 4–5 | 80 | 6 | 11 | 87.9 | 93.0 |
| >5 | 240 | 0 | 0 | 100.0 | 100.0 |
| Any size | 355 | 14 | 21 | 94.4 | 96.2 |

TP – true positive; FP – false positive; FN – false negative; CTA – CT angiography; PPV – positive predictive value.

**Table 3.** Factors influencing false negative or false positive results of the CTA studies.

| Main factors influencing the results of CTA study | | Number (%) of false results | | |
|---|---|---|---|---|
| | | FN (n=21) | FP (n=14) | FN + FP (n=35) |
| Size of an aneurysm | ≤5 mm<br>≤3 mm | 21 (100.0)<br>10 (47.6) | 14 (100.0)<br>8 (57.1) | 35 (100.0)<br>18 (51.5) |
| Localization on the ICA | | 10 (47.6) | 5 (35.7) | 15 (42.8) |
| Localization at the PCoA origin | | 8 (38.1) | 2 (14.3) | 10 (28.6) |
| The presence of other adjacent aneurysms | | 8 (38.1) | 3 (21.4) | 11 (31.4) |
| The presence of remote aneurysm | | 8 (38.1) | 6 (42.9) | 14 (40.0) |
| Severe atheromatous changes | | 4 (19.0) | 3 (21.4) | 7 (20.0) |
| Vasospasm | | 2 (9.5) | 2 (14.3) | 4 (11.4) |
| Technical and motion artifacts | | 4 (19.0) | 1 (7.1) | 5 (14.3) |

CTA – CT angiography; FN – false negative; FP – false positive; ICA – internal carotid artery; PCoA – posterior communicating artery.

parameters (sensitivity 96.1%, specificity 98.6%, accuracy 97.6%) are similar to the results of Villablanca et al. [24], who calculated CTA sensitivity in detecting MCA aneurysms as 97%. The high efficiency of CTA in MCA aneurysms seems to result from their location far from bone structures, thus allowing easy assessment of both source and reconstructive images. Very small aneurysms of the MCA division may be difficult to detect on source images; however, 3D reconstructions usually allow their precise assessment. The main diagnostic problems which were noted in our material were atypical proximal M1 location and marked tortuosity of the MCA branches.

In the ACA-ACoA complex, the sensitivity, specificity, and accuracy of CTA were slightly lower than in the MCA region (94.9%, 97.9%, and 96.5% respectively). The high CTA efficiency in detecting ACA-ACoA aneurysms, like in the MCA aneurysms, seems to result from their location far from bone structures and easy assessment of both source and reconstructive images. Many aneurysms in this location are quite often diagnosed even on conventional, contrast-enhanced CT scans. Imakita et al. noted that the inferior view of 3D reconstruction is particularly useful in evaluating ACoA aneurysms, and this was proved in one of our cases in which only this view visualized the aneurysm. It has to be stressed that the inferior view is hardly available in conventional angiography [49]. Apart from the anatomical variants and cases of multiple aneurysms of the ACA-ACoA complex, the main diagnostic problems were caused by the low position of ACoA close to the tuberculum sellae and sphenoid plane. On the other hand, hypoplasia of the A1 segment of the ACA, which is the most common anatomical variant in this area, usually does not cause interpretive problems; moreover, it helps to define the side from which the aneurysm is supplied [50]. In the analyzed material there were nine double ACoA aneurysms (7.4%). Although such a diagnosis does not influence qualification for a neurosurgical or endovascular procedure, it is undoubtedly important in planning such procedures.

The lowest CTA sensitivity (90.4%) was noted for the ICA region. The main reasons for the lower efficiency of CTA in ICA aneurysms, also emphasized by other authors [19,23,39,51], are the vicinity of bone structures and the cavernous sinus as well as the common occurrence of atheromatous changes and a characteristic infundibulum-like shape of the origin of the PCoA. The latter occurs in 5-10% of cases and is defined as a local dilatation of the PCoA, not exceeding 3 mm, with its distal end continuous with the further course of the PCoA [52]. Such dilatations are generally considered as clinically insignificant, although there were reports of hemorrhage caused by the rupture of the "infundibulum" [11] as well as its transformation to an aneurysm [53]. In our material, 8 of 10 undiagnosed ICA aneurysms were located near the PCoA origin and in 3 of these cases, infundibulum of the PCoA was suspected. On the other hand, 2 of 5 false positive results concerned the ICA/PCoA region and the suspected aneurysms proved to be dilated origins of the PCoA. Diagnostic difficulties in differentiating aneurysm and the infundibulum of the PCoA are emphasized by many authors [21,41,54,55,56], who claim that this can be caused by the limited capability of CTA to visualize small-caliber vessels, including the PCoA. According to Nakano et al., CTA with a collimation of 1 mm and a pitch of 1 allows the demonstration of 70–80% of 1-mm arteries, 20–30% of 0.5-mm arteries, and less than 10% of the vessels below 0.5 mm. On the other hand, DSA demonstrates the PCoA in less than half of cases [50] and not always enables a clear differentiation between the "infundibulum" and an aneurysm.

Among the five false positive results, two were caused by strong enhancement of the cavernous sinus, which obscured the outline of the intracavernous part of the ICA. The difficulties in the assessment of intracavernous ICA aneurysms are emphasized by Strayle-Batra et al. [55] and Villablanca et al. [22]. On the other hand, they also concluded that the intracavernous fat that separates the sinus from the ICA usually enables correct diagnosis of aneurysm. Baron [19] indicated that CTA acquisition time should not exceed 30–40 s to make opacification of the cavernous sinuses as weak as possible. In our material, the ICA bifurcation was also the cause of two misdiagnoses, resulting in one false negative and one false positive result. Small ICA bifurcation aneurysms, which are usually located parallel to the long axis of the C1 segment of the ICA, may be difficult to identify on the source images, in contrast to other ICA aneurysms, which are usually perpendicular to the long axis of the artery.

It should be emphasized that in the ICA area, due to the proximity of bone structures and cavernous sinuses as well as tortuosity of the ICA, 3D reconstructions are of limited value and analysis of the source images, supplemented by 2D reconstructions, plays the crucial role [19,22,23,51].

In our study, the size of an aneurysm was one of the most important features influencing the diagnostic efficiency. The sensitivity of detecting aneurysms larger than 5 mm was 100%, while corresponding values for 4- to 5-mm aneurysms and those not exceeding 3 mm were 96.7% and 77.8%, respectively, with the positive predictive values of CTA for those subgroups estimated as 100%, 98.2%, and 81.4%, respectively. Early studies on the usefulness of CTA in diagnosing cerebral aneurysms reported its low efficiency in detecting small (≤5 mm) and very small (≤3 mm) aneurysms. Dillo et al. [57] claimed that due to its low spatial resolution, CTA had a limited value in detecting aneurysms <5 mm and thus could not be a method of excluding aneurysms. Ogawa et al. [58] calculated the sensitivity of CTA in detecting aneurysms <5 mm as only 24%, and 5–7 mm aneurysms as 64%, and other authors indicated that it is useful only in large aneurysms [30,59]. White et al. [60], on the basis of a meta-analysis to 1998, assessed the sensitivity of CTA in aneurysms >3 mm at 96% and for aneurysms ≤3 mm at only 61%.

Comparing these results with our material, we note a marked improvement in CTA sensitivity in small and very small aneurysms, which is very important in establishing CTA as an alternative method to angiography. One hundred percent efficiency in detecting aneurysms >5 mm in our material is of great clinical value. There is even a tendency to increase CTA efficiency in diagnosing small aneurysms with the use of the new-generation multi-slice CT scanners. Korogi et al. [61] and Dammert et al. [62], using four-slice CT units, calculated the sensitivities in detecting 3–4 mm aneurysms as 84% and 83%, respectively, which is similar to what we found in our material. To our knowledge, the best results in detecting small aneurysms with CTA were presented by Villablanca et al. [22], who calculated CTA sensitivity in diagnosing aneurysms <5 mm to be 95% referred to DSA and 100% referred to surgery; however, they analyzed a small group of 25 patients.

The next important factor influencing aneurysm detection by CTA was the coexistence of other aneurysms, both in adjacent and remote areas. In our material, 25.5% of the patients had multiple aneurysms, while it was nearly 40% in the subgroup of patients with false negative results. Similar results were reported by Anderson et al. [38], who noted false negative results in 24 of 174 patients and all of them involved incidental, small (below 4 mm) aneurysms in patients with multiple aneurysms. The lower diagnostic efficiency of CTA in detecting incidental aneurysms was also stressed by Gonzales et al. [63] and Velthuis et al. [56], who analyzed the sensitivity of CTA separately in detecting bleeding aneurysms (verified surgically) and incidental ones (verified angiographically). A possible explanation for this problem is the suggestion of the location of a suspected aneurysm by SAH distribution [64] and the usually larger size of symptomatic vs. incidental aneurysms [65]. In patients with multiple aneurysms, an additional factor may be the lower "diagnostic awareness" of the radiologist after identifying symptomatic lesion. This was also noted by Villablanca et al. [23], who indicated that one of the overlooked aneurysms in their material was located on a vessel supplying a large arteriovenous malformation.

In approximately 20% of the false diagnoses there were severe atheromatous changes and/or tortuous course of the intracranial arteries, which made interpretation of the study more difficult. Pedersen et al. indicated these factors as one of the main causes of the false positive results [66].

Many authors noted cases of aneurysms overlooked in angiography, but detected in CTA and then confirmed intraoperatively [23,32,41,67,68]. Hashimoto et al. [67] reported six small aneurysms (five on the ACoA and one on the MCA) detected with CTA despite negative results found in angiography. Matsumoto et al. [41] described a 0.8-mm aneurysm of the ACoA overlooked in angiography, but diagnosed in CTA and confirmed surgically. Villablanca et al. [23] claim that false negative results of angiography concern mostly very small aneurysms which are overlapped by vessels, especially in cases of the anatomical variants of the Willis's circle. Takabatake et al. [68] reported cases of aneurysms which were visible on additional angiographical projections designed on the basis of CTA. In our material, CTA revealed two ACoA and one ICA aneurysm which

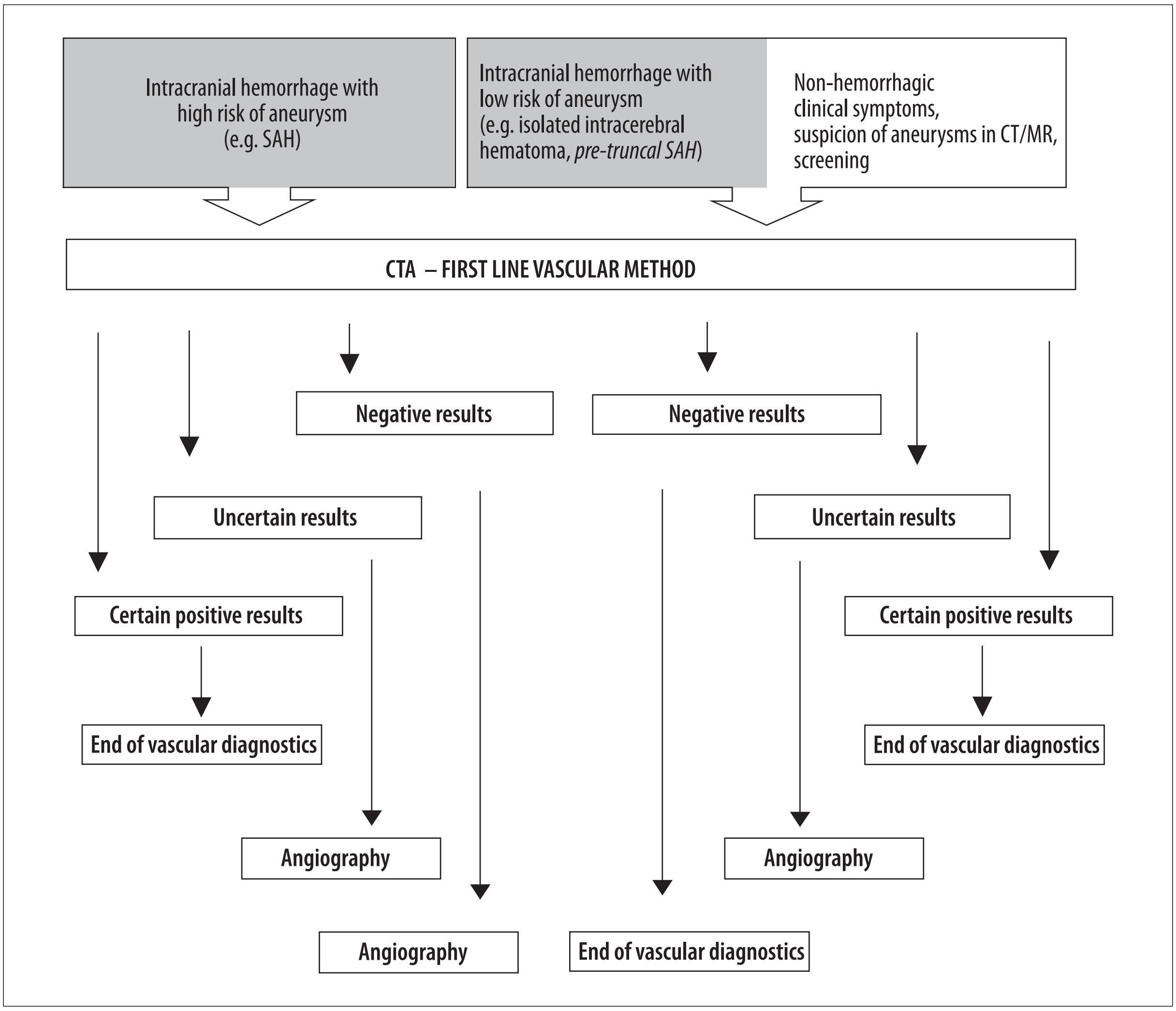

**Figure 8.** The diagnostic algorithm in patients with a suspected cerebral aneurysm.

were not detected in angiography, but were confirmed surgically. In one ACoA aneurysm, the false negative result of angiography was probably caused by an anatomical variant: triple pericallosal artery. In the ICA aneurysm, the false negative result of angiography was probably caused by severe atheromatous changes. Many authors stress the value of atypical projections of CTA in diagnosing small aneurysms [19,23,40,41,69]. Villablanca et al. [23] described two tiny ACoA aneurysms which were visible only in several CTA projections which cannot be obtained with standard angiography. However, it should be stressed that in both the papers mentioned above and in our material, CTA was compared with standard angiography. Three-dimensional angiography, which is becoming more and more available, is more efficient in detecting and assessing small aneurysms and, according to Piotina et al. [70], is superior to CTA.

The improved efficiency of CTA in the diagnostics of aneurysms and the increased confidence in the new method have recently resulted in a growing number of patients qualified for neurosurgical or endovascular procedures exclusively on the basis of CTA. The first cases of patients who had emergency operations based only on the CTA results were reported by Le Roux et al. in 1993 [71]. Velhuis et al. [56] analyzed retrospectively 87 CTA studies and found that in 64 patients (73.6%) with symptomatic aneurysms, the qualification to surgery was based on CTA only, while in the remaining 23 cases, DSA had to be performed due to unclear appearances of CTA. The same authors analyzed prospectively 51 patients [21]. Twenty-three of them (45.1%) were operated on without DSA, and among those who had DSA, only in two cases it provided any additional information.

The first larger group (93 patients) with ruptured aneurysms operated on on the basis of CTA was described by Matsumoto et al. in 2001 [41]. The same authors, in a subsequent paper from 2002, analyzed a group of 128 operated patients with ruptured aneurysms, among whom the diagnosis was based on the CTA results in 121 cases (94.5%) [72]. Only in 7 patients with BA bifurcation aneurysms and suspicion of dissecting aneurysms CTA was followed by angiography. In the material of Dehdashti et al. [73], of 100 patients with SAH, qualification for neurosurgical (61) or endovascular (26) procedures was based on CTA in 89 cases, and unclear CTA appearances required performing DSA only in 11 cases.

Our material shows the constant marked increase in the number of patients operated on only on the basis of CTA. From the group of 316 operated patients, 264 subjects (83.5%) were qualified for the operation only on the basis of the CTA study. In the first year of performing CTA, 40% of patients were referred to angiography due to doubts in the interpretation of the CTA appearances. In the following years, the percentage of cases requiring angiographic verification gradually decreased and reached 7.7% in the fifth year, which is comparable with the data presented by the authors mentioned above [41,73].

In our opinion, CTA is an excellent method for diagnosing cerebral aneurysm, although it has its limitations, such as insufficient sensitivity in cases of very small aneurysms. However, it is worth remembering that intra-arterial cerebral angiography also has a limited ability to diagnose very small aneurysms. The diagnostic efficiency of both CTA and DSA will increase in the future due to technical development and the introduction of multi-slice CT units as well as 3D rotational angiography; thus the competition between these two method will continue.

In the authors' opinion, there is no need to establish definitely the superiority of either of these methods. Both CTA and angiography can play an important role in the clinical process of managing patients suspected for cerebral aneurysms and should be treated as complementary methods. In our opinion, CTA should be the first-line method for all patients with suspected aneurysm, the basic method for patients treated surgically, and the preliminary method in patients treated endovascularly. On the other hand, angiography should be used first of all in interventional neuroradiology cases and as a supplementary method in patients with unclear CTA appearances.

The great advantage of CTA in patients with acute intracranial hemorrhage is the possibility to perform it directly after plain head CT. We believe that CTA should be performed routinely in patients with diagnosed intracranial hemorrhage. In this group, a positive CTA result enables one to stop vascular diagnostics and perform neurosurgical procedures without the delay caused by intra-arterial angiography. On the basis of our results and long experience, with very good cooperation with neurosurgeons, we propose the diagnostic algorithm in patients with a suspected cerebral aneurysm as shown in the figure (Figure 8).

## Conclusions

1. CTA using a one-slice CT scanner is a very valuable method for diagnosing intracranial aneurysms.

2. In patients suspected of cerebral aneurysms, CTA is a minimally invasive, easy to perform, fast, and inexpensive method and should be a primary modality of vascular diagnostics.

3. In most patients, diagnosing an aneurysm in CTA does not require confirmation in angiography and provides sufficient information for planning surgical or endovascular procedures.

4. CTA and angiography should be complementary techniques: uncertain CTA results should be verified in angiography and uncertain angiographic examinations should be followed by CTA studies.

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