O R I G I N A L A R T I C L E

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Assessing the quality of angiographic display of brain blood vessels aneurysms compared to intraoperative state

Procena kvaliteta angiografskog prikaza aneurizmi krvnih sudova mozga u odnosu na intraoperativni nalaz

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Abstract

Background/Aim. Aneurysms in brain blood vessels are expanding bags composed of a neck, body and fundus. Clear visibility of the neck, the position of the aneurysm and surrounding structures are necessary for a proper choice of methods for excluding the aneurysm from the circulation. The aim of this study was to evaluate the reliability of spatial reconstruction of blood vessels of the brain based on the original software for 3D reconstruction of the equipment manufacturer and a personal computer model developed earlier in the Clinic for Neurosurgery, Clinical Center of Serbia, Belgrade, compared to intraoperative identification of these aneurysms. **Methods.** This study included 137 patients of both sexes. The presence of an aneurysm was verified by angiographic methods [computed tomographic angiography (CTA), multislice computed tomography angiography (MSCTA), magnetic resonance imaging angiography (MRA), or digital subtraction angiography (DSA)]. **Results.** The quality score (0 to 5) for CTA was 3.180 ± 0.961, MSCTA 4.062 ± 0.928, and for DSA 4.588 ± 0.758 ($p < 0.01$). The results of this study favorite conventional angiography as the gold standard for diagnostic of intracranial aneurysms. **Conclusion.** The results of this study are consistent with current publications review and clearly recognize the advantages and disadvantages of diagnostic neuroradiological procedures, with DSA of brain blood vessels as a binding preoperative diagnostic procedure in cases in who it is not possible to clearly visualize the supporting blood vessel and neck of the aneurysm by using the findings of CTA, MRA and MSCTA.

Key words:
intracranial aneurysm; diagnosis; angiography; tomography, x-ray computed; magnetic resonance angiography; angiography, digital subtraction.

Apstrakt

Uvod/Cilj. Aneurizme na krvnim sudovima mozga predstavljaju vrećasta proširenja kod kojih se razlikuju vrat, telo i fundus. Jasna vizualizacija vrata, položaj aneurizme i odnos sa okolnim strukturama su uslov za adekvatnu odluku o izboru metode za isključenje aneurizme iz cirkulacije. Cilj ovog rada bio je da se proceni pouzdanost prostorne rekonstrukcije krvnih sudova mozga zasnovane na originalnom softveru za 3D rekonstrukciju proizvođača opreme i personalnom kompjuterskom modelu ranije razvijenom u Neurohirurškoj klinici Kliničkog Centra Srbije u odnosu na intraoperativnu identifikaciju ovih aneurizmi. **Metode.** Ova studija obuhvatila je 137 bolesnika oba pola (90 žena i 47 muškaraca). Prisustvo aneurizmi verifikovano je jednom od angiografskih metoda: kompjuterizovanom tomografskom angiografijom (CTA), multislajsnom kompjuterizovanom tomografskom angiografijom (MSCTA), angiografijom magnetnom rezonancom (MRA) ili digitalnom suptrakcionom angiografijom (DSA). **Rezultati.** Ocena kvaliteta (skor od 0 do 5) za CTA bila je 3,180 ± 0,961 za, MSCTA 4,062 ± 0,928, i za DSA 4,588 ± 0,758 ($p < 0.01$). Rezultati ove studije favorizuju konvencionalnu angiografiju kao zlatni standard u dijagnostici aneurizmi. **Zaključak.** Rezultati ove studije u skladu su sa pregledom aktuelnih publikacija i jasno prepoznaju dijagnostičke prednosti i nedostatke neuroradioloških procedura, pri čemu se DSA krvnih sudova mozga izdvaja kao obavezujuća preoperativna dijagnostička procedura kod bolesnika kod kojih nije moguća jasna vizualizacija nosećeg krvnog suda i vrata aneurizme na osnovu nalaza CTA, MSCTA i MRA.

Ključne reči:
aneurizma, intrakranijalna; dijagnoza; angiografija; tomografija, komjuterizovana, rendgenska; magnetna rezonanca, angiografija; angiografija, digitalna suptrakcijska.

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Introduction

Aneurysms in brain blood vessels are expanding bags composed of a neck, body and fundus. A connection, an interaction between the neck and the body is not constant and determined, thus, there are small wide neck aneurysms, but also giant aneurysms with small necks. Clear visibility of the neck, the position of the aneurysm and surrounding structures are necessary for making a proper decision on methods for excluding an aneurysm from the circulation. In addition to conventional digital subtraction panangiography (DSA) of brain blood vessels [1], the development of sophisticated diagnostic procedures – computed tomography (CT) and magnetic resonance imaging (MRI) has enabled noninvasive imaging technology of blood vessels of the brain: CT angiography (CTA), 3D multislice (MSCT) angiography (MSCTA) and magnetic resonance angiography (MRA) [2].

Today's CTA technology allows visualization of aneurysm diameters greater than 0.7 mm, the console stand-out point of 100–120 HU, and shows only lumens of blood vessels with contrast and bone [3]. But despite this, the specified diagnosis is commonly used in many institutions as a screening method of choice, and sometimes even 3D-CTA is used as the sole diagnostic method [4–8].

Digital subtraction angiography (DSA) is based on digital elimination of bony structures so that the image shows an isolated artery in which we inject an iodine contrast agent. This is achieved by increasing the resolution until it reaches the value of 0.05 mm or by increasing the number of shoots until it reaches the number of 4–6 frames per second. 3D DSA is a software model based on rotational angiography that can show the fine structure of brain blood vessels, and this method is more accurate than standard DSA [9–11].

MRA is a noninvasive technique based on time-of-flight (TOF) sequences and contrast-enchanced MR (CEMR). There is a problem of spatial resolution, and the minimum detection volume is 3 mm [12]. It is possible to visualize aneurysm diameters less than 3 mm and is usually to detect those larger than 5 mm [13, 14]. Despite the developed software, sensitivity is less than that of DSA and is about 86–95% with a resolution of 0.2 mm^2. [8, 15–17], making it ideal as a noninvasive screening procedure [12, 14, 18].

Despite technological advances, digital DSA remains the gold standard for diagnosis. Newer methods, unfortunately, have much lower accuracy in the diagnosis [19, 20]. Microaneurysms can be visualized almost by the use of the DSA [8].

The aim of this study was to evaluate the reliability of spatial reconstruction of blood vessels of the brain based on the original software for 3D reconstruction of the equipment manufacturer and a personal computer model developed earlier in the Clinic of Neurosurgery at the Clinical Center of Serbia [21, 22] compared to the intraoperative identification of these aneurysms.

Methods

This study included 137 patients of both sexes. The presence of an aneurysm was verified by the angiographic methods (CTA, MSCT, MRA, or DSA). The analysis included patients who fulfiled the following requirements: clinically, lumbar puncture (LP) and endocranial CT verified attack of spontaneous subarachnoid hemorrhage (SAH); one or more aneurysms of the anterior cerebral artery stream of the base of the brain were verified using one or more angiographic procedures, made surgery or embolization; aneurysms of the carotid artery trunk (according to the small number of surgically treated aneurysms of the vertebrobasilar trunk).

In the analysis were used angiographic findings, spatial reconstruction of blood vessels of the brain based on the original software for 3D reconstruction of the equipment manufacturer, and based on computer models previously developed in our Clinic [21, 22].

A score of 0 to 5 was given to each angiographic finding according to the following criteria: aneurysm verification (negative findings exclude other criteria), aneurysm shape (0/1), aneurysm size (0/1), aneurysm orientation (0/1), aneurysm relationship to the carrying blood vessel (0/1), relationship of the aneurysm with perforators (0/1).

Aneurysm morphometric analysis, a comparative analysis of angiographic findings, and comparison of the quality of angiography in relation to the intraoperative findings were entered into questionnaire, followed by descriptive (measures of central tendency and dispersion measures), and analytical statistics. We used parametric (*t*-test) and non-parametric tests (χ^2 test, and median), as well as correlation tests (linear correlation and regression).

Data analysis was performed on a personal computer with Intel processor (generation of Intel Pentium III at 950 MHz, Intel QuadCore 6600 in the 2GHz Intel T6500 CoreTM2 Duo at 2.1 GHz) with a graphics card from Nvidia TNT 2 Pro with 32 MB, and Gforce Gforce G105M 8800 with 512 MB VRAM. Digitalisation of images when it was not in DICOM format was done using a scanner A4 HP ScanJet 5P (300 to 1200 dpi) and PoweShot camera Canon A710 IS (7.1 Mpixel).

Results

A total of 137 patients of both sexes (90 women and 47 men), the mean age 50.39 ± 8.25 years, were included in the study. The mean ages of the female and male patients were 52.15 ± 6.64 years, and 46.84 ± 9.96 years, respectively. The youngest patient was a 21-year-old and the oldest one a 72-year-old. There were 185 aneurysms in observed group: 164 (88.65%) were located in the carotid stream and 21 (11.35%) in the vertebrobasilar stream. The distribution of aneurysms by the carrying artery is shown in Table 1.

In 52 (37.96%) patients angiography was performed by using CTA. In 33% cases it was the only method of preoperative angiography. There were 17 diagnosis that were supplemented by DSA, and in 2 patients with MSCTA. In 9 (17.31%) patients, CTA was initially falsely negative, which was later confirmed by the subsequent diagnosis using DSA or MSCT. The largest number of false negative results was related to the internal carotid artery (ICA) (5).

Table 1

Carrying artery aneurysms distribution

Artery	Number
Internal carotid artery (ICA)	50
Anterior cerebral artery (ACA-A_1)	2
Anterior communication artery (AcoA)	41
Pericallosal artery (PA)	4
Medial cerebral artery (MCA)	67
Posterior cerebral artery (PCA)	3
Basilar artery (BA)	8
Superior cerebral artery (SCA)	4
Inferior anterior cerebral artery (IACA)	1
Posterior inferior cerebral artery (PICA)	3
Vertebral artery (VA)	2

A quality score was determined by CTA in 50 patients because ICA occlusion in the neck was found in 2 patients, and aneurysm was not visualized intraoperatively. The reliability score was 3.18 ± 0.96 with a median (Med) = 3. MSCTA was performed in 18 patients. Only in 5 patients it was the only method that was performed. A false-negative finding was observed in one patient with aneurysm on the anterior communication artery (AcoA) complex. Here, the aneurysm was confirmed with DSA and intraoperatively. In 13 patients, MSCTA was supplemented with DSA.

A quality score was determined by MSCTA in 16 patients, because in 2 patients embolization was performed, and aneurysm was no interoperatively visualized. The score was 4.06 ± 0.93 with a Med = 5

MRA was performed as initial diagnostic method in 12 patients during the acute phase of illness when they hospitalized in other centers. After diagnosing spontaneous subarachnoid hemorrhage caused by ruptured aneurysm they were referred for further treatment in the Clinic of Neurosurgery, Clinical Center of Serbia. All the patients underwent additional angiographic diagnosis by using DSA (11 patients) or CTA (4 patients).

It was shown that by using CTA significantly lower score for ICA aneurysm angiographic finding quality was obtained in comparison with the score obtained by using DSA. Statistically significant difference was not found between CTA and DSA in scores for medial cerebral artery (MCA) and AcoA aneurysm angiographic finding quality.

Due to the small number of patients submitted to MRA, which was not the only diagnostic procedure in neither case, statistical analysis of this method was not performed. Also, MRA was not performed on the same equipment in neither case, but at different magnetic fields (from 1.0 to 3.0 T).

DSA was performed in 97 patients. In 66 of the patients DSA was the only angiographic method for verification of intracranial aneurysms. In the remaining cases (n = 31), conventional angiography was the additional diagnostic procedure in preparing patients for surgery.

In all the patients angiography was performed for 3D reconstruction. In 46 patients 3D rotational angiography was performed as a part of diagnostic procedure, while the 51st patient subsequently made a spatial reconstruction based on 2D images and protocol for reconstruction in MatLab.

The quality score of DSA was determined in 71 patients submitted to direct intracranial aneurysm surgery. For other patients, occlusion was performed by endovascular procedure. The aneurysm was not visualized interoperatively. The quality score was 4.59 ± 0.76 with a Med = 5. If we compared DSA scores for MCA, ACA and ACI aneurysm visualization finding no statistically significant differences were found.

After evaluating reliability analysis for each of the diagnostic procedures used, comparative analysis among the differnet diagnostic procedures was done, with the exception of MRA. Table 3 shows the results of testing comparative reliability quality scores of CTA, MSCTA and DSA.

Table 2

Mean quality score of computed tomography angiography (CTA) and digital subtraction angiography (DSA) for carotid aneurysms

Carrying artery	CTA		DSA	
	mean	SD	mean	SD
MCA	3.48	1.40	4.65	0.80
AcoA	3.41	1.003	4.63	0.83
ICA	2.33	1.37	4.41	0.71

MCA – medial cerebral artery; ICA – internal carotid artery; AcoA – anterior communication artery.

Table 3

The results of the *t*-test for comparison of angiographic methods

Angiographic method	*t*	DF	*p*
CTA/MSCTA	3.222	64	< 0.01
CTA/DSA	8.310	119	< 0.01
MSCTA/DSA	2.080	85	< 0.05

CTA – computed tomography angiography; MSCTA – multislice computed tomography angiography; DSA – digital subtraction angiography.

Discussion

In the observed group of patients standardized CTA was performed in 52 patients, while MSCTA was performed in 18 patients. MSCTA was performed in a much smaller number of cases because the equipment was purchased later (it entered in the second half of the study). False negative findings on CTA were found by the subsequent additional diagnostics (DSA or MSCTA) in 9 (17.31%) patients, while 5 of them had the ICA aneurysms. When evaluating the reliability of methods for intracranial aneurysms detection and its relationship with the supporting blood vessel and perforators, CTA assessment received score of 3.18 ± 0.96, and MSCTA 4.06 ± 0.93 (found only one false-negative finding). Despite of almost equal quality of CTA and DSA for detection of middle cerebral artery aneurysms, the grades observed sample was considerably different and there was a statistically significant difference in Korst DSA as a better method [23]. On the other hand, Dehdasti et al. [24] in comparative analysis indicate that CTA is still insufficient compared to DSA.

Because of the fact that the accuracy in the diagnosis of intracranial aneurysms according to literature data is about 84.6%, we emphasize that our findings are consistent with the literature [25]. This lack of precision primarily relates to the detection of small aneurysms, subtraction bone in infraclinoid aneurysms, the lack of the knowledgable of radiologists, and artifacts that give previously placed clips or coil [3, 26–31]. The problem with small aneurysms detection, and increased accuracy compared to standard CTA that works on a four- or 16-slice aparatus 64MSCTA somewhat beyond, and it can be almost comparable with the standard 2D DSA [26, 32]. But still for aneurysms less than 4 mm a combination of DSA with 3D rotational angiography (3DRA) is the method of choice [33]. Also, the development of "dual-energy direct bone removal" CTA technique (DE-BR-CTA) was started in the late 70s, has enabled great progress in subtraction bone structures in MSCT, thus the image quality is much closer to conventional angiography [32, 34]. 64MSCTA can be used as an initial diagnostic procedure and to assess whether it is suitable for direct aneurysm surgery or embolization, given the possibility of 3D reconstruction in subtraction [32]. A significant progress in subtraction resulted in orbital synchronized helical scan (OSHST) technique that allows a piston or a subtraction coil on postoperative recordings [35]. However, despite the development of all CT, angiography is limited in diagnosing aneurysms of the posterior stream [36].

Despite the shortcomings CTA and MSCT are not only used as initial diagnostic procedure and the screening method of choice, but in some establishments 3D-CTA is used as the sole diagnostic method for preoperative treatment of patients with spontaneous subarachnoid hemorrhage [4–8, 37, 38]. We should not ignore the cost of diagnostic procedures, because the cost of 3D CTA is significantly lower than the cost of DSA, and can be considered as the method of choice in screening [39]. Due to lower prices and a small number of complications, this method is very suitable for postoperative monitoring and evaluation, as well as the only diagnosis in elderly patients with degenrative altered blood vessels, where catheter placement is difficult [40, 41].

Conventional angiography is an invasive method for radiological detection of blood vessels and their pathological changes. The biggest positive step forward is made by the introduction of digital substraction and computer models with which we eliminate the bone structure. DSA with spatial reconstruction is the gold standard in diagnosing intracranial aneurysms [42–44]. Also, van Rooij et al. [45, 46], in their studies emphasize the advantage of rotational angiography over conventional angiography for detection of small aneurysms. They believe that negative DSA angiographic findings should be done by the 3D-DSA, because in a great number of cases small aneurysms can be detected with this method [45]. According to Hai et al. [47] it is of great benefit in planning 3DRA embolization of small aneurysms, the procedure itself reduces the radiation dose in comparison to conventional DSA.

However, Hirai et al. [48] stress that the lack of methods is false pseudostenosis of the intracranial blood vessels. This phenomenon is related to the angle at which it is rotational angiography and length of blood vessel [48]. A reduction in artifacts of pseudostenosis solved by the introduction of flat panel detector (FPD) system [49].

In more than 2/3 (70.8%) of the patients in the observed group DSA was performed. Study on comparative analysis of biplanar DSA and 3D angiography demonstrated the advantages of 3-dimensional images, suggesting that all patients should be subjected to it for spatial reconstruction of brain blood vessels and intracranial aneurysms. It is done either in the form of 3DRA as a part of standard diagnostic apparatus using the Siemens Axiom Artis, or in the form of computer reconstructions based on MatLab biplanarnih shots (PA and lateral projections) [21, 22, 50–52].

False negative findings were not found in any case, reliability score was performed in 71 patients with direct aneurysm surgery. DSA with spatial reconstruction in the observed group received a high score of 4.59 ± 0.76. This relatively higher score of reliability is consistent with literature. DSA with 3D angiography is still considered to be a gold standard, because of the fact that microaneurysms can be visualized almost by the use of the DSA [8, 42, 45, 53, 54]. Imperfections in the diagnosis among other things can be explained by Jou et al. [55]. Artifacts can be created by the effect of pulsations, gravity and unequal density and contrast levels.

Aneurysms of various localization were slightly less noticeable than aneurysms in ICA, but if we compare the grades among themselves there were no statistically significant differences ($p > 0.05$). It is not a small problem in the conversion of pixels as the relative size in millimeters, *ie.* real size. Fox et al. [56] conducted a study on comparative analysis of digital angiography in different picture archiving and communication systems (PACS). Kawashima et al. [57] emphasize that there are differences in morphometric measurements between biplanar DSA and 3D subtraction angiography. In this study comparative analysis of the intraoperative findings was not performed, thus the conclusion about a more realistic value could not be drawn. Beck et al. [58] find that the dimensions of aneurysms by 3DRA are not less than by biplanar DSA and are close to their actual sizes.

Several studies demonstrated the application of 3DRA within the system neuronavigation. Raabe et al. [59] carried out a number of operations of the intracranial aneurysms using BrainLab's apparatus for neuronavigation, Vector Vision 2 and the Philips Integris Allura System angiographic. Previously it was used during diagnostic frame for registration. During the work it was shown that the maximum error is in the angulation of 90° and 90° in the rotation. According to them, and despite the fact that such a system requires further improvement it provides a useful topographical information about the vascular anatomy [59]. Willems et al. [60] developed the integrated 3DRA neuronavigation system and the first phantom, and then applied it in the course of operations. They used a Philips Integris BV5000 angiographic apparatus and Medtronic's neuronavigation StealthStation system. Impossibility of direct transfer of data from the angiographic system console to the console of the neuronavigation system, they overcame by using a dynamic reference frame (DRF). By this way they were enabled to enhance visualization of the operation of complex giant aneurysms and arteriovenous malformations [60].

MRI, or nuclear magnetic resonance (NMR) imaging, is a noninvasive diagnostic procedure without the use of ionizing radiation. Because of that it is ideal as a noninvasive screening procedure [12, 14, 18]. Also it is grateful for its noninvasive and long-term monitoring of patients after treatment [61–63]. With magnetic field intensification and matrix size recording, resolution and sensitivity increase as indicated by phantom studies [64, 65]. Clinical study on diagnosing unruptured aneurysms using DSA of 1.5T and 7.0T as the reference standard by Mönninghoff et al. [66] showed the advantage of a stronger magnetic field in the detection of intracranial aneurysms. Gibbs et al. [67] obtained similar results. They also reduced magnetic field amplification and recording time.

Sensitivity, despite the developed software, is always lower than in DSA and is about 86–95% with a resolution of 0.2 mm^2 [20]. Schwab et al. [53] did a comparative analysis of MRA and DSA findings in 133 patients with aneurysms and found deviation of MRA findings with regard to DSA in as much as 59%. These differences relate not only to the location and number of aneurysms, but also to the type of aneurysm. Therefore, they recommend screening before using CTA as a less invasive method of DSA [53]. In order to assess the quality of MRA as a screening method, Hiratsuka et al. [68] worked comparative analysis of 3T MRA 64MDCTA with 3D-DA as a reference standard. Their study of 38 patients with nonruptured aneurysms showed no statistically significant difference between MRA and MDCT. In both methods we used volume rendering, and the advantage of it is contrary to Schwab et al. [53] because MRA is completely noninvasive and does not use contrast agents [68].

Conclusion

The results of this study, consistent with the review of current publications, clearly recognize the advantages and disadvantages of diagnostic neuroradiological procedures, with DSA of brain vessels as a binding preoperative diagnostic procedure in case that findings on CT, MRA and MSCT are not enough for clear visualization of the supporting blood vessel and the neck of aneurysm.

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