ORIGINAL PAPER/*ARTYKUŁ ORYGINALNY*

Results of endovascular treatment of aneurysms depending on their size, volume and coil packing density

Porównanie wyników leczenia wewnątrznaczyniowego tętniaków według skali Montreal w zależności od wielkości tętniaka, objętości worka tętniaka i gęstości wypełnienia spiralami

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Abstract

Background and purpose: In contrast to neurosurgery, which is more efficient, endovascular treatment (EVT) is less invasive. The main purpose of EVT is complete occlusion of the aneurysm and protection from subarachnoid haemorrhage. Accurate measurements of the aneurysm (size, volume) obtained using a 3D digital subtraction angiography (DSA) workstation can assist in the proper assessment of coil packing density (CPD), which affects possible distant recanalization. The main disadvantage of endovascular treatment of intracranial aneurysms compared to neurosurgery is the high recurrence rate. We evaluated the results of endovascular treatment of aneurysms depending on their size, volume and coil packing density.
Material and methods: Thirty-five patients with intracranial aneurysms underwent endovascular embolization with bare platinum coils. Three-dimensional DSA was used to evaluate aneurysms' morphology. Eighteen patients underwent 3D DSA follow-up 6-45 months after treatment. Initial and follow-up results of embolization were assessed with the Raymond-Montreal scale. The impact of aneurysms' morphology, volume and initial CPD on endovascular treatment was evaluated.
Results: Among 35 patients, complete initial embolization was achieved in 74%. Mean initial aneurysm volume in 3D

Streszczenie

Wstęp i cel pracy: Chirurgiczne zabezpieczenie tętniaka za pomocą klipsa skuteczniej zapobiega rekanalizacji, ale leczenie wewnątrznaczyniowe (*endovascular treatment* – EVT) jest mniej inwazyjne. Głównym celem EVT jest całkowita okluzja tętniaka wewnątrzczaszkowego i zapobieganie krwotokowi podpajęczynówkowemu. Największą wadą leczenia wewnątrznaczyniowego w porównaniu z neurochirurgicznym klipsowaniem jest duża częstość rekanalizacji. Celem pracy było porównanie wyników leczenia wewnątrznaczyniowego tętniaków według skali Montreal w zależności od wielkości tętniaka, objętości worka tętniaka i gęstości wypełnienia spiralami (*coil packing density* – CPD).
Materiał i metody: Zabieg EVT wykonano u 35 pacjentów z tętniakami wewnątrzczaszkowymi. Morfologia oraz objętość tętniaków zostały wyliczone przy użyciu stacji roboczej 3D DSA. U każdego pacjenta z wykorzystaniem komercyjnego oprogramowania wyliczono CPD w tętniaku. U 18 pacjentów przeprowadzono kontrolne badanie 3D DSA po upływie 6–45 miesięcy. Wyniki oceniano w skali Raymond-Montreal bezpośrednio po zabiegu i w badaniu kontrolnym.
Wyniki: Wśród 35 pacjentów całkowitą wstępną embolizację osiągnięto u 74% osób. Wstępna średnia objętość tętniaka w 3D DSA wynosiła 0,517 ml i zmniejszyła się istotnie po embolizacji ($p = 0{,}017$). Wyjściowo po embolizacji CPD

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DSA was 0.517 mL and decreased significantly after embolization. Initial CPD varied from 74% to 2% depending on aneurysm diameter (12.1% for aneurysms ≥ 10 mm, 22.5% for aneurysms < 10 mm). Results of embolization on the Raymond-Montreal scale significantly depended on aneurysms' CPD. Aneurysms' recanalization rate on 3D DSA follow-up was 36%, with complete recanalization in 3.3%.
Conclusions: We can achieve a better outcome if size and volume of the aneurysm sac is smaller and if CPD is higher.

Key words: intracranial aneurysms, embolization, recanalization, coil packing density.

wahała się od 2% do 74% w zależności od objętości tętniaka (średnio 12,1% dla tętniaków ≥ 10 mm i 22,5% dla tętniaków < 10 mm). Wyniki embolizacji w skali Raymond-Montreal istotnie statystycznie zależały od CPD. Częściowa rekanalizacja w badaniu kontrolnym dotyczyła 36% pacjentów (w tym u 3,3% obserwowano całkowitą rekanalizację).
Wnioski: Im mniejszy tętniak i objętość worka oraz im większa CPD, tym lepszy wynik końcowy (tzn. niższa klasa w skali Montreal).

Słowa kluczowe: tętniaki wewnątrzczaszkowe, embolizacja, rekanalizacja, gęstość wypełnienia spiralami.

Introduction

Endovascular treatment of cerebral aneurysms with Guglielmi detachable coils (GDC) or other systems is becoming more and more popular [1-3]. Introduction of embolization as an alternative for neurosurgical clipping of intracranial aneurysms provided a unique chance for patients with high-risk aneurysms [4]. Both safety and efficacy of endovascular treatment (EVT) of aneurysms have been proven [5]. The selection of therapeutic modality depends on size, location and morphology of an aneurysm, its technical accessibility as well as general condition and age of the patient. When compared to surgical clipping, endovascular treatment, even though it is less efficient with regard to aneurysm recanalization, still is much less invasive. Endovascular treatment aims at complete elimination of an aneurysm from the circulation, thus protecting a patient from subarachnoid haemorrhage (SAH) [6].

The main problem related to aneurysms' coiling concerns the precise density of coils packed within an aneurysm sac and related risk of recanalization that varies from 10 to 55% according to various reports. Recanalization after endovascular treatment leads to recurrent filling of an aneurysm that increases the risk of SAH [7]. Factors that increase the risk of recanalization include: wide neck of an aneurysm, large and giant aneurysms, and partial embolization [8-10]. A number of reports prove that coiling density between 20 and 25% prevents recanalization of an aneurysm [8,11,12].

In our opinion, digital subtraction angiography (DSA) combined with a 3D DSA workstation that enables three-dimensional radiographic reconstructions, thus extending the functionality of radiographic systems, assists in the meticulous evaluation of aneurysm morphology. The detailed aneurysm measurements combined with volume measurements collected from the 3D DSA workstation should enable more precise evaluation of aneurysm packaging efficacy, which in turn affects possible later recanalization [13,14].

Material and methods

We performed a retrospective analysis of 35 patients who were referred to the Department of Radiodiagnostics and Nuclear Medicine from the Department of Neurosurgery of Prof. Kornel Gibiński Central Clinical Hospital of the Silesian Medical University in Katowice for diagnostics and treatment of cerebral aneurysms. Our cohort included 29 women and 6 men aged 28 to 67 years who underwent embolization of 35 cerebral aneurysms (the number of aneurysms equalled the number of patients) including 20 ruptured (57.1%) with SAH symptoms and 15 (42.9%) unruptured, asymptomatic ones.

The majority of aneurysms were located on the internal carotid artery: 9 on the right and 9 on the left. The second most frequent location was the basal artery (6 aneurysms), then the anterior communicating artery (4 aneurysms), right middle cerebral artery (2 aneurysms), left middle cerebral artery (2 aneurysms) and left vertebral artery (2 aneurysms). In one case, an aneurysm was located on the right vertebral artery.

Inclusion criteria for the study comprised (1) patients with an aneurysm visualized on previous imaging studies who qualify for endovascular treatment; (2) patients with SAH who qualify for endovascular treatment; and (3) patients who underwent 3D DSA.

Exclusion criteria consisted of (1) patients with traumatic subarachnoid haemorrhage; (2) lack of patient's consent; (3) patients without 3D DSA.

Diagnostics were initiated with Seldinger method access to the femoral artery, then a 5F diagnostic catheter (Cordis Johnson & Johnson, Piscataway, New Jersey) was introduced into the common carotid artery or vertebral artery based on the aneurysm location. During examination the patient was under analgosedation supervised by an anaesthesiologist. Non-ionic contrast (Iomeprolum, Iomeron 300, Bracco ALTANA Pharma, Konstanz, Germany) was injected with an automatic syringe (Medrad, Mark V ProVis, Indianola, Pennsylvania). For a single series during the rotational study, an average of 15 mL (from 10 to 18 mL) was injected with an average speed of 3.5 mL/s (from 3 to 5 mL/s) based on current study conditions. Injection delay time varied from 0 to 1 s. All of the patients underwent DSA on a Philips Integris Allura Monoplane system (Philips Medical Systems, Best, Netherlands) with predefined protocols. Subsequently, a 3D DSA Integris 3D-RA Three-Dimensional Rotational Angiography workstation (Philips Medical Systems, Best, Netherlands) was launched in order to perform further image analysis (Fig. 1).

Aneurysms were analysed with the 3D DSA workstation based on three-dimensional, rotational digital subtraction angiography. Evaluation criteria included: (1) location; (2) dimensions of the aneurysm sac – the longest dimension of the length, height and width; (3) measurement of the aneurysm volume – an automatic measurement with sphere-shaped grid that is part of the 3D DSA workstation software package, placed manually over a secluded aneurysm (Fig. 2); (4) measurements of the aneurysm neck – diameter measured in two extreme dimensions; (5) ratio of the sac to the neck – for calculations the longest dimensions of the sac and the neck were used and subsequently divided into 3 groups: a ratio < 1.2, between 1.2 and 1.5, and > 1.5 [13]; and (6) the size of the aneurysm – based on their size aneurysms were categorized as: small aneurysm < 10 mm in diameter, large 10-24 mm in diameter, and giant > 24 mm [8,12].

A multidisciplinary team that included a neurosurgeon and interventional radiologist qualified patients for EVT based on poor general condition of the patients, a location of aneurysms that was challenging for surgical clipping, lack of patient's consent for surgical clipping, and favourable relationship of the sac to the neck of the aneurysm. Guglielmi Detachable Coils (GDC-10 and/or GDC-18: regular, soft and ultrasoft, 3D, 360, helical: Boston Scientific, Fremont, USA) were used for embolization of 33 aneurysms; in 2 cases mechanically detachable coils (TruFill DCS complex and helical; Cordis, Miami, Florida) were implemented. Due to the presence of the wide neck of an aneurysm in one of the patients, a stent (Neuroform, Target Therapeutics, Fremont, USA) was also used. Coils were placed within an aneurysm sac via a microcatheter and detached under fluoroscopic guidance. The aim of EVT was to pack an aneurysm as dense as possible with the coils. Accordingly, coils were introduced into the aneurysm sac until it was full and no further coils could be implanted or angiographic control showed no contrast inflow into the aneurysm sac.

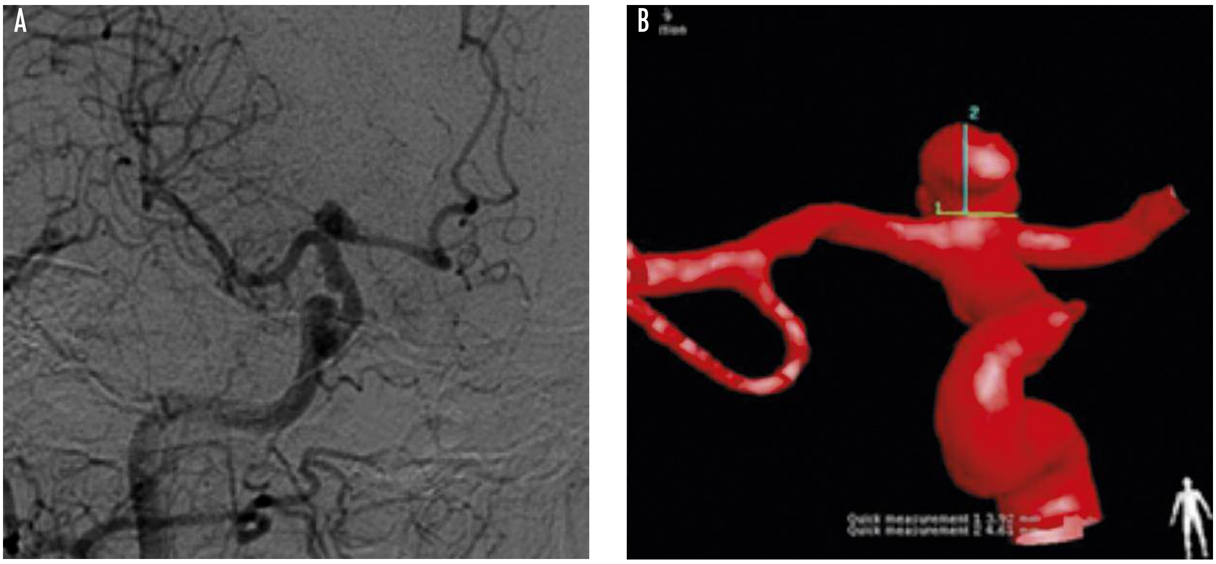

Fig. 1. Aneurysm in the bifurcation of the right internal carotid artery: (A) DSA in oblique projection; (B) 3D DSA in anteroposterior projection

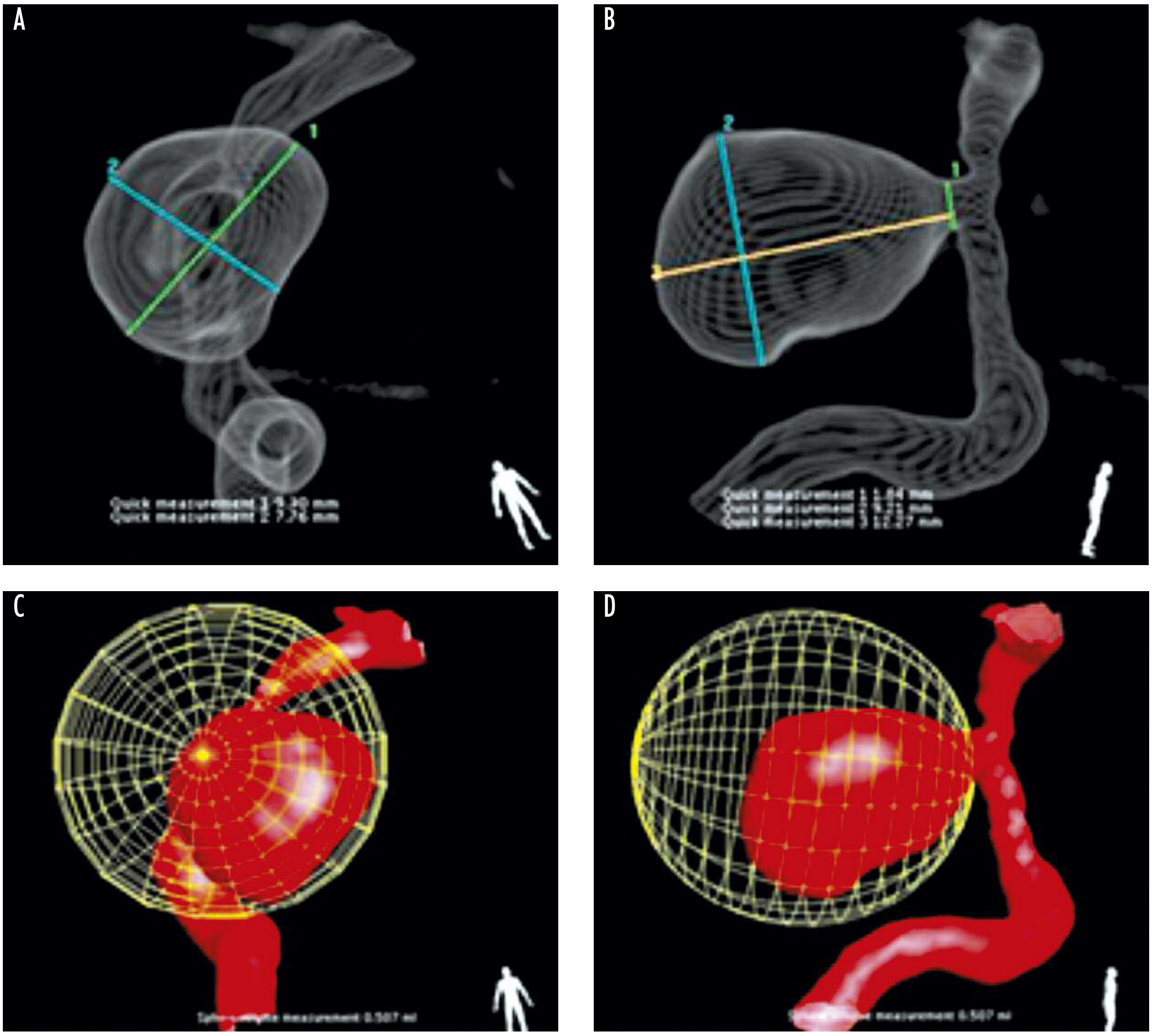

Fig. 2. Measurements of the aneurysm: (A-B) length, width, height and neck of the aneurysm; (C-D) automatic volume measurement

Next, coil volume was calculated based on size and count of coils that were introduced into the sac:

$$\text{Volume of coils} = \pi\ (\text{radius})^2 \times \text{length}$$

The equation for packing density was defined as the relationship between the volume of the coils within an aneurysm and the volume of the aneurysm expressed as a percentage:

$$\text{Coils packing density} = (\text{coil volume}/\text{aneurysm volume}) \times 100\%$$

A follow-up DSA was performed 6 months after embolization in order to verify the outcome. The aneurysm's angiographic evaluation was performed according to the Montreal scale [15]: class 1 – total aneurysm occlusion along with the neck; class 2 – neck contrast inflow remnant, i.e. aneurysm neck not filled with embolization material; class 3 – aneurysm contrast inflow remnant.

Subsequently, a statistical analysis of the results was performed with the χ^2 test and Fisher exact test along with Student t-test and Wilcoxon signed rank test. Differences were considered significant at $p < 0.05$. Additionally, a regression analysis was also performed in order to assess possible relationships between the variables in question. The protocol was approved by the Bioethics Committee of the Silesian Medical University (decision no. NN-6500-58/06).

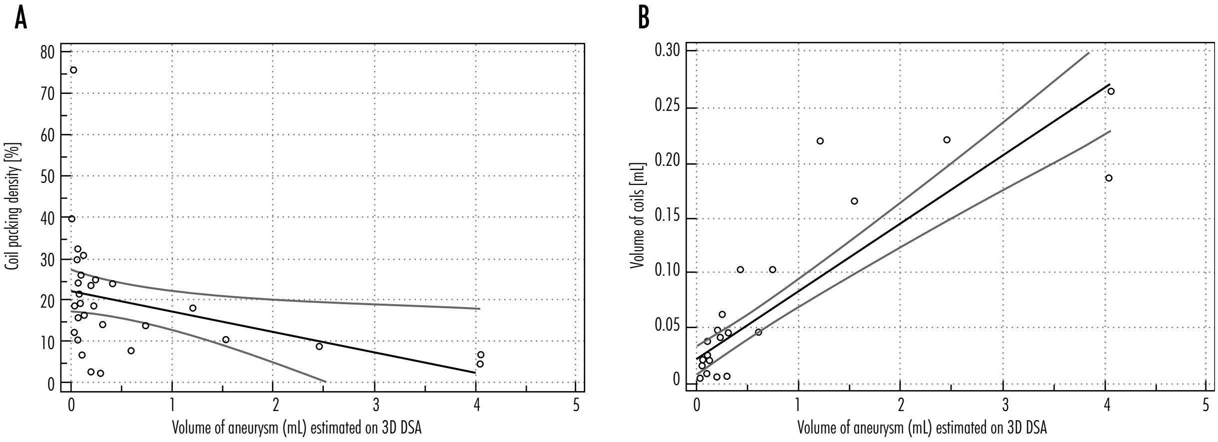

Fig. 3. (A) Linear relationship between coil packing density (%) and the volume (mL) of the aneurysm in 3D DSA; (B) linear relationship between the volume of coils (mL) and the volume of aneurysm (mL)

Results

In our cohort we found 26 (74.3%) patients with small (i.e. < 10 mm) aneurysms and 9 (25.7%) patients with large aneurysm (≥ 10 mm and ≤ 24 mm).

In 25 cases (71.4%), aneurysms showed a high (> 1.5) sac to neck ratio. Only 4 patients (11.4%) had a sac/neck ratio < 1.2 while in 6 patients (17.1%) the sac/neck ratio ranged from 1.2 to 1.5.

The aneurysm volume calculated with the automated 3D DSA method averaged 0.517 mL (range: 0.010-4.061 mL) while the coil packing density averaged 19.89% (range: 2-74%).

When measured with the automated 3D DSA method, the packing density was inversely proportional to the aneurysm volume. Accordingly, a larger aneurysm volume gives a lower packing density. This relationship was statistically significant ($p = 0.024$) with the correlation coefficient at $R = -0.3801$ (Fig. 3A). Due to its strong practical significance for evaluation of total aneurysm occlusion during the procedure, based on previous data on coil volume and aneurysm volume we also analysed the relationship between the coil volume provided by the manufacturer and the calculated aneurysm volume. For 3D DSA automatic measurements, the correlation between aneurysm volume and coil volume as provided by the manufacturer was strong and highly statistically significant ($R = 0.882$; $p < 0.001$) (Fig. 3B).

Packing density assessed based on a 3D DSA automatic aneurysm volume measurement for small aneurysms (i.e. < 10 mm) averaged 22.5%. Likewise, for large aneurysms (≥ 10 mm and ≤ 24 mm) it averaged 12.1%. The difference in the packing density between aforementioned groups of aneurysms was statistically significant ($p = 0.042$) (Fig. 4).

Post-embolization follow-up

Late follow-up DSA was performed in 18 patients. Seventeen patients had no follow-up angiography for independent reasons (in 12 cases patients did not show up for follow-up examination or refused to give their consent; the remaining 5 patients died prior to the scheduled follow-up – the cause of death unknown).

Mean time from EVT to follow-up angiography averaged 19.5 months (range: 6 to 45 months). Aneurysm volume prior to the procedure averaged 0.810 mL in this group of patients while immediately after it averaged 0.303 mL. The difference at –0.507 was statistically significant ($p = 0.012$). For half of the patients, a total aneurysm occlusion was achieved (Fig. 5).

Aneurysm packing density measurements in the endovascular treatment of intracranial aneurysms with

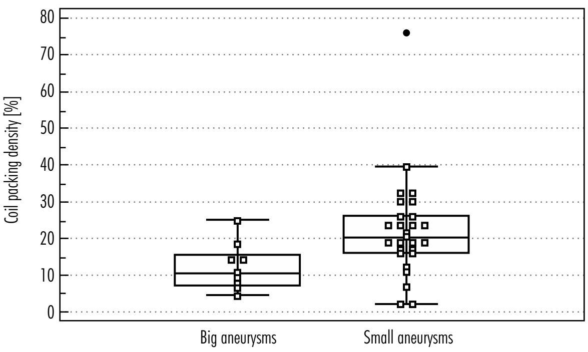

Fig. 4. The mean coil packing density (%) of the aneurysm in correlation to its size in 3D DSA

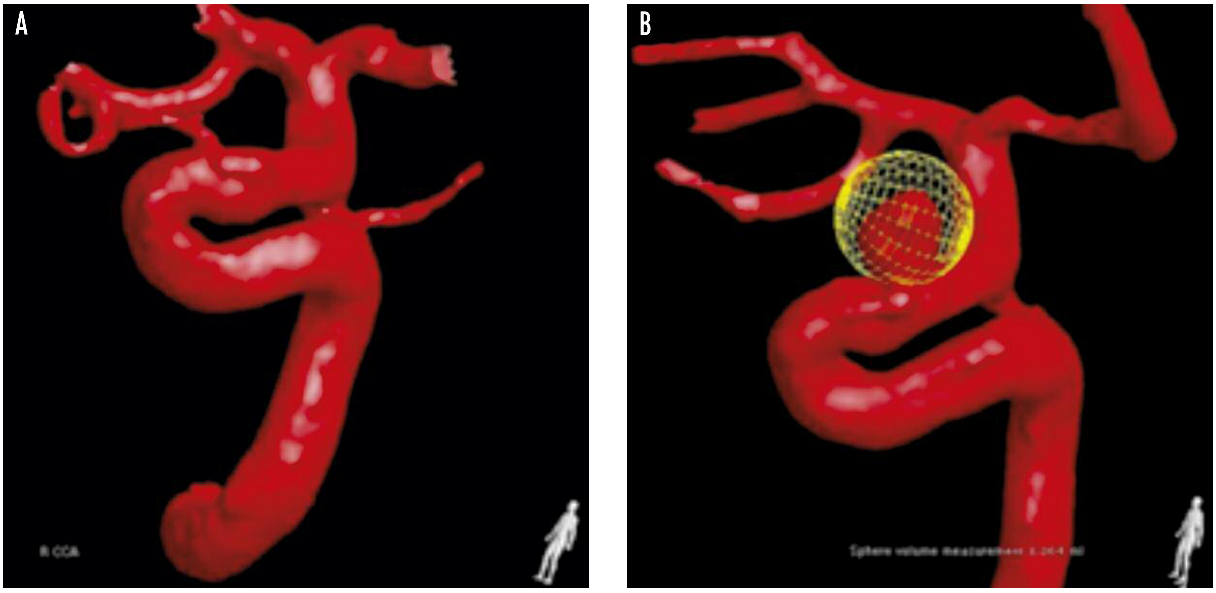

Fig. 5. Right internal carotid artery aneurysm: (A) automatic volume measurement before endovascular treatment; (B) complete obliteration during follow-up examination

3D DSA were subsequently compared to the standard, i.e. the Montreal scale (as mentioned above).

Immediately after the procedure, 26 (74.3%) patients were qualified as class 1 on the Montreal scale. Nine patients (25.7%) showed remnant inflow of the contrast within the aneurysm including 4 (11.4%) within the neck (class 2 on the Montreal scale) and 5 (14.3%) within the sac (class 3 on the Montreal scale). Coil packing density immediately after the procedure varied from 22.45% in class 1, 16.85% in class 2, to 9.0% in class 3.

Treatment efficacy was assessed in 18 patients. On immediate control in our group of 18 patients total aneurysm occlusion was achieved in 10 (55.66%) patients, remnant contrast flow within the neck in 3 (16.67%) and remnant flow within the sac (class 3 on the Montreal scale) in 5 patients (27.78%).

Two patients showed deterioration on their follow-up when compared to the immediate control. We found packing density below 20% in those two patients with worse outcome of EVT on late follow-up (change from class 1 to class 2 and from class 1 to class 3 on the Montreal scale). Interestingly, two patients showed improvement of EVT results from class 2 to class 1 (one of them showed packing density at 32% while the other one only 2%) in follow-up studies. Treatment outcome according to the Montreal scale proved to be inversely proportional to the aneurysm packing density. The Spearman correlation coefficient for this relationship is relatively high and statistically significant (immediate control: $R = -0.424, p = 0.008$; late control: $R = -0.491, p = 0.043$). Consequently, the higher the packing density the better the outcome (lower Montreal class), both immediate as well as long-term.

Aneurysm embolization outcome on the Montreal scale in our cohort significantly depended on the initial aneurysm volume measured with the automatic 3D DSA method ($p = 0.017$).

Montreal class in the late angiographic controls showed a significant relationship with aneurysm size (large vs. small). Five out of 6 large aneurysms (83%) were in class 3 on the Montreal scale during follow-up while 9 out of 12 small aneurysms (75%) were in class 1 on the Montreal scale, which suggests better outcomes of treatment of small aneurysms.

Discussion

The three-dimensional DSA workstation allows 3D reconstructions from rotational digital subtraction angiography with a high spatial resolution previously available only for computed tomography angiography or magnetic resonance angiography sequences [16]. Piotin *et al.* [17] proved in their studies that 3D DSA workstation precision (Philips Medical Systems, Integris 3D-RA Best, Netherlands) allows recognition of calculated aneurysm dimensions as actual ones.

The aim of the present study was to compare the aneurysm volumes calculated with automatic 3D DSA along with the assessment of the usefulness of aneurysm packing density measurements based on 3D DSA for endovascular treatment of intracranial aneurysms.

Several articles have been published concerning the problem of intracranial aneurysm volume. However, significant discrepancies in their results exist that are related to the study cohort selection [12,17,18]. Piotin's study [19] is a good example with its cohort of 255 aneurysms. Their volume averaged 0.152 mL (median 0.066 mL, 0.004-2.619 mL) on 3D DSA. Kimchi *et al*. [20], on the other hand, calculated an average volume of 39 aneurysms based on three dimensions measured on 3D DSA and an equation for ellipsoid volume and came up with a value of 0.143 mL (0.095 mL; 0.014-0.904 mL). In comparison, the average volume for 35 aneurysms in our study was 0.517 mL (median 0.112 mL, 0.010-4.061 mL).

Aneurysm volume measurements are of importance as aneurysm volume precisely calculated with an automatic method facilitates accurate calculation of aneurysm coil packing density following EVT.

In our study packing density averaged 19.9% when measured with the automatic 3D DSA method while Piotin *et al*. reported values that averaged 27% [19]. On the other hand, Sluzewski in his study demonstrated average density at 26.6% when measured with an analogous automatic method. It is worth mentioning that EVT procedures were performed with various types of coils and with variable outcome.

One of the EVT-related problems involves the remnant inflow of contrast within the aneurysm sac or neck that arises from insufficient packing of the sac with coils. Whenever the coil packing density is insufficient, it increases the probability of contact between blood and coils within the aneurysm neck, which results in compactness of coils within the aneurysm sac, thus increasing the risk of recanalization [9-11].

The most commonly cited aneurysm coil packing density that ensures optimal protection from recanalization varies from 20% according to Tamatani and Gallas [8,21] to 24% according to Slob and Sluzewski [12].

In our study we found that higher volume of the aneurysms is related to smaller packing density; this relationship is statistically significant.

One of the small volume aneurysms reached a packing density of 74%. This high packing density could arise from very good coil compactness within the sac as all the coils introduced were very soft. The other possible explanation arises from aneurysm expansion on filling of its lumen.

In our study, based on the analysis of packing density related to the aneurysm size (small, large) calculated with the 3D DSA method we proved that the average coil packing density in the aneurysm depends on the size of the aneurysm. The larger an aneurysm is the more difficult it becomes to achieve a sufficient packing density that prevents recanalization. Others have found a similar relationship [8,22]. Uchiyama *et al*. [22] in their study implemented analogous aneurysm size classification and packing density measurement technique and found that for large aneurysms the packing density averaged 15.6% while in small ones it averaged 19.9%. In our study, we attained a main packing density of 12.5% for large and 33.8% for small aneurysms.

However, for EVT outcome evaluation it is important to estimate aneurysm embolization not only immediately after the procedure but also at the late follow-up. The aneurysm occlusion rate after EVT is very difficult to assess. We elected to use a classification proposed by Raymond and his colleagues, i.e. the Montreal scale that is defined as: class 1 – total aneurysm occlusion along with the neck; class 2 – neck contrast inflow remnant, i.e. aneurysm neck not filled with embolization material; class 3 – aneurysm contrast inflow remnant [15,21].

One should remember that endovascular treatment is less efficient than surgical clipping when it comes to complete aneurysm occlusion [23]. Moreover, recanalization is more frequent after EVT. Roy *et al*. [24] proved that the aneurysm sac's isolation from the circulation with EVT without or with a neck remnant (class 1 or class 2) is sufficient for rebleeding prevention for 98% of patients with an acute SAH. Class 3 on the Montreal scale, however, does not prevent aneurysm re-rupture after EVT. Accordingly, we decided to evaluate the percentage of patients secured, i.e. class 1 and 2, along with those not secured, i.e. Montreal class 3 patients, upon immediate as well as late follow-up.

In our cohort, we found that 74% of aneurysms qualified as Montreal class 1, 11% as class 2, and 14% as class 3 immediately after the procedure. Roy *et al*. [24] reported 47% of aneurysms with total obliteration, 42% with neck remnant and 5% with aneurysm remnant. On the other hand, Ng *et al*. [26] described complete occlusion in 46% of cases, neck remnant in 16% and aneurysm remnant in 38%. This discrepancy might arise from different anatomical criteria due to subjective and non-standardized evaluation protocols between the centres [24]. Therapeutic team skills and proper selection of coil shape are also of great importance [25].

Regardless of immediate outcome after the procedure, recanalization might occur in any category. A thorough analysis by Ng *et al*. [26] proved that almost one fourth of completely occluded aneurysms recanalize within the first year and another 8% during the next.

Our data showed recanalization in 2 patients (36%) on late follow-up when compared to immediate follow-up. One patient (18% of the whole group) deteriorated from class 1 to class 2 on the Montreal scale. The other one (18%) switched from class 1 to class 3 of the Montreal scale. It is worth mentioning, though, that packing density in one of the patients achieved 32% and only 2% in the other. Such a low packing density was probably related to an early aneurysm clotting during the EVT procedure. In comparison, Roy *et al*. [24] reported the recanalization level at 20%. They also showed that 8% of aneurysms deteriorated from class 1 to class 2 during follow-up. The majority of aneurysms (88%) from class 2 showed a good outcome on late control while 12% deteriorated (class 3).

To sum up, our data show recanalization at 36% of cases. Literature reports recanalization at 5 to 60% of cases [24].

We also proved that treatment efficacy measured with the Montreal scale is inversely proportional to the packing density. The higher a packing density is, the better the outcome (lower Montreal class) both immediately after the procedure and on late follow-up. Our results are in concert with previous reports of Roy *et al*., Sluzewski *et al*. as well as others [5,6,12,21,24,27].

There were several limitations found in our study. The strict inclusion criteria limited patients to approximately 50% of all who underwent EVT in our department at a given time. Moreover, follow-up angiography was feasible in only 48.6% of the patients who underwent embolization. A multicenter study with a larger group of patients and longer follow-up periods seems to be a necessity in the future.

Conclusions

1. Immediate and late outcome of aneurysm treatment (Montreal scale class) directly depends on the size of the aneurysm, its volume and coil packing density. Accordingly, the smaller an aneurysm and its volume is and the higher the packing density is, the better the outcome (lower class on the Montreal scale).
2. A larger study with more patients is necessary to verify the aforementioned findings.

Disclosure

Authors report no conflict of interest.

References

1. Guglielmi G., Viñuela F., Sepetka I., et al. Electrothrombosis of saccular aneurysms via endovascular approach, I: electro-chemical basis, technique, and experimental results. *J Neurosurg* 1991; 75: l-7.
2. Juszkat R., Nowak S., Kociemba W., et al. Endovascular treatment of cerebral aneurysms using hydraulically detachable coils. *Pol J Radiol* 2006; 71: 57-63.
3. Suri M.F., Memon M.Z., Qureshi A.I. Treatment of unruptured intracranial aneurysms using internally expanding coils. *J Vasc Interv Neurol* 2008; 1: 42-45.
4. Kiyosue H., Okahara M., Tanoue S., et al. Detection of the residual lumen of intracranial aneurysms immediately after coil embolization by three-dimensional digital subtraction angiographic virtual endoscopic imaging. *Neurosurgery* 2002; 50: 476-485.
5. Murayama Y., Nien Y.L., Duckwiler G., et al. Guglielmi detachable coil embolization of cerebral aneurysms: 11 years experience. *J Neurosurg* 2003; 98: 959-966.
6. Guilbert F., Raymond J., Roy D., et al. Complete occlusion remains the primary goal of endovascular coiling of intracranial aneurysms. *Radiology* 2008; 246: 643.
7. Babiker M.H., Gonzalez L.F., Albuquerque F., et al. Quantitative effects of coil packing density on cerebral aneurysm fluid dynamics: an in vitro steady flow study. *Ann Biomed Eng* 2010; 38: 2293-2301.
8. Tamatani S., Ito Y., Abe H., et al. Evaluation of stability of aneurysm after embolization using Guglieimi detachable coils: correlation between stability of aneurysms and embolized volume of aneurysms. *AJNR Am J Neuroradiol* 2002; 23: 762-767.
9. Tomalski W., Majchrzak A., Stech W., et al. Posterior circulation aneurysm coiling using platinium mechanical detached coils. *Pol J Radiol* 2004; 69 (Suppl 1): 180-190.
10. Szajner M., Jargiełło T., Szczerbo-Trojanowska M. The use of GDC-10 coils in treatment of small – "baby" (< 4 mm in diameter) intracranial aneurysms by percutaneous embolisation. *Pol J Radiol* 2004; 69 (S1): 39-40.
11. Kai Y., Hamada J., Morioka M., et al. Evaluation of the stability of small ruptured aneurysms with a small neck after embolization with Guglielmi detachable coils: correlation between coil packing ratio and coil compaction. *Neurosurgery* 2005; 56: 785-792.
12. Slob M.J., Sluzewski M., van Rooij W.J. The relation between packing and reopening in coiled intracranial aneurysms: a prospective study. *Neuroradiology* 2005; 47: 942-945.
13. Kiyosue H., Tanoue S., Okahara M., et al. Anatomic features predictive of complete aneurysm occlusion can be determined with three-dimensional digital subtraction angiography. *AJNR Am J Neuroradiol* 2002; 23: 1206-1213.
14. Sugahara T., Korogi Y., Nakashima K., et al. Comparison of 2D and 3D digital subtraction angiography in evaluation of intracranial aneurysms. *AJNR Am J Neuroradiol* 2002; 23: 1545-1552.

15. Raymound J., Roy D. Safety and efficacy of endovascular treatment of acutely ruptured aneurysms. *Neurosurgery* 1997; 41: 1235-1244.
16. Serafin Z., Strześniewski P., Lasek W., et al. Metody i schemat okresowy kontroli obrazowej po przeznaczyniowym leczeniu tętniaków wewnątrzczaszkowych: systematyczny przegląd piśmiennictwa. *Neurol Neurochir Pol* 2011; 45: 421-430.
17. Piotin M., Oaghman B., Mounayer C., et al. Ellipsoid approximation versus 3D rotational angiography in the volumetric assessment of intracranial aneurysms. *AJNR Am J Neuroradiol* 2006; 27: 839-842.
18. Costalat V., Maldonado I.L., Strauss O., et al. Toward accurate volumetry of brain aneurysms: combination of an algorithm for automatic thresholding with a 3D eraser tool. *J Neurosci Methods* 2011; 198: 294-300.
19. Piotin M., Spelle L., Mounayer C., et al. Intracranial aneurysms: treatment with bare platinum coils-aneurysm packing, complex coils, and angiographic recurrence. *Radiology* 2007; 243: 500-508.
20. Kimchi T.J., Willinsky R.A., Spears J., et al. Endovascular treatment of intracranial aneurysms with matrix coils: immediate posttreatment results, clinical outcome and follow-up. *Neuroradiology* 2007; 49: 223-229.
21. Gallas S., Pasco A., Cottier J.P., et al. A multicenter study of 705 ruptured intracranial aneurysms treated with Guglielmi detachable coils. *AJNR Am J Neuroradiol* 2005; 26: 1723-1731.
22. Uchiyama N., Kida S., Nomura M., et al. Significance of volume embolization ratio as a predictor of recanalization on endovascular treatment of cerebral aneurysm with Guglielmi detachtable colis. *Interv Neuroradiol* 2006; 6 (Suppl 1): 59-63.
23. Thornton I., Bashir Q., Aletich V.A., et al. What percentage of surgically clipped intracranial aneurysms have residual necks? *Neurosurgery* 2000; 46: 1294-1298.
24. Roy D., Milot G., Raymond J. Endovascular treatment of unrupted aneurysms. *Stroke* 2001; 32: 1998-2004.
25. Mehra M., Hurley M.C., Gounis M.J., et al. The impact of coil shape design on angiographic occlusion, packing density and coil mass uniformity in aneurysm embolization: an in vitro study. *J Neurointervent Surg* 2011; 3: 131-136.
26. Ng P., Khangure M.S., Phatouros C.C., et al. Endovascular treatment of intracranial aneurysms with Guglielmi detachable coils: analysis of midterm angiographic and clinical outcomes. *Stroke* 2002; 33: 210-217.
27. Wakhloo A.K., Gounis M.J., Sandhu J.S., et al. Complex-shaped platinum coils foe brain aneurysms: higher packing density, improved biomechanical stability, and midterm angiographic outcome. *AJNR Am J Neuroradiol* 2007; 28: 1395-1400.