Comparison of Cerebral Aneurysm Volumes as Determined by Digitally Measured 3D Rotational Angiography and Approximation from Three Diameters

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Summary

This study compared digital measurement of aneurysm volume by 3D rotational angiography (3D-RA) with an approximation technique using three diameters of an aneurysm to re-interpret previously reported optimal packing densities (volume embolization ratio, VER) in coil embolization of intracranial aneurysms. Estimation of the volume of saccular aneurysms is important for calculation of the VER, which is in turn reported to be useful for prediction of coil compaction. The conventional formula for the volume estimation is $V=4/3 \pi(A/2)(B/2)(C/2)$, where A, B, and C are the aneurysmal height, length, and width measured on 3D-RA image respectively.

Using 3D rotational angiography data from 74 aneurysms, the approximated volume generated using the conventional formula was directly compared with the digitally measured volume.

The digitally measured volume varied from 0.003 ml to 7.935 ml, and the dome-to-neck ratio (D/N) from 0.79 up to 4.62. We found that the conventional formula almost systematically underestimated the volume by up to 50 %, particularly when the neck was large relative to the dome ($D/N < 2$). On average, digitally measured volume was 1.26~1.29 times larger than the approximated volume obtained using the conventional formula.

Conventional 2D angiography based aneurysm volume calculation tends to underestimate an aneurysm volume, so the so-called VER (volume embolization ratio) could be overestimated.

Introduction

In endosaccular coil embolization of intracranial aneurysms, it is known to be important to pack coils as tightly as possible to avoid recanalization, and incomplete embolization is one of the major risk factors for recanalization¹⁻³. Even when using bioactive coils, which promote thrombus organization, incomplete packing is likely to result in aneurysm recanalization⁴. To evaluate the tightness of coil embolization, the volume embolization ratio (VER: ratio of coil volume and aneurysm volume $\times 100\%$) has been used in some institutes. The usefulness of VER to predict coil compaction and recanalization has been reported previously⁵⁻⁹. As most of these reports were based on 2D angiography, aneurysm volume was approximated using three diameters (height, length, and width) under the assumption that the aneurysm has an ellipsoidal body^{5,6,8,9}. The conventional formula used is:

$$V=4/3 \pi(A/2)(B/2)(C/2), \quad (1)$$

where A, B, and C are the aneurysm height, length, width, respectively. The volume of coils was calculated using the equation:

$$V=\pi(p/2)^2L, \quad (2)$$

where L represents the coil length, and p the coil diameter.

Using these equations, Kawanabe et al.⁶ reported that coil compaction occurred only in patients with VER below 20%. Tamatani et al.⁸ reported a similar result. Yagi et al.⁹ recom-

Figure 1 Scheme of measurement of aneurysm diameters; height (A), length (B) and width (C). These diameters were measured on 3D-RA images.

mended 25% as the lowest requirement of VER. Kai et al.⁵ showed that coil compaction did not occur in patients with VER over 24%. These findings suggest that a VER of more than 20-25% is likely to prevent coil compaction. However, these data are based on aneurysm volumes approximated under the assumption that the aneurysm is always ellipsoidal in shape. As all aneurysms are not ellipsoidal but are often irregular in shape, and may be partially ellipsoidal as in the case of broad-neck aneurysms, this approximation may not always be reliable in predicting the true volume.

Recently, three-dimensional rotational angiography (3D-RA) has enabled digital measurement of aneurysm volume, and is expected to be more accurate than the above approximation^{5,6}. We therefore compared the formula-generated approximated volume (V_a) and the digitally measured aneurysm volume (V_m) to investigate possible discrepancies in the recommended value of VER.

Methods and Materials

Patients with aneurysms

Among the aneurysm patients admitted to our institute in 2006, 74 patients with aneurysms that were measured with 3D-RA were included in this study. The aneurysms were 64 small aneurysms (maximum diameter <12 mm), eight large (12 mm~25 mm), and two giant (>25 mm). Our Institutional Review Board did not require its approval or patient informed consent for this study.

Figure 2 The relationship between the efficiency of approximation (V_m/V_a) and dome to neck ratio (D/N). Open circles indicate smaller aneurysms (<0.2 ml), and closed circles indicate larger aneurysms (>0.2 ml). Aneurysms with a smaller neck (larger D/N) are better estimated, irrespective of their volume. Exponential fitting curve ($y = 2.426 e^{-1.628 x} + 1$, goodness-of-fit: $r^2 = 0.3842$) is plotted.

3D-RA

All the 3D-RA examinations were performed using a C-arm digital angiography suite (Integris Allura; Philips Medical Systems, Best, The Netherlands) with an FOV of 17.78 cm (7 inches) and a frame rate 30 f/s. Images were acquired with a head-end propeller C-arm orientation at a rotational speed of 55°/s covering 120° LAO to 185° RAO. Fifteen ml of nonionic contrast medium was injected through a 4F catheter by use of an injector with a velocity of 3 ml/s. Image acquisition was started 1s after the start of the injection. The acquisition time of images was 4 s. Volume-rendered 3D images were reconstructed with a 100% magnification and a matrix of 256×256×256 pixel by using the 3D-RA volumetric measurement of the system software (Philips Medical Systems). Voxels were cubes with a side length of 0.34 mm. The threshold for the volume-rendered image was fixed as the default value provided by the software. With this threshold setting, we conducted a phantom study using acryl spheres with diameters of 6, 10 and 20 mm. The 3D-RA software underestimated by 1.2 % to 3.6 % of the actual volume of the acryl spheres (data not shown).

Measurement of aneurysm sizes and volume

In previous reports, some authors measured the size of aneurysm on the lateral and antero-posterior views of the angiogram^{5,6} or the direction of the angiogram was unclear^{8,9}. Thus in this study, the size was measured in two ways.

First, as is often employed in endovascular surgery, aneurysm size was measured from a “working angle” view of the 3D angiogram in which the aneurysm neck does not overlap with the parent artery: A (height) and B (length), and on a plane vertical to it: C (width) (Figure 1). The size of the aneurysm neck (N) was also measured from the working angle view of the 3D image. Dome-to-neck ratio (D/N) was also calculated using the equation,

$$D/N = (B + C)/2N. \quad (3)$$

Second, the size of each aneurysm was measured in three planes (height, length and width) on the anteroposterior and lateral (AP-lateral) views of the 3D angiogram: A', B' and C'. Using these diameters, two types of approximated volume (V_a and $V_{a'}$) were calculated from these data using Eq (1). To digitally measure the aneurysm volume (V_m), the aneurysm was manually segmented from the parent artery on this 3D reconstruction and volume was calculated by using machine software (3D-RA workstation, Philips Medical Systems, Best, The Netherlands). When the aneurysm had a bleb with more than 1 mm height, the sizes and the volume were measured after removing the bleb from the image of the aneurysm.

Data analysis

V_a , $V_{a'}$, and V_m were calculated for each aneurysm. The ratio of V_a and V_m (V_m/V_a), and the ratio of $V_{a'}$ and V_m ($V_m/V_{a'}$) were calculated. Values of V_m/V_a were not significantly different from those of $V_m/V_{a'}$ (paired t-test, $t=1.208$, two-tailed $p=0.231$), indicating that aneurysm volume is similarly approximated by Eq (1) using data from either the “working angle” view or AP-lateral view. Thus V_m/V_a and dome-to-neck ratio (D/N) were plotted and a curve fitted to this plot.

Results

The plot of V_m/V_a and D/N show that conventional approximation with Eq. (1) almost systematically underestimated the aneurysm volume by up to 50 %, particularly when the aneurysm neck was large relative to the dome ($D/N < 2$). The digitally measured volume (V_m) varied from 0.003 ml to 7.935 ml, and the dome-to-neck ratio (D/N) from 0.79 to 4.62. The average values of V_m/V_a and $V_m/V_{a'}$ were 1.26

and 1.29, respectively. Irrespective of the volume size, the degree of underestimation can be corrected by exponential fitting of

$$y = 2.426 e^{-1.628 x} + 1, \quad (4)$$

where y, measured /approximated volume ratio; and x, D/N (goodness-of-fit: $r^2=0.3842$). (Figure 2).

Discussion

Degree of aneurysm occlusion after the initial endovascular treatment is reported to be related to the risk of recanalization in a long-term follow-up¹⁻³. Recent multicenter studies on treatment of ruptured aneurysms showed that incomplete occlusion was not unusual but was not related to the increased risk of mid to long-term rebleeding¹⁰⁻¹², meanwhile it was shown to be related to the increased risk of rebleeding in short term posttreatment period especially within 30 days¹². Degree of aneurysm occlusion was categorized based on angiographic appearance in above studies, i.e., complete occlusion, neck remnant and dome filling or incomplete occlusion. Though VER itself has not been shown to correlate with these angiographic evaluations, it may be useful as numerical indicator to achieve adequate packing density to avoid recanalization as reported in some articles⁵⁻⁹.

We compared approximated aneurysm volumes generated by a conventional formula and digitally measured volumes to see if previously recommended VER values of 20~25 % for the lowest requirement to avoid recanalization^{5,6,8,9} are still applicable, given the data that can be collected from 3D-RA methods. Results showed that the conventional approximation formula (Eq. (1)) almost systematically underestimated aneurysm volume, which would produce overestimates of VER. As the average of V_m/V_a and $V_m/V_{a'}$ were 1.26 and 1.29 respectively, the conventional recommended VER of 20~25% is roughly interpreted as 15.5~19.4% when the volume is digitally measured with 3D-RA. When the neck was large relative to the dome ($D/N < 2$), the discrepancy between V_m and V_a was large. This is probably because the shape of a small neck aneurysm is close to that of an oval sphere and, therefore, it is more likely to adhere to the assumptions of the conventional approximation formula. On the other hand, the shape of a wide neck aneurysm is bet-

ter described as an oval sphere with wide skirt, and therefore, the volume of the skirt is neglected when applying the conventional formula, resulting in volume underestimation.

When reconstructing a 3D-angiographic image, the threshold value for definition of contours of vessels can be selected by users. The threshold value selected influences the resulting measurement of aneurysm volume and diameters. In this study, the threshold for the volume-rendered image was fixed as the default value provided by the software. Our phantom study showed the error with this threshold was approximately 1.2 to 3.6 % underestimation. As the approximated volume was calculated using the three diameters measured on the 3D angiogram, the threshold was identical. Therefore the relation between the approximation and the direct measurement conceivably holds true even if the default threshold is modified.

Piotin et al. published extensive works on aneurysm volume measurement and packing density in aneurysm embolization. In their study of comparing digital volume measurement with conventional approximation based on aneurysm diameters measured on 3D-RA images¹³, the conventional approximation (V_{calc}) overestimated by $15 \pm 38\%$ of the volume given by 3D-RA. The V_{calc} was relatively accurate for pericallosal and basilar tip aneurysms, probably

owing to their spherical or elliptic shape. Conversely, it showed more significant differences in irregularly shaped lesions, such as posterior communicating aneurysms.

Also in the present study, the discrepancy is small in cases of small neck aneurysms. The difference with the study by Piotin et al. may be due to diversity of aneurysm shape and difference in the method to measure the aneurysm diameters. They measured the largest horizontal diameter (a) and the largest vertical diameter (b). The third diameter was presented as the average of a and b. Therefore the volume of each aneurysm was calculated according to the following equation:

$$V_{calc} = \frac{4}{3} \pi (a/2)(b/2)(a+b)/4$$

In our study, the third diameter was actually measured on rotated 3D image by 90 degrees.

In conclusion, conventional 2D angiography based aneurysm volume calculation tends to underestimate an aneurysm volume especially those with a wide neck, thus, so-called VER (volume embolization ratio) could be overestimated. To apply the previously reported recommended VER to recent practice with 3D-RA, it may be necessary to correct previous data of VER that are based on the conventional approximation, if broad-neck aneurysms were included in a large percentage.

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