How to Size Intracranial Aneurysms: A Phantom Study of Invasive and Noninvasive Methods

D. Behme, N. Amelung, T. Khakzad, and M.-N. Psychogios

ABSTRACT

BACKGROUND AND PURPOSE: Endovascular treatment of intracranial aneurysms has relevantly changed over the past decades. Multiple new devices such as intrasaccular flow diverters have broadened the treatment spectrum but require very exact aneurysm sizing. In this study, we investigated multidetector and flat panel angiographic CT and digital subtraction imaging as well as different postprocessing methods (multiplanar reconstruction, volume-rendering technique, 3D DSA, and conventional 2D angiography) for their ability to exactly size 2 aneurysm models.

MATERIALS AND METHODS: Two aneurysm models with known aneurysm sizes were placed inside a human skull. After injection of iodine contrast media, imaging was performed using a 128-slice CT scanner or an Artis Q biplane angiosuite, respectively. Aneurysms were measured for width, neck, and height, and the mean difference from the known sizes was calculated for each technique. The technique with the most exact measurement was defined as the criterion standard. We performed Bland-Altman plots comparing all techniques against the criterion standard.

RESULTS: Angiograms adjusted according a previous 3D run with a short object-to-detector distance resulted in the most exact aneurysm measurement: \(-0.07 \pm 0.61\) mm for aneurysm 1 and \(-0.17 \pm 0.39\) mm for aneurysm 2. Measurements of conventional DSA images were similar, and CT-based images were significantly inferior to the criterion standard.

CONCLUSIONS: 2D DSA with a short objective-to-detector distance adjusted according to a previous 3D run resulted in the most exact aneurysm measurement and should therefore be performed before all endovascular aneurysm treatments.

ABBREVIATIONS: FDCTA = flat panel detector CTA; MDCTA = multidetector row CTA; VRT = volume-rendering technique

Endovascular treatment of ruptured aneurysms has become the standard of care, and it is also a well-accepted alternative to microsurgical clipping for the treatment of unruptured aneurysms.\(^1,2\) However, in anatomically challenging aneurysms such as broad-based bifurcational aneurysms, coil embolization alone is of limited use. Therefore numerous adjunctive devices and intraluminal and intrasaccular flow diverters for intra-arterial aneurysm repair have been developed during the past decade and are currently used in clinical practice.\(^3-5\) Some of these new devices such as the Woven EndoBridge (WEB) aneurysm embolization system (Sequent Medical, Aliso Viejo, California) require a very exact preinterventional aneurysm sizing for favorable angiographic results.\(^4\) Simultaneously, aneurysm imaging has emerged significantly with the introduction of 3D digital subtraction angiography and different reconstruction modalities (MPR) and the volume-rendering technique (VRT) for multidetector row CT angiography (MDCTA) and flat panel detector CT angiography (FDCTA). However, until recently, only a few studies have examined the capability of these different techniques regarding the accuracy of intracranial aneurysm sizing, yielding contradictory findings.\(^6-9\) The aim of this study was to evaluate different image-acquisition and reconstruction techniques in regard to their ability to optimize preinterventional device sizing in endovascular aneurysm repair.

MATERIALS AND METHODS

Phantom Preparation and Image Acquisition

Intracranial aneurysms were simulated using 2 different 3D aneurysm models printed according to a 3D angiographic dataset with a Form 2 printer (Formlabs, Somerville, Massachusetts). Known sizes of the aneurysms were the following—aneurysm 1:
For a better simulation of a clinical setting, the models were placed in a human skull (Fig 1). Both models were examined in the 3 different modalities (MDCTA, FDCTA, DSA) 5 times with different positions of the model. For MDCTA and FDCTA, the silicone models were filled with diluted iodinated contrast agent (Iomeron 400, iopamidol; Bracco, Milan, Italy). For DSA runs, 50% diluted contrast agent and saline flush were injected during image acquisition. DSA runs were performed with 3 different detector distances from the model (as short as technically possible near; as far away as possible = long; and in middle position = middle); 3D DSA and DSA runs that were adjusted to the optimal projection of the 3D run, again with 3 different positions of the detector. Each examination was performed with 5 different positions of the skull/aneurysm, resulting in 90 acquisitions and 120 datasets.

The nomenclature used in this study is as follows: MDCTA or FDCTA, MPR and VRT. DSA long, middle, or near represents 2D-DSA images with different detector differences; and DSA rotation near, middle, and long represents 2D-DSA images that were acquired according an optimal projection from the rotational images of a 3D-DSA. Additionally, 3D-DSA MPR and VRT represent reconstructed images from the 3D-DSA.

Table 1: Examination parameters

|             | MDCTA | FDCTA | 3D DSA | DSA     |
|-------------|-------|-------|--------|---------|
| FOV (cm)    | 10 × 10 | 10 × 10 | 10 × 10 | 15 × 15  |
| Matrix size | 512 × 512 | 512 × 512 | 512 × 512 | 1024 × 1024 |
| In-plane resolutions (mm) | 0.2 | 0.2 | 0.29 | 0.15 |
| Cumulative dose (mGy)       | 30 | 40 | 9 | 53 |

RESULTS

Of all applied techniques and reconstructions, 2 DSA images acquired in an optimal projection according to a previous rotational angiogram and a short object-to-detector distance (DSA rotation near) resulted in the smallest mean difference and SD compared with the known aneurysm size. The measurements of all 3 raters resulted in a $-0.07 \pm 0.61$ mm mean difference for aneurysm 1 and $0.12 \pm 0.25$ mm mean difference for aneurysm 2. 2D-DSA images with medium and long detector distances resulted in similar measurements, whereas MPR and VRT from either MDCTA, FDCTA, or even DSA resulted in larger mean differences. (For an overview of all techniques, see Tables 2 and 3 and Fig 3.) Accordingly, the analysis of the
mean differences in DSA rotation near was defined as the criterion standard, and Bland–Altman plots were calculated for all other techniques compared with the criterion standard (Fig 3). When compared with DSA images acquired in the same projection (optimized according the rotational images) but with other distances of the detector, the smallest differences in the mean were found. The arithmetic mean difference between DSA rotation near and DSA rotation middle was 0.01 (95% CI, −0.08 to 0.11; lower limit: −0.89; 95% CI, −1.05 to −0.7; upper limit: 0.91; 95% CI, 0.75–1.08) and 0.9 (95% CI, −0.04 to 0.21, lower limit: −1.13; 95% CI, −1.36 to −0.91; upper limit: 1.31; 95% CI, 1.09–1.54) for DSA rotation long, respectively. In comparison with normal DSA images (no optimized projection), the smallest difference in the mean was found for the DSA images obtained with a long detector-to-object distance, with a mean difference of −0.48 (95% CI, −0.63 to −0.33; lower limit: −1.90; 95% CI, −2.16 to −1.64; upper limit: 0.94; 95% CI, 0.68–1.20). The mean difference was −0.51 (95% CI, −0.67 to −0.36; lower limit: −1.19; 95% CI, −2.25 to −1.71; upper limit: 0.95; 95% CI, 0.68–1.22) for the near detector position.

When comparing DSA rotation near measurements with MPR and VRT images derived from 3D-DSA, a smaller mean difference was found for rotational DSA MPR images: −0.72 (95% CI, −0.98 to −0.46; lower limit: −3.19, 95% CI, 3.64 to −2.74; upper limit: 1.75; 95% CI, 1.30–2.20 versus −0.86; 95% CI, −1.03 to −0.69; lower limit: −2.49, 95% CI, −2.9 to −2.19; upper limit: 0.77; 95% CI, 0.47–1.07) for rotational DSA VRT images. The comparison with angiographic images from MDCT resulted in a mean difference of −0.84 (95% CI, −1.05 to −0.62; lower limit: −2.89; 95% CI, −3.27 to −2.52; upper limit: 1.22; 95% CI, 0.85–1.60). Comparable measurements were obtained using VRT images derived from the MDCTA data, resulting in a mean difference from DSA rotational near of −1.34 (95% CI, −1.56 to −1.13; lower limit: −3.37; 95% CI, −3.74 to −2.99; upper limit: 0.68; 95% CI, 0.31–1.05).
When image acquisition was performed using the flat panels of the angiography scanner, we measured the following mean differences:

- For VRT images reconstructed from a FDCTA run and 0.67 (95% CI, 0.86 to 0.49; lower limit: 2.37; 95% CI, 2.68 to 2.06; upper limit: 1.02; 95% CI, 1.40–2.32). For an overview of all arithmetic means and lower and upper limits including CIs see Table 4; all Bland-Altman plots can be found in Fig 3.

**DISCUSSION**

Endovascular aneurysm repair has become the standard of care for ruptured intracranial aneurysms during the past decades. Along with this clinical development, a broad range of adjunctive devices for the endovascular treatment of intracranial aneurysms has been developed, and several of them are currently used in clinical practice. For all of these devices, sizing is a critical issue and additionally too adjunctive devices and all types of flow diverters; even the sizing of standard coils has a relevant impact on occlusion rates after endovascular treatment. From a technical and clinical point of view, sizing should thereby have the accuracy of ±1 mm because most devices are available in 1-mm steps. However, until recently, there were no guidelines or consensus on how intracranial aneurysm sizing should be performed, and only a few studies have focused on this issue though there is growing evidence for the importance of the chosen image technique and reconstruction method applied. Considering the above-mentioned dimension of 1-mm deviation to be clinically relevant, our study revealed 2D-DSA images adjusted to previous 3D DSA (optimal projection) performed the best in terms of accuracy when comparing the absolute mean difference and SD of the aneurysm dimensions with 0.07 for aneurysm 1 and 0.12 for the second aneurysm model. Therefore, all other techniques in this study were compared with this predefined criterion standard.

Considering the lower and upper limits of the Bland-Altman plots to represent our defined goal of 1-mm accuracy, only DSA images with optimized projection (according to a previous 3D run) and middle detector position fulfilled the requirement of being equivalent to 2D-DSA images with optimal projection and short detector distance.
Table 4: Statistical analyses of the Bland-Altman plots comparing all techniques against DSA rotation “near” images

| Statistics/Technique | Arithmetic Mean Differences (95% CI) | Lower Limit (95% CI) | Upper Limit (95% CI) |
|----------------------|-------------------------------------|----------------------|----------------------|
| FDCTA MPR            | −0.64 (−0.91 to −0.37)              | −3.34 (−3.60 to −2.68) | 1.86 (1.40–2.32)     |
| FDCTA VRT            | −0.67 (−0.86 to −0.49)              | −2.37 (−2.68 to −2.06) | 1.02 (0.71–1.33)     |
| MDCTA MPR            | −0.84 (−1.05 to −0.63)              | −2.89 (−3.27 to −2.52) | 1.22 (0.85–1.60)     |
| MDCTA VRT            | −1.34 (−1.56 to −1.13)              | −3.37 (−3.74 to −2.99) | 0.68 (0.31–1.05)     |
| DSA long             | −0.48 (−0.63 to −0.33)              | −1.90 (−2.16 to −1.64) | 0.94 (0.68–1.20)     |
| DSA middle           | −0.51 (−0.67 to −0.36)              | −1.98 (−2.25 to −1.71) | 0.95 (0.68–1.22)     |
| DSA near             | −0.58 (−0.75 to −0.41)              | −2.15 (−2.44 to −1.86) | 0.99 (0.70–1.28)     |
| 3D DSA MPR           | −0.72 (−0.98 to −0.46)              | −3.19 (−3.64 to −2.74) | 1.75 (1.30–2.20)     |
| 3D DSA VRT           | −0.86 (−1.03 to −0.69)              | −2.49 (−2.9 to −2.19)  | 0.77 (0.47–1.07)     |
| DSA rotation long    | 0.89 (−0.04 to 0.21)                | −1.13 (−1.36 to −0.91) | 1.31 (1.09–1.54)     |
| DSA rotation middle  | 0.01 (−0.08 to 0.11)                | −0.89 (−1.05 to −0.71) | 0.91 (0.75–1.08)     |

Table 5: Interclass correlation coefficient for all techniques

| Technique           | ICC       | 95% CI     |
|---------------------|-----------|------------|
| FDCTA MPR           | 0.8801    | 0.7912–0.9366 |
| FDCTA VRT           | 0.9518    | 0.9078–0.9759 |
| MDCTA MPR           | 0.9532    | 0.9065–0.9772 |
| MDCTA VRT           | 0.9849    | 0.9712–0.9925 |
| DSA long            | 0.9652    | 0.9377–0.9820 |
| DSA middle          | 0.9838    | 0.9705–0.9917 |
| DSA near            | 0.9806    | 0.9648–0.9901 |
| 3D DSA MPR          | 0.9063    | 0.7781–0.9577 |
| 3D DSA VRT          | 0.8638    | 0.7676–0.9275 |
| DSA rotation long   | 0.8638    | 0.7676–0.9275 |
| DSA rotation middle | 0.9834    | 0.9700–0.9915 |
| DSA rotation near   | 0.9855    | 0.9737–0.9926 |

Note: ICC indicates interclass correlation coefficient.

There are several limitations to our study. The main limitation is the phantom design, though it allows a comparison with known aneurysm sizes. However, as we have described above, 3D printing may have influenced our study results. Additionally, there were only 2 aneurysm models, and both were saccular aneurysms; the investigation of very complex aneurysms, therefore, might have led to other results. Another limitation is the use of standardized contrast attenuation for most investigations (MDCTA and FDCTA) but also 3D-DSA as has been described recently by Lauric et al.12

In this study, different kernels were used for different purposes, and we found 3D-DSA VRT and MPR images from smooth/normal kernel reconstructions to overestimate aneurysm sizes, in line with findings of Lauric et al12 recently. Most interesting, Lauric et al and O’Meara et al6 compared different techniques and different reconstruction kernels with 3D-DSA images, which we found to significantly overestimate aneurysm sizes and therefore were not recommended for use as a criterion standard in aneurysm sizing. In another study, Ruedinger et al16 reported that edge-enhancement reconstructions with a smooth or normal kernel resulted in the most accurate measurements of aneurysms, which supports our experimental setup using these reconstruction algorithms. Additionally, Bland-Altman plot analysis showed that 3D-DSA MPR and VRT images overestimated larger aneurysm dimensions more than smaller dimensions. In terms of accuracy, FDCTA MPR and VRT images had smaller mean differences to the known aneurysm sizes compared with MDCTA or 3D-DSA (Tables 2 and 3). When we compared FDCTA VRT and MPR versus MDCTA VRT and MPR, it became evident that both had smaller mean differences in sizing with the chosen criterion standard (DSA rotation near). These findings are similar to those reported in the literature for intracranial vessels or stenosis measurement and for intracranial aneurysms.6,7,15,17

From a clinical point of view, most techniques investigated in this study produced accurate measurements of the aneurysm models. However, when it comes to device sizing, one should be aware that only optimized DSA images (ie, optimal projection) resulted in almost perfect measurements with <1-mm deviation toward the lower and upper limits of the Bland-Altman plots. Regarding the radiation dose applied, a 3D-DSA run with a 5-second rotation time has a significantly lower dose compared with a biplane DSA run or MDCTA/FDCTA, which suggests that an initial 3D run for planning of optimized 2D images (optimized projection) leads to optimal 2D images for aneurysm measurement and treatment planning and lower doses.18,19

AJNR Am J Neuroradiol 39:2291–96  Dec 2018 www.ajnr.org 2295
REFERENCES

1. Molyneux A, Kerr R, Stratton I, et al; International Subarachnoid Aneurysm Trial (ISAT) Collaborative Group. International Subarachnoid Aneurysm Trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomised trial. Lancet 2002;360:1267–74 CrossRef Medline

2. Wiebers DO, Whisnant JP, Huston J 3rd, et al; International Study of Unruptured Intracranial Aneurysms Investigators. Unruptured intracranial aneurysms: natural history, clinical outcome, and risks of surgical and endovascular treatment. Lancet 2003;362:103–10 CrossRef Medline

3. Behme D, Weber A, Kowoll A, et al. Low-profile Visualized Intraluminal Support device (LVIS Jr) as a novel tool in the treatment of wide-necked intracranial aneurysms: initial experience in 32 cases. J Neurointerv Surg 2015;7:281–85 CrossRef Medline

4. Behme D, Berlis A, Weber W. Woven EndoBridge intrasaccular flow disruptor for the treatment of ruptured and unruptured wide-neck cerebral aneurysms: report of 55 cases. AJNR Am J Neuroradiol 2015;36:1501–06 CrossRef Medline

5. Gory B, Aguilar-Pérez M, Pomero E, et al. One-year angiographic results after pCONus stent-assisted coiling of 40 wide-neck middle cerebral artery aneurysms. Neurosurgery 2017;80:925–33 CrossRef Medline

6. Struffert T, Doelken M, Adamek E, et al. Flat-detector computed tomography with intravenous contrast material application in experimental aneurysms: comparison with multislice CT and conventional angiography. Acta Radiol 2010;51:431–37 CrossRef Medline

7. Zwarzany L, Poncyljusz W, Burke TH. Flat detector CT and its applications in the endovascular treatment of wide-necked intracranial aneurysms—A literature review. Eur J Radiol 2017;88:26–31 CrossRef Medline

8. Wong GK, Yu SC, Poon WS. Radiological measurements of dimensions of acutely ruptured internal carotid artery aneurysm: a comparative study between computed tomographic angiography and digital subtraction angiography. Clin Pract 2012;2:e75 CrossRef Medline

9. Wong SC, Nawawi O, Ramli N, et al. Benefits of 3D rotational DSA compared with 2D DSA in the evaluation of intracranial aneurysm. Acad Radiol 2012;19:701–07 CrossRef Medline

10. Hodis S, Ding YH, Dai D, et al. Relationship between aneurysm occlusion and flow diverting device oversizing in a rabbit model. J Neurointerv Surg 2016;8:94–98 CrossRef Medline

11. Griessenauer CJ, Adeeb N, Foreman PM, et al. Impact of coil packing density and coiling technique on occlusion rates for aneurysms treated with stent-assisted coil embolization. World Neurosurg 2016;94:157–66 CrossRef Medline

12. Lauric A, Hippelheuser JE, Malek AM. Critical role of angiographic acquisition modality and reconstruction on morphometric and haemodynamic analysis of intracranial aneurysms. J Neurointerv Surg 2018;10:911–15 CrossRef Medline

13. O’Meara B, Rahal JP, Lauric A, et al. Benefit of a sharp computed tomography angiography reconstruction kernel for improved characterization of intracranial aneurysms. Neurosurgery 2014;10(Suppl 1):97–105; discussion 105 CrossRef Medline

14. Lauric A, Heller RS, Schimansky S, et al. Benefit of cone-beam CT angiography in visualizing aneurysm shape and identification of exact rupture site. J Neuroimaging 2015;25:56–61 CrossRef Medline

15. Psychogios MN, Schramm P, Amelung N, et al. Evaluation of non-invasive follow-up methods for the detection of intracranial in-stent restenosis: a phantom study. Invest Radiol 2013;48:98–103 CrossRef Medline

16. Ruedinger KL, Rutkowski DR, Schafer S, et al. Impact of image reconstruction parameters when using 3D DSA reconstructions to measure intracranial aneurysms. J Neurointerv Surg 2018;10:285–89 CrossRef Medline

17. Yang P, Schafer S, Royalty K, et al. Measurement in the angiography suite: evaluation of vessel sizing techniques. J Neurointerv Surg 2016;8:965–68 CrossRef Medline

18. Struffert T, Hauer M, Banckwitz R, et al. Effective dose to patient measurements in flat-detector and multislice computed tomography: a comparison of applications in neuroradiology. Eur Radiol 2014;24:1257–65 CrossRef Medline

19. Guberina N, Lechel U, Forsting M, et al. Dose comparison of classical 2-plane DSA and 3D rotational angiography for the assessment of intracranial aneurysms. Neuroradiology 2016;58:673–78 CrossRef Medline