ORIGINAL RESEARCH

AngioSuite: an accurate method to calculate aneurysm volumes and packing densities

Keith Woodward, David A Forsberg

Cascade Medical, Knoxville, Tennessee, USA

Correspondence to
Dr D A Forsberg, Cascade Medical, 2450 EJ Chapman Dr, 104A, Knoxville, TN 37996, USA; david.forsberg@cascademedical.us.com

Received 24 February 2012
Revised 2 June 2012
Accepted 9 June 2012

ABSTRACT

Objective AngioSuite was developed to allow the easy and accurate calculation of cerebral aneurysm volumes and packing densities. The present study was undertaken to validate its accuracy.

Methods Mathematical models and software were created to facilitate more complex aneurysm volume calculations than previously described three-dimensional geometric models. 20 phantom aneurysm clay models were created and analyzed (length, width, depth and volume) using angiographic mathematical modeling (AngioSuite), geometric modeling (AngioCalc) and three-dimensional volume reconstructions from the vendor's Leonardo workstation (Siemens).

Results The mean volumes of all phantoms analyzed by the AngioSuite system differed from true volumes by an average of 2.2%. Mean volumes of all phantoms analyzed by the AngioCalc system differed from true volumes by an average of 11.3%. Mean volumes obtained from the Leonardo workstation windowed for best appearance differed by an average of 5.18%.

Conclusions The AngioSuite software system provides an accurate means of calculating aneurysm volumes. Typical packing densities (40% or less) are thus accurate within ±1%. Angiographic mathematical modeling with AngioSuite is more accurate than geometric modeling and three-dimensional volume reconstructions windowed for best appearance (Leonardo).

INTRODUCTION

The ability to assess packing density during endovascular treatment of aneurysms is limited by multiple factors. First and foremost is the ability to accurately calculate aneurysm volume. Many authors have noted the difficulty of determining true aneurysm volumes.[1–6] Three-dimensional volume calculations are operator dependent and greatly affected by choices of threshold windows and levels. Volume calculations based on two-dimensional images can be adversely affected by the lack of a fiduciary marker and irregular aneurysm shapes as well as overly simplistic spherical or elliptical geometric models. The accuracy of three-dimensional rotational angiography volumes and mathematical models for estimating volumes is largely unknown.

Most authors believe that increased packing densities result in lower compaction and decreased rates of aneurysm recurrence.[2 3 6–16]

Precise packing densities are easily calculated if accurate aneurysm volumes have been obtained. Nevertheless, algorithms to quickly predict the effect of coil choice on packing density are not routinely used during coil selection. The AngioSuite system was developed to expediently perform these calculations. This software facilitates accurate aneurysm volume calculations and allows the neurointerventionalist to proactively predict packing density with each coil selection. This should help one achieve higher packing densities. The purpose of the present study was to determine the accuracy of angiographic mathematical modeling, geometric modeling and three-dimensional rotational angiography for volume and packing density analysis in cerebral aneurysms.

METHODS AND MATERIALS

Development of the AngioSuite software

Imaging algorithms were developed for aneurysm volume calculations that are more complex than previously described three-dimensional geometric models. This algorithm was then extensively back tested against two-dimensional projections from known three-dimensional shapes. After verification of the accuracy from simple shapes, the system was then tested on more complex shapes that more readily approximate aneurysm morphologies. The model uses the working view of a two-dimensional angiogram to calculate maximum and minimum diameters as well as circumference. The software then extrudes a volume based on these measurements, accounting for aneurysm irregularity in two dimensions and estimating irregularity in the third dimension (see figures 1 and 2).

The AngioSuite software was coded to allow for accurate aneurysm volume calculation, packing density calculation (based on an extensive database of endovascular coils from all manufacturers) as well as occlusion analysis and case reporting. Technically, the software is easy to use on either an iPhone or iPad and it not only calculates aneurysm volumes and packing densities, but it also allows for case archival as well as case sharing.

Creating phantom aneurysm models

Twenty consecutive aneurysms from our institution's clinical practice were reviewed by two independent physicians. Phantom clay models were created to reflect aneurysm appearance based on a review of two-dimensional and three-dimensional angiograms of this patient population (see figure 3). Phantoms ranged from 5.0 to 9.5 cm in size. Larger aneurysms were utilized for ease of measurement. We sought to minimize the effect of measurement error on results. This would ensure that calculated

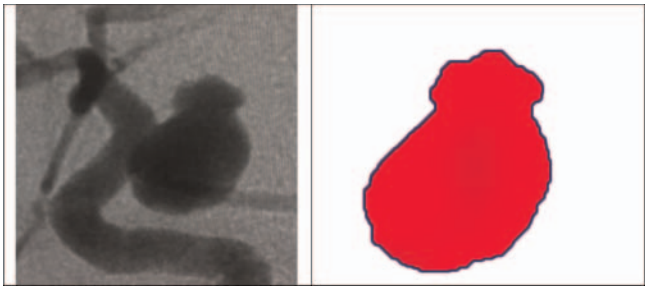

Figure 1 Software generated representation of an aneurysm taken from a two-dimensional working view projection of a clinical case in our practice.

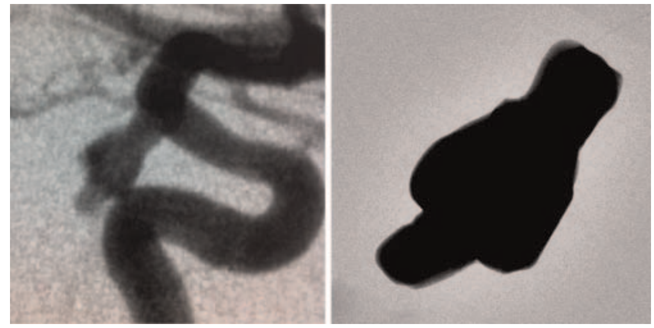

Figure 3 The image on the left is the working view of an aneurysm taken from our clinical practice. The spot film on the right is a clay model phantom created to simulate the in vivo appearance.

aneurysm volumes were more dependent on the mathematical algorithms employed.

Angiography and volume calculations

Digital subtraction angiography and three-dimensional rotational angiography of the phantoms was performed on an AXIOM biplane system (Siemens, Erlangen, Germany). Aneurysm dimensions were obtained from biplane angiograms after calibration from known fiduciary markers. Additionally, subtracted three-dimensional rotational angiography was performed, and transferred to a Leonardo workstation (Siemens) for analysis. Aneurysm volumes were then calculated using the AngioSuite, AngioCalc and Leonardo software systems. Biplane angiographic images were loaded into the AngioSuite system (Cascade Medical, Knoxville, TN, USA) and volumes were calculated using calibration performed from the two-dimensional measurements (as well as three-dimensional measurements and fiduciary markers). Measurements from the two-dimensional and three-dimensional angiograms were then used to estimate volumes using ellipsoid and multi-lobular geometric models (AngioCalc). Three-dimensional rotational angiograms were analyzed on a Leonardo (Siemens) workstation for aneurysm dimensions and volumes. This was performed using two different methodologies. In the first, three-dimensional analysis was based on a subjective 'best windowing appearance,' the approach most often used in clinical practice. In the second, calibration with a quarter fiduciary was performed. Phantom images were windowed until the quarter measured exactly its known length (24.3 mm). This was done in an attempt to assess the maximum possible performance of the three-dimensional system. A quarter was utilized as a larger fiduciary size results in a smaller relative (percentage) measurement error. Models were weighed in distilled water at room temperature and the weight of the displaced water was measured. Based on the specific gravity of water at a known temperature, the volume of each phantom was then calculated.

Results were subjected to statistical analysis using Levene's test for homogeneity of variances. Prediction intervals were then calculated using O'Neill and Matthews modification of Levene's test.[17 18]

RESULTS

The mean volumes of all phantoms analyzed with the AngioSuite system differed from true volumes by 2.2% (range −8.2% to +7%). The average difference from true volumes using geometric modeling (AngioCalc) was 11.3% (range −12.5% to +34%) (figure 4). This resulted in consistent overestimation of true aneurysm volumes. In clinical practice, this would result in underestimating true packing density.

Varying windows on the three-dimensional workstation resulted in wide variations in true volume (figure 5). In this example, calculated aneurysm volume varied from 42 to 61 mm^3 solely because of window selection.

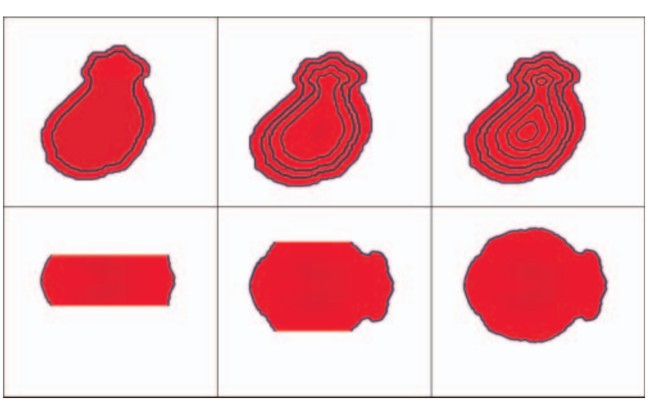

Figure 2 The top row shows aneurysm morphology in the two-dimensional plane based on the working view, as in figure 1. The bottom row shows estimation of depth in the orthogonal plane based on the software extrusion and accounting for irregularity in the frontal projection.

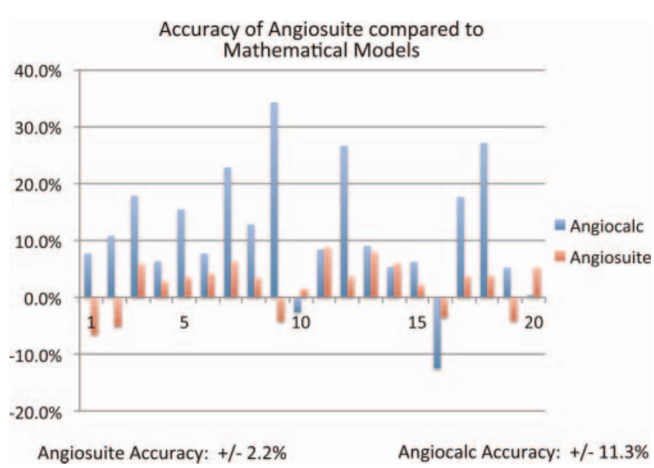

Figure 4 Simple geometric models almost always overestimate aneurysm volume and in our study had an average accuracy of ±11.3%. AngioSuite had much greater accuracy of ±2.2% compared with true volume.

J NeuroIntervent Surg 2012;0:1–5. doi:10.1136/neurintsurg-2012-010317

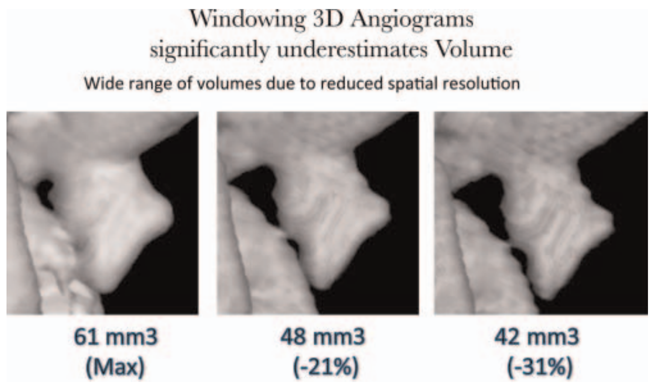

Figure 5 Images from a three-dimensional Angiogram of one of the phantoms demonstrate the effect of varying the window on aneurysm appearance and volume calculations.

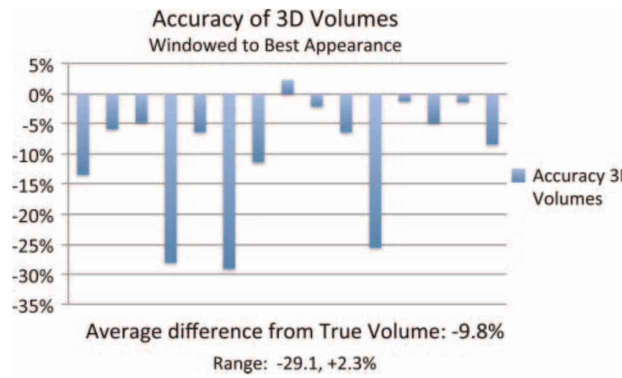

Figure 6 Accuracy of three-dimensional volume calculations based on best appearance (the normal clinical scenario). Note that true aneurysm volumes are almost always underestimated by an average of 9.8%.

When windowed to best appearance, three-dimensional calculated volumes of phantoms ranged from −29.1% to +2.3% with an average of −9.8% (see figure 6). In general, true aneurysm volume was almost always underestimated. Clinically, this would result in spuriously overestimating true packing densities in clinical practice.

Phantoms analyzed with three-dimensional rotational angiography and a quarter as a fiduciary marker differed on average from true volume by 0.21% (range −5.25% to +2.0%).

Figure 7 summarizes the calculated aneurysm volumes using the Angiosuite, AngioCalc and optimized Leonardo systems. Figure 8 provides a graphical representation of results obtained

Aneurysm Volumes

Aneurysm	AngioSuite	AngioCalc	3D (Optimized)	Actual
1	52.5	60.5	56.8	56.2
2	77.3	90.3	81.3	81.5
3	62.9	70.0	60.5	59.4
4	103.7	107.2	100.5	100.9
5	76.6	85.4	75.4	74.0
6	76.2	78.9	73.0	73.2
7	72.9	84.2	69.7	68.6
8	100.9	110.1	97.7	97.6
9	39.4	55.2	41.8	41.1
10	100.5	96.5	96.0	99.0
11	45.5	46.1	43.3	42.5
12	96.9	118.5	92.0	93.6
13	59.6	60.2	55.7	55.2
14	83.4	83.0	79.0	78.8
15	63.9	66.4	63.2	62.5
16	92.0	83.5	95.6	95.4
17	52.5	59.5	51.6	50.6
18	142.1	174.0	129.8	136.9
19	54.8	60.1	57.5	57.1
20	100.4	105.5	105.8	105.9
Avg Variation	**2.2%**	**11.3%**	**0.21%**	

Figure 7 Calculated aneurysm volumes using all three methods, AngioSuite, AngioCalc and optimized three-dimensional Leonardo system, versus actual volume. Volumes are given in cubic centimeters with aneurysm ranging in size from 5.0 to 9.5 cm in greatest length. Actual aneurysm volumes were calculated by weighing the phantoms in and out of water.

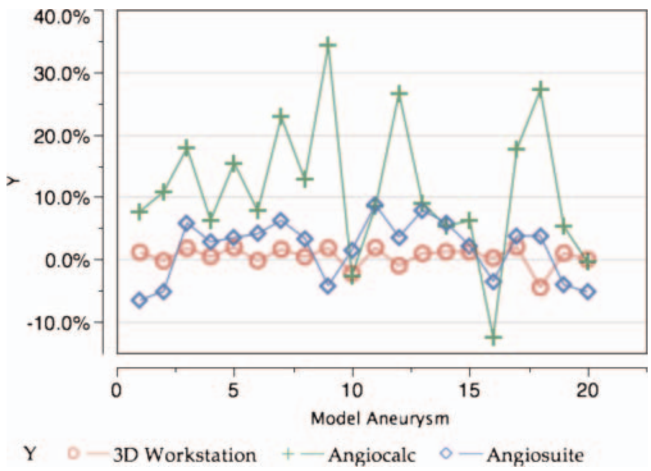

Figure 8 Deviation from true volume in all phantoms. The plot demonstrates that the AngioSuite measurement method rivals the three-dimensional workstation method. The three-dimensional workstation method, as presented here, is not clinical. (These three-dimensional calculations were optimized. Rather than windowing for best appearance as in figure 5, these samples were windowed to a fiduciary—a quarter, until 24.3 mm, the exact size of a quarter was achieved. The fiduciary was then used for calibration.) Statistically, the variation in the AngioSuite method is shown to be significantly better than the geometric modeling method. Levene's test for homogeneity of variances yields a p value of 0.0088; these results would be achieved by chance less that 1% of the time or $\alpha<0.01$.

by all three methods. A Levene test for homogeneity of variances shows the results to be statistically significant, with a p value of <0.0088; thus these results would be achieved by chance less than 1% of the time or $\alpha<0.01$.

DISCUSSION

The present study was undertaken to validate the accuracy of the AngioSuite system. Accurate aneurysm volume calculations are essential to the determination of accurate packing densities. Analysis of clay models with the AngioSuite software showed it to be more accurate than AngioCalc and three-dimensional rotational angiography windowed to the best visual appearance. Piotin *et al*,[4] Sluzewski *et al*[2] and others have noted that aneurysm volumes estimated from angiographic images are often inaccurate 'due to several factors including lack of fiduciary markers and irregular aneurysm shapes that cannot be defined by spherical or elliptical models'. Simple geometric models do not account for this irregularity. Three-dimensional rotational angiography can be highly accurate under controlled settings but suffers from inaccuracies introduced by thresholding.[5]

This can affect aneurysm appearance, minimizing irregularities by smoothing. In the present study, 20 aneurysm phantoms were created from 20 consecutive clinical cases and thus mirror real life experience. Models were irregular, and were taken from both ruptured and unruptured aneurysms, accurately reflecting in vivo appearance. As such, these phantoms were ideal for assessing the accuracy of the various volume measurement systems. Limitations of this approach include larger aneurysm size. It is possible that measurement of smaller aneurysms might result in differences that were less statistically significant. In addition, phantoms were utilized so as to obtain true volume measurements. The present study was not performed with in vivo aneurysms.

Increased packing density is thought by most authors to result in decreased compaction and fewer aneurysm recurrences. Piotin *et al*[9] noted a 44.4% recurrence rate in aneurysms with packing densities ≤25% and a 29.8% recurrence of aneurysm with packing densities >25%. Sluzewski *et al*[2] showed that aneurysms packed to >24% did not show compaction at 6 months. Others have failed to show a positive correlation between packing density and aneurysm recurrence[8] but their methods of aneurysm volume calculation and thus packing densities were questioned 'based on erroneous methodology of aneurysm–volume calculation, leading to structural over-calculation of aneurysm volumes and hence lower packing densities'.[6] Cloft *et al*[13] noted a 19% aneurysm recurrence rate for aneurysms with packing densities of ≥50% and an 18% recurrence rate for aneurysms with packing densities <50%. Intuitively, one would expect aneurysms with high packing densities to have fewer recurrences. It is likely that a lower threshold packing density would show statistically significant differences in recurrence rates. These authors admitted 'the packing attenuation calculations were very error prone'. The optimal packing density or range of densities is probably not yet known. Preliminary results at our own institution in a retrospective review of 40 aneurysms showed increases in packing densities for similar sized aneurysms using the software in a prospective manner to aid coil selection. Goddard *et al*[8] stated "At our institution we try to pack aneurysms as much as possible and stop the procedure only when the last coil cannot be introduced inside the sac". Our data suggest higher packing densities can be consistently obtained using the AngioSuite software prospectively. Future studies are being undertaken to assess the impact of packing density on recurrence rates. Our present validation of the software's accuracy in determining aneurysm volumes and packing densities should facilitate this pursuit.

In summary, The AngioSuite software system provides an easy and accurate means of calculating aneurysm volumes when calibrated from fiduciary markers, with volume accuracies of 2.2%. Typical packing densities (40% or less) are thus accurate to within 1%. Mathematical models, as well as three-dimensional rotational angiographic volumes windowed for best appearance, are particularly inaccurate. The validation of the AngioSuite system will allow future studies to be undertaken which more definitively and accurately determine the affect of packing density on aneurysm recurrence. An optimal packing density or range of densities should thus ensue.

Contributors Each author contributed equally to the basic research and preparation of the manuscript.

Competing interests AngioSuite is supported by Codman, eV3, Penumbra and Stryker. KW and DAF are co-owners or Cascade Medical, makers of AngioSuite.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

1. **Sadato A,** Hayakawa M, Tanaka T, *et al*. Comparison of cerebral aneurysm volumes as determined by digitally measured 3D rotational angiography and approximation from three diameters. *Intervent Neuroradiol* 2011;**17**:154–8.
2. **Sluzewski M,** van Rooij WJ, Slob MJ, *et al*. Relations between volume, packing, and compaction in 145 cerebral aneurysms treated with coils. *Radiology* 2004;**231**:653–8.
3. **Vallee JN,** Pierot L, Bonafe A, *et al*. Endovascular treatment of intracranial wide-necked aneurysms using three-dimensional coils: predictors of immediate anatomic and clinical results. *AJNR* 2004;**25**:298–306.
4. **Piotin M,** Daghman B, Mounayer C, *et al*. Ellipsoid approximately versus 3D rotational angiography in the volumetric assessment of intracranial aneurysms. *AJNR* 2006;**27**:839–42.
5. **Bescos JO,** Slob MJ, Slump CH, *et al*. Volume measurement of intracranial aneurysms from 3D rotational angiography: improvement of accuracy by gradient edge detection. *AJNR* 2005;**26**:2569–72.

6. **Van Rooij WJ,** Sluzewski M. Packing density in coiling of small intracranial aneurysms. *AJNR* 2006;**27**:725–6.
7. **Tamatani S,** Ito Y, Abe H, *et al*. Evaluation of the stability of aneurysms after embolization using detachable coils: correlation between stability of aneurysms and embolized volume of aneurysms. *AJNR* 2002;**23**:762–7.
8. **Goddard JK,** Moran CJ, Cross DT III,, *et al* Absent relationship between the coil-embolization ratio in small aneurysms treated with a single detachable coil and outcomes. *AJNR* 2005;**26**:1916–20.
9. **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**:500–8.
10. **Cognard C,** Weill A, Spelle L. Long-term angiographic follow-up of 169 intracranial berry aneurysms occluded with detachable coils. *Radiology* 1999;**212**:348–56.
11. **Kawanabe Y,** Sadato A, Taki W, *et al*. Endovascular occlusions of intracranial aneurysms with guglielmi detachable coils: correlation between coil packing density and coil compaction. *Acta Neurochirurg* 2001;**143**:451–5.
12. **Piotin M,** Spelle L, Mounayer C, *et al*. Intracranial aneurysms coiling with matrix. Immediate results in 152 patients and midterm anatomic follow-up from 115 patients. *Stroke* 2009;**40**:321–3.
13. **Cloft HJ.** HydroCoil for Endovascular Aneurysm Occlusion (HEAL) Study: 3–6 month angiographic follow-up results. *AJNR* 2007;**28**:152–4.
14. **Taussky P,** Kallmes DF, Cloft H. Mathematical analysis of incremental packing density with detachable coils: does that last coil matter much? *AJNR* 2012; **33**: e74–5.
15. **Slob MJ,** van Rooij WJ, Sluzewski M. Coil thickness and packing of cerebral aneurysms: a comparative study of two types of coils. *AJNR* 2005;**26**:901–3.
16. **Hacein-Bey L,** Provenzale J. Current imaging assessment and treatment of intracranial aneurysms. *AJR* 2011;**196**:32–44.
17. **O-Neill M,** Mathews K. Levene tests of homogeneity of variance for general block and treatment designs. *Biometrics* 2002;**58**:216–24.
18. **Levene H.** Robust tests for equality of variances. In: Olkin H, Ghurye SG, Hoeffding W, *et al*. *Contributions to probability and statistics.* Palo Alto: Stanford University Press, 1960:278–92.

AngioSuite: an accurate method to calculate aneurysm volumes and packing densities

Keith Woodward and David A Forsberg

J NeuroIntervent Surg published online July 11, 2012