Relationship Between the Contrast Effects of Raw Data Projection Images from Three-Dimensional Digital Subtraction Angiography and the Optimal Volume Rendering Parameters

Satoshi Takagi · Hideyuki Tokumitsu · Shigeru Sanada

Published online: 2 December 2014
© Society for Imaging Informatics in Medicine 2014

Abstract Volume rendering (VR) is a technique commonly used for the reconstruction of three-dimensional (3D) digital subtraction angiography (DSA) images, and the rendering parameters greatly affect the characteristics of the 3D image. This study aimed to test whether the optimal VR parameters for 3D DSA could be estimated from the contrast effects in rotational two-dimensional (2D) DSA images acquired using 3D DSA. Simulated blood vessels filled with various concentrations of contrast medium were scanned, and the 3D DSA data sets were reconstructed. The syngo AX vessel analysis software that was able to analyze 3D DSA VR image was used for objective measures. Raw data projection images of the 3D DSA data sets in which the mean diameter was calculated as a true value by the software at nine different thresholds for vessel segmentation were selected. In each image set, five images of all 133 rotational 2D DSA images were selected, and the contrast-enhanced area was extracted using a region-growing algorithm. Mean values and standard deviations of each contrast-enhanced area were calculated, and as the thresholds for vessel segmentation of the software increased by 500 every time, significant differences were observed in the mean values ($P<0.01$). This optimal threshold can be applied to the window settings of the VR technique. Therefore, the optimal VR parameters for 3D DSA may be determined by analyzing the contrast effects of the raw data projection images, and user-dependent over- and underestimations of 3D DSA VR images also may be prevented.

Keywords Two-dimensional (2D) digital subtraction angiography (DSA) · Three-dimensional (3D) DSA · Volume rendering (VR) · Rendering parameters · Contrast effect

Background

Two-dimensional (2D) digital subtraction angiography (DSA) provides detailed vascular structure and hemodynamic information. Furthermore, recent angiographic suites offer three-dimensional (3D) DSA combining 2D DSA and gantry rotation, which was proven to be a useful technique [1–10].

Volume rendering (VR) is a technique commonly used for the reconstruction of 3D DSA images [3–10], and the rendering parameters greatly affect the characteristics of the 3D image [11, 12]. To our knowledge, no study has identified the optimal rendering parameters for 3D DSA images. The purpose of this study was to test whether the optimal VR parameters for 3D DSA could be estimated from the contrast effects in rotational 2D DSA images acquired using 3D DSA.

Methods

Data Acquisition and Reconstruction

All 3D DSA experiments were performed using a biplane flat-panel detector angiographic suite (Artis zee BA Twin; Siemens AG, Erlangen, Germany). The parameters were as follows: 5-s rotation; rotation angle, 200° with 1.5° increments resulting in 133 projections; rotation speed, 40°/s; frame rate, 26.6 frames/s; acquisition matrix, 1240×960; dose, 0.36 μGy/f. These parameters of 3D DSA technique are common worldwide and change of the parameters is not permitted. 3D DSA reconstruction was performed on a commercially available

S. Takagi (✉) · H. Tokumitsu
Radiological Center, National Defense Medical College Hospital,
3-2, Namiki, Tokorozawa, Saitama 359-8513, Japan
e-mail: rt.stakagi@gmail.com

S. Sanada
Division of Health Sciences, Graduate School of Medical Science,
Kanazawa University, 5-11-80, Kodatsuno, Kanazawa,
Ishikawa 920-0942, Japan

workstation (syngo X-Workplace; Siemens AG) with the following parameters: kernel type, HU; image characteristics, normal; reconstruction mode, sub; slice matrix, 512×512; voxel size, 0.47 mm. An extension tube of 2.2-mm internal diameter (LX2-FL150CT; TOP Corporation, Tokyo, Japan) was used to simulate a blood vessel filled with nonionic iodinated contrast medium (Iomeron 350, Eisai, Tokyo, Japan) of various concentrations mixed with saline. The simulated vessels were scanned, and the 3D DSA data sets were reconstructed. The syngo AX vessel analysis software that was able to analyze 3D DSA VR image by setting the threshold and two points to identify the vessel was used for objective measures of the 3D DSA data sets (Fig. 1). Raw data projection images of the 3D DSA data sets in which the mean diameter was calculated as a true value (2.2 mm) by the software at nine different thresholds for vessel segmentation (500, 1000, 1500, 2000, 2500, 3000, 3500, 4000, and 4500) were selected (Fig. 2). In addition, plain (unenhanced) 3D DSA images were scanned, and plain rotational 2D DSA images were acquired. Therefore, a total of 10 data sets of rotational 2D DSA images were included in this study.

Image Analysis of Rotational 2D DSA Image

In each data set, five images (frontal, right anterior oblique, left anterior oblique, right lateral, and left lateral) of all 133 rotational 2D DSA images were selected, and a 620×620 area from the image center was extracted for analysis (Fig. 3a). The threshold pixel value of the background noise level of rotational 2D DSA image was determined as mean−3 standard deviations (SDs) of the plain rotational 2D DSA image set. The contrast-enhanced area of the nine data sets selected was defined as the pixels lower than the threshold pixel value of the background noise level and was extracted using a region-growing algorithm (Fig. 3b). Means±SDs of the pixel value of each extracted region were calculated. Custom software was developed using Microsoft Visual C#.

Statistical Analysis

Means±SDs of the pixel value of the contrast-enhanced area of the nine data sets were compared using Welch's *t*-test. Statistical significance was ascribed to *P* values <0.01.

Results

Mean±SD of the pixel value of the plain rotational 2D DSA image set was 3144±69. Therefore, the threshold pixel value of the background noise level of rotational 2D DSA image was defined as 2937 (mean−3 SDs).

The means and SDs of the pixel value of the contrast-enhanced nine data sets are summarized in Table 1. There

Fig. 1 Volume rendering technique (a) and results of the measurements (b) using syngo AX vessel analysis software

were significant differences in the mean values of the extracted contrast-enhanced area as the thresholds for vessel segmentation of the software increased by 500 every time; in these images, the mean diameter was calculated as true value by the software (*P*<0.01).

Discussion

The rendering parameters for 3D DSA images have never been investigated and are dependent on user's preference,

Fig. 2 Rotational 2D DSA images in which the mean diameter was calculated as a true value by syngo AX vessel analysis software at thresholds of 4500 (**a**), 2500 (**b**), and 500 (**c**)

leading to over- and underestimation of VR images. In this study, we have revealed that there was a significant difference between the contrast effects of rotational 2D DSA images and

Fig. 3 In the region of the 620×620 area at the center of the rotational 2D DSA image (**a**), the contrast-enhanced area was extracted (**b**)

the optimal threshold of syngo AX vessel analysis software for vessel segmentation. This optimal threshold can be applied to the window settings of the VR technique. Therefore, when the optimal VR parameters for 3D DSA are determined by analyzing the contrast effects of the raw data projection images, the VR images become independent of user's preference. However, the relationship has been revealed in a pair of reconstruction parameters created by the manufacturer. Therefore, the revelation of different pairs of reconstruction parameters of various manufacturers is required. Although contrast enhancement of blood vessels is not constant during 5 s of 3D DSA examination because of heart beat and blood flow, the influence of this variable appears to be minimized by analyzing several projection images.

Furthermore, the revelation of the optimal VR parameters for 3D DSA is thought to lead to optimization of the injection parameters for 3D DSA. The volume and injection rate of contrast medium for 3D DSA are generally determined not by patient hemodynamics but by the position of the catheter tip

Table 1 Relationship between the optimal threshold of syngo AX vessel analysis software and mean±SD of the pixel value of the extracted contrast-enhanced area from rotational 2D digital subtraction angiography images

Threshold	Mean±SD	Approximate concentration (%)	
500	2549±180	] $P<0.01$	35
1000	2490±210		40
1500	2370±261	] $P<0.01$	50
2000	2260±316		60
2500	2164±362	] $P<0.01$	70
3000	2108±396		80
3500	2009±444	] $P<0.01$	90
4000	1899±505		95
4500	1808±547	] $P<0.01$	100

SD standard deviation

[5–10]. These injection parameters are considered not optimal and seem to be excessive in order to ensure examination success. In general, 2D DSA is performed at specific projection angles before 3D DSA. Although further study of the relationship of injection parameters and contrast effects between 2D DSA and 3D DSA is needed, there is the possibility that the optimal injection parameters for 3D DSA can be determined from the injection parameters and contrast effects of pre-acquired 2D DSA images. Then, the amount of contrast medium for 3D DSA can be reduced in almost all examinations.

Conclusion

The present study clarified the relationship between the contrast effects of the raw data projection images and the optimal

VR parameters for 3D DSA. This relationship may prevent user-dependent over- and underestimations of 3D DSA VR images. Further study of the relationship of injection parameters and contrast effects between 2D DSA and 3D DSA can realize the determination of the optimal injection parameters for 3D DSA.

References

1. Wong SC, Nawawi O, Ramli N, Abd Kadir KA: Benefits of 3D rotational DSA compared with 2D DSA in the evaluation of intracranial aneurysm. *Acad Radiol* 19:701–707, 2012
2. Luo B, Yang X, Wang S, Li H, Chen J, Yu H, Zhang Y, Zhang Y, Mu S, Liu Z, Ding G: High shear stress and flow velocity in partially occluded aneurysms prone to recanalization. *Stroke* 42:745–753, 2011

3. Leng LZ, Rubin DG, Patsalides A, Riina HA: Fusion of intraoperative three-dimensional rotational angiography and flat-panel detector computed tomography for cerebrovascular neuronavigation. *World Neurosurg* 79:504–509, 2013
4. Sun G, Ding J, Lu Y, Li M, Li L, Li GY, Zhang XP: Comparison of standard- and low-tube voltage 320-detector row volume CT angiography in detection of intracranial aneurysms with digital subtraction angiography as gold standard. *Acad Radiol* 19:281–288, 2012
5. Lescher S, Samaan T, Berkefeld J: Evaluation of the pontine perforators of the basilar artery using digital subtraction angiography in high resolution and 3D rotation technique. *Am J Neuroradiol* 35: 1942–1947, 2014
6. Ide S, Hirai T, Morioka M, Kai Y, Yano S, Kawano T, Tochihara S, Shigematsu Y, Uetani H, Murakami Y, Watanabe K, Yamashita Y: Usefulness of 3D DSA-MR fusion imaging in the pretreatment evaluation of brain arteriovenous malformations. *Acad Radiol* 19: 1345–1352, 2012
7. Serafin Z, Strześniewski P, Lasek W, Beuth W: Follow-up after embolization of ruptured intracranial aneurysms: a prospective comparison of two-dimensional digital subtraction angiography, three-dimensional digital subtraction angiography, and time-of-flight magnetic resonance angiography. *Neuroradiology* 54:1253–1260, 2012
8. Kucukay F, Okten RS, Tekiner A, Dagli M, Gocek C, Bayar MA, Cumhuri T: Three-dimensional volume rendering digital subtraction angiography in comparison with two-dimensional digital subtraction angiography and rotational angiography for detecting aneurysms and their morphological properties in patients with subarachnoid hemorrhage. *Eur J Radiol* 81:2794–2800, 2012
9. Göllitz P, Struffert T, Ganslandt O, Saake M, Lücking H, Rösch J, Knossalla F, Doerfler A: Optimized angiographic computed tomography with intravenous contrast injection: an alternative to conventional angiography in the follow-up of clipped aneurysms? *J Neurosurg* 117:29–36, 2012
10. Lu L, Zhang LJ, Poon CS, Wu SY, Zhou CS, Luo S, Wang M, Lu GM: Digital subtraction CT angiography for detection of intracranial aneurysms: comparison with three-dimensional digital subtraction angiography. *Radiology* 262:605–612, 2012
11. Fishman EK, Ney DR, Heath DG, Corl FM, Horton KM, Johnson PT: Volume rendering versus maximum intensity projection in CT angiography: what works best, when, and why. *Radiographics* 26: 905–922, 2006
12. Calhoun PS, Kuszyk BS, Heath DG, Carley JC, Fishman EK: Three-dimensional volume rendering of spiral CT data: theory and method. *Radiographics* 19:745–764, 1999