3D multislice CT angiography in post aortic stent grafting: A pictorial essay

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Abstract

Helical CT angiography has been widely used in both pre-and post-aortic stent grafting and has been confirmed to be the preferred modality when compared to conventional angiography. Recent development of multislice CT (MSCT) has further enhanced the applications of CT angiography in aortic stent grafting. One of the advantages of MSCT angiography over conventional angiography is that 3D reconstructions based on volumetric CT data provide additional information in the follow-up of aortic stent graft. While endovascular repair has been increasingly used in clinical practice, 3D MSCT imaging in endovascular repair continues to play an important role. In this pictorial essay, we aimed to discuss the diagnostic performance of 3D MSCT angiography in post aortic stent grafting, including the most commonly used surface shaded display, curvilinear reformation, maximum intensity projection, volume rendering and virtual endoscopy. Advantages and disadvantages of each 3D reconstruction were also explored.

Key words: Stent graft, multislice computed tomography, three-dimensional reconstruction, abdominal aortic aneurysm

Introduction

Since its first introduction in clinical practice more than a decade ago, endovascular repair of abdominal aortic aneurysm (AAA) has been widely used and reported to be an effective alternative to conventional open surgery, especially in patients with comorbid medical conditions (1-3). Unlike open surgical repair of AAA, successful completion of endovascular repair largely depends on medical imaging, and helical CT angiography (CTA) has been confirmed to be the preferred modality in both preoperative planning and postoperative follow-up of endovascular aortic repair (4,5).

The development of multislice CT (MSCT) has provided important advantages over single slice CT with regard to CT angiography of the aorta and aortic stent graft (6, 7). MSCT enables faster scans than single slice CT by providing high-volume coverage and thin-section image within a single breath hold, resulting in improved spatial resolution in the longitudinal plane. MSCT has been reported to be superior to single slice CT in nearly all clinical applications (6). Helical CTA in imaging aorta and stent graft has been complemented by a series of 3D postprocessing reconstructions, including surface shaded display (SSD), maximum-intensity projection (MIP), curvilinear reformation (CVR), volume rendering (VR) and virtual intravascular endoscopy (VIE). These 3D reconstructions have been applied in both pre-and post-operative assessment of aortic stent grafting. However, 2D axial CT images still remain the standard reference in most of the pre-operative situations, such as measurements of the aneurysm sac and neck diameter, visualization of aortic wall calcification, etc (8). In contrast, 3D CT images were found useful for visualization of the relationship between stent graft and arterial branches (9-11). Reliable recognition of the diagnostic performance of these 3D reconstructions will assist clinicians to choose appropriate image visualization for assessment of endovascular aortic repair, and make efficient use of the MSCT imaging modality for clinical purpose. In this pictorial essay, we discussed the diagnostic value of each 3D reconstruction in a group of patients with AAA treated with aortic stent graft, based on MSCT angiography scanning.

Patient data and MSCT scanning protocol

The study was performed on 18 patients (15 men and 3 women, mean age 75, age range 63-84) who underwent endovascular repair of abdominal aortic aneurysms between 1999 and 2001. The patients were recommended to receive stent graft treatment from the vascular surgeons because they were unsuitable for open surgical repair due to comorbid medical conditions (hypertension, cardiovascular disease). All patients were treated with the Zenith AAA Endovascular Graft (William Cook Europe, Bjaeverskov, Denmark) with a suprarenal uncovered component placed above the renal arteries for obtaining proximal fixation. The stent graft is an endoprosthesis constructed of nitinol monofilament annexed into a tubular zigzag configuration. A thin woven polyester fabric was used to cover the nitinol wire frame. The patients were referred for follow-up examinations after endovascular repair at 1 week, 1 month, 3 month, 6 month, 1 year and then annually. The initial CT scan was performed on a single slice CT scanner, and the most recent one was on a multislice CT scanner. Therefore, only MSCT data were used for 3D reconstructions. MSCT angiography was performed on a 16-slice scanner (Toshiba Medical Systems Europe, Netherlands) with the scanning protocol as follows: 16 x 0.75mm beam collimation, pitch 2.0, and reconstruction interval of 1mm. MSCT angiography was performed with an intravenous injection of 100 ml of non-ionic contrast media (Niopam 300, Bracco UK Ltd. High Wycombe) administered at a rate of 2 ml/second with a scan delay of 30 seconds.

3D image generation

CT volume data were converted from original DICOM (Digital Imaging and Communication in Medicine) images with a commercially available software Analyze V 5.0 (www.Analyzedirect.com Mayo Clinic, USA). Bony structures were removed by using region of interest drawings for generation of a series of SSD and MIP images. The connectivity and opacity transfer function for VR were determined to maximize vascular visualization while minimizing non-vascular display. Visualization of VIE images was based on CT number thresholding and details of generation of VIE images have been described elsewhere (9). CVR was generated by setting the line at the centre of the abdominal aorta in order to produce coronal or sagittal images for demonstration of stent graft and aortic branches. Technical details for generation of these 3D reconstructions have been described elsewhere (12).

3D visualization and diagnostic performance of MSCT

3D reconstructions were successfully generated in all patients. The follow-up time ranged from 24 months to 54 months, with a mean period of 40 $\pm$7.6 months. Endoleaks were found in 5 cases, with type I and III in one patient respectively, and type II in three cases. Renal function was evaluated by measuring the serum creatinine levels and it was not significantly affected in all cases, except in one patient, who developed chronic renal failure due to atrophic left renal artery and received renal dialysis. Distal stent graft migration occurred in 4 patients and the treatment was under observation at the current follow-up.

Surface shaded display-SSD

SSD represents the surface of a structure within a volume dataset. It is fast to generate because it relies on simple thresholding. It has the superiority in speed and flexibility in image rendering in the visualization of stent graft and arterial branches

(Fig 1A). However, the surface is derived from only a small proportion of the available data (less than 10%), and it is prone to artifacts (Fig 2A), which is especially apparent in patients treated with stent graft due to the high density of metal wires. Thus, calcification in aortic wall and configuration of aneurysm sac cannot be accurately assessed on SSD images when compared to corresponding MIP images (Fig 1B, 2B). SSD has little role to play in the follow-up of aortic stent grafting as no additional information cannot be obtained when compared to axial 2D images (8).

Maximum intensity projection-MIP

MIP was found to be valuable in post stent grafting as it creates angiographic like images similar to those from conventional angiographic examinations. High density calcification, contrast-enhanced vessels, aortic stent wires, 3D relationship of aortic stent graft and the arterial branches can be clearly visualized on MIP images (Fig 1B, 2B). MIP images were also found to be useful for assessment of stent graft migration at regular follow-ups, which was reported to be more accurate than axial 2D images (Fig 3) (13). One of the disadvantages of MIP generation is to remove the bony component from the volume data, which is a time-consuming procedure. However, development of computer software allows user to automatically remove bony structures and the processing time has been decreased significantly, which makes MIP image processing become an acceptable technique in routine clinical practice.

Curvilinear reformation-CVR

As most of the abdominal aortic aneurysms are angulated to variable extents and have a curved path along the abdominal aorta, conventional multiplanar reformation is not always able to reveal the anatomical information required for assessment. Curvilinear reformation allows for generation of images with desired anatomy by segmenting the anatomical structure with a curved central lumen line (Fig 4).

However, caution should be taken into account while choosing the selection plane as the line must be set in the centre of anatomical structures, otherwise, not all of the information will be displayed in the reformatted images and some of them are missing (Fig 5). Therefore, a series of CVR images instead of individual ones are required for accurate evaluation of aortic stent grafting, which is the main limitation of the CVR.

Volume rendering-VR

VR was able to demonstrate all the anatomical structures such as stent graft, aortic branches because it uses all of the information contained inside a volume dataset. Moreover, each anatomical structure can be coded with a specific colour and opacity value of every attenuation value of the CT data (Fig 6 A). This allows observers to easily identify particular structure within the volume dataset and clearly demonstrates the 3D relationship between stent graft and arterial branches (Fig 6B, C). Because the generation of VR images relies on the threshold selection and no requirement is needed to remove unwanted structures, the processing time is very short, which takes only a few minutes (14). The main limitation of VR is that final image quality depends on the segmentation of the volume dataset that are given to the rendering algorithm (Fig 7). Therefore, acquisition of optimal source CT data is of utmost importance to ensure the image quality of VR.

Virtual intravascular endoscopy-VIE

Unlike other 3D reconstructions, VIE provides unique intraluminal information about the stent wires relative to the arterial branch ostia. The number of stent wires crossing the arterial ostia and configuration of encroachment can be visualized clearly on VIE (Fig 8). VIE images enhance our understanding of the effect of aortic stent graft on arterial branch ostia, especially in patients with AAA treated with suprarenal stent graft (8, 9). Our experience showed that VIE could be a valuable visualization technique in the follow-up of aortic stent grafting. Comparison of VIE images at regular follow-up also allows clinicians to assess the effect of stent wires on arterial ostia, or observation of stent wires regarding the distal migration or reduction of cross-sectional area of the aortic ostia (Fig 9) (13). One of the limitations of VIE visualization is that it is a time-consuming procedure, which takes about 30 minutes. However, with experience gathered, the time required for generation of VIE has been greatly reduced. Another limitation is that stent wire thickness is overestimated on VIE images due to point spread function, which makes stent wire looks thicker that it really is (Fig 9). Thus, the actual coverage of stent wires to the aortic ostia is hard to estimate, although we know that only a small proportion of the aortic ostium is covered (15).

Discussion and Conclusion

With the introduction of MSCT scanners, CT angiography of the aortic stent graft is becoming more important. In contrast to single slice CT, CTA can be performed more efficiently with MSCT scanners because of faster scanning speed and higher spatial and temporal resolution. In an early study, Rubin et al (7) showed that CTA with a four-detector row CT scanner was faster, and the scanning was possible with thinner collimation and a reduced dose of contrast medium. However, studies using 16 slice CT scanners with submillimeter section thickness demonstrated higher quality CT angiograms than those obtained from 4 slice scanners in the evaluation of aortoiliac and lower extremity arteries (16, 17). With recent introduction of 64 slice scanner, spiral scanning with even shorter time represents a further leap in improving spatial and temporal resolution for routine clinical applications of CTA (18, 19). Therefore, for patients undergoing stent graft treatment, CT angiographic examinations with submillimeter resolution in the pure arterial phase will become feasible even for extended anatomic ranges. Two of our patients' volume source data were suboptimal and image quality of VR was affected as shown in Fig 7. In one patient the CT attenuation was measured to be lower than 200 HU at the level of renal artery. Although adequate contrast enhancement was obtained in another patient (CT attenuation of 230 HU), image quality was still affected due to low signal to noise ratio (increased image noise). We believe that improved longitudinal resolution with 64 slice scanner will overcome these limitations that we encountered in our study.

3D CT postprocessing and reconstruction has become part of the clinical protocol and has been widely used as an effective alternative to conventional angiography for pre-operative planning and post-operative follow-up of aortic stent grafts (5, 20). 3D CT angiography is our routine imaging modality to perform essential measurements for planning of aortic stent graft placement, assess patency of stent-covered renal arteries and detect endoleaks for post stent grafting follow-up (8). Our results demonstrated the potential value of 3D MSCT reconstructions including MIP, VR and VIE which provide clinicians with additional information for evaluation of the effects of endovascular repair. MIP clearly shows the aortic stents and arterial branches and it was more accurate in measurement of the stent graft migration than conventional 2D images (13), while VR is an efficient visualization tool in demonstrating the 3D relationship between stent graft and arterial branches. As long-term effect of aortic stent grafting is unclear, especially transrenal fixation, the additional information provided by VIE is considered to be valuable for surgeons to assess the outcomes of transrenal fixation in the following two areas: potential interference with renal blood flow by demonstrating the encroachment of stent wires to renal artery ostia, which may alter the haemodynamics and lead to the dispersion of late multiple emboli (21); or any reduction of cross-sectional area of aortic branch ostia caused by presence of stent wires (15), which may affect physiologic change of renal function such as renal perfusion. Diagnostic value of CT VIE in aortic stent grafting has been discussed in detail elsewhere (8, 9, 13, 15).

In conclusion, 3D CT reconstructions offer additional information when compared to 2D axial images in post-stent grafting, based on our experience. Reliable recognition of the diagnostic performance of each reconstruction is of paramount importance for clinicians to utilize MSCT imaging technique efficiently as some of the 3D postprocessings are time-consuming such as MIP and VIE. VR is the most efficient reconstruction method for visualization of aortic stent graft relative to arterial branches. Whereas VIE is a valuable tool in the visualization of intraluminal encroachment of stent wires to the aortic ostia.

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References

1. Buth J, van Marrewijk CJ, Harris PL, Hop WC, Riambau W, Laheij RJF, et al. Outcome of endovascular abdominal aortic aneurysm repair in patients with conditions considered unfit for an open procedure: a report on the EUROSTAR experience. J Vasc Surg 2002; 35: 211-221
2. Cao P, Verzini F, Parlani G, Romano L, Rango PD, Pagliuca V, et al. Clinical effect of abdominal aortic aneurysm endografting: 7-year concurrent comparison with open repair. J Vasc Surg 2004; 40: 841-848
3. Prinssen M, Verhoeven EL, Buth J, Cuypers PW, van Sambeek MR, Balm R, et al. A randomized trial comparing conventional and endovascular repair of abdominal aortic aneurysms. N Eng J Med 2004; 14 (351): 1607-1618
4. Broeders IAMJ, Blankensteijn JD, Olree M, Mali W, Eikelboom BC. Preoperative sizing of grafts for transfemoral endovascular aneurysm management: a prospective comparative study of spiral CT angiography, arterial angiography and conventional CT imaging. J Endovasc Surg 1997; 4: 252-261
5. Armerding MD, Rubin GD, Beaulieu CF, Slonim SM, Olcott EW, Samuels SL. et al. Aortic aneurysmal disease: Assessment of stent-grafted treatment-CT versus conventional angiography. Radiology 2000; 215: 138-146
6. Hu H, He HD, Foley WD, Fox SH. Four multidetector-row helical CT: image quality and volume coverage speed. Radiology 2000; 215: 55-62
7. Rubin GD, Shiau MC, Leung AN, Kee ST, Logan LJ, Sofilos MC. Aorta and iliac arteries: single versus multiple detector-row helical CT angiography. Radiology 2000; 215: 670-676

8. Sun Z, Winder J, Kelly B, Ellis P, Kennedy P, Hirst D. Diagnostic value of CT virtual intravascular endoscopy in aortic stent grafting. J Endovasc Ther 2004; 11: 13-15
9. Sun Z, Winder J, Kelly B, Ellis P, Hirst D. CT virtual intravascular endoscopy of abdominal aortic aneurysms treated with suprarenal endovascular stent grafting. Abdom Imaging 2003; 28: 580-587
10. Davis CP, Ladd ME, Romanowski BJ, Wildermuth S, Knoplioch JF, Debatin JF. Human aorta: preliminary results with virtual endoscopy based on three-dimensional MR imaging data sets. Radiology 1996; 199: 37-40
11. Neri E, Bonanomi C, Vignali R, Cioni R, Ferrari M, Petruzzi P, et al. Spiral CT virtual endoscopy of abdominal arteries: clinical applications. Abdom Imaging 2000; 25: 59-61
12. Luccichenti G, Cademartiri F, Pezzella FR, Runza G, Belgrano M, Midiri M, et al. 3D reconstruction techniques made easy: know-how and pictures. Eur Radiol 2005; 15: 2146-2156
13. Sun Z. 3D visualization of stent graft migration in transrenal fixation of aortic stent graft: Mid-term follow-up. J Endovasc Ther 2006 (in press)
14. Sun Z, Zheng H. Helical CT angiography of aortic stent grafting: Comparison of three-dimensional rendering techniques. Lecture Notes in Computer Sciences 2004, 3314: 544-549
15. Sun Z, Zheng H. Cross-sectional area reduction of the renal ostium by suprarenal stent wires: in vitro phantom study by CT virtual angioscopy. Comput Med Imaging Graph 2004; 28: 345-351
16. Willman JK, Baumert B, Schertler T, Wildermuth S, Pfammatter T, Verdun FR, et al. Aortoiliac and lower extremity arteries assessed with 16-detector row CT

angiography: prospective comparison with digital subtraction angiography. Radiology 2005; 236: 1083-1093

17. Schertler T, Wildermuth A, Alkadhi H, Kruppa M, Marincek B, Boehm T. Sixteen-detector row CT angiography for lower-leg arterial occlusive disease: analysis of section width. Radiology 2005; 237: 649-656
18. Raff GL, Gallagher MJ, O'Neill WW, Goldstein JA. Diagnostic accuracy of non-invasive coronary angiography using 64-slice spiral computed tomography. J Am Coll Cardiol 2005, 46: 552-557
19. Flohr T, Stierstorfer K, Raupach R, Ulzheimer S, Bruder H. Performance evaluation of a 64-slice CT system with z-flying focal spot. Fortschr Roentgenstr 2004; 176: 1803-1810
20. Rydberg J, Kopecky KK, Lalka SG, Johnson MS, Dalsing MC, Persohn SA. Stent grafting of abdominal aortic aneurysms: Pre- and postoperative evaluation with multislice helical CT. J Comput Assist Tomogr 2001; 25: 580-586
21. Chong CK, How TV. Flow patterns in an endovascular stent-graft for abdominal aortic aneurysm repair. J Biomechanics 2004; 37: 89-97

Figure legends

Figure1. An 84-year man with an infrarenal AAA was treated with aortic stent graft and followed-up at 48 months. MSCT SSD clearly shows the aortic branches and stent graft. Corresponding MSCT MIP image demonstrates clearly the calcification in the aortic wall besides the aortic stent graft and arterial branches. Suprarenal stent grafts were shown to deploy above the renal arteries (arrows). Arrowheads point to the calcification. (Reprint with permission from Ref 13)

Figure2A shows a SSD image acquired in an 80-year old man with AAA after endovascular repair. Although aortic branches can be visualised, calcifications in the aortic wall cannot be clearly demonstrated when compared to corresponding MIP image as shown in Figure 2B (arrows).

Figure3. A 74-year old man was found to have distal stent migration of 10.2 mm due to foreshortening of the longitudinal aneurysm sac at a follow-up period of 24 months (A, B). Arrows in Fig 3A and 3C indicates a type II endoleak due to retrograde flow of patent inferior mesenteric artery, which resolved spontaneously. (Reprint with permission from Ref 13)

Figure4. CVR reconstructions in a patient following endovascular repair of AAA. Aortic branches, stent graft and aneurysm sac are shown altogether in the figure.

Figure5. CVR reconstruction in another patient after endovascular repair of AAA. In contrast to what is shown in Fig 4, not all of the information is displayed in this image and the left common iliac artery is missing (arrows) as the anatomy is not in the selected plane.

Figure6. 3D VR images were generated in a 65-year old woman after 36 months of endovascular repair. Different colours were applied to variable structures including aortic stent graft, arteries, and bones (A-C). As shown in sagittal view (C), the top of

suprarenal stents (short arrows) was placed just below the superior mesenteric artery (long arrow).

Figure7. 3D VR images were acquired in two patients with suboptimal source image quality, which affects the visualization of anatomical structures on VR. The signal to noise ratio measured in these two cases was less than 10 (6-8.2) at the levels of renal artery and common iliac arteries, which resulted in poor demonstration of renal parenchyma or common iliac arteries (A, B).

Figure8. VIE images acquired from two patients after endovascular repair of AAAs showed the different encroachment of stent wires to the renal ostia. Two stent wires were shown to cross the left renal ostium peripherally in Fig 8A, while one stent wire crosses the right renal ostium peripherally as shown in Fig 8B. Long arrows indicate the stent wires, while short arrows point to the renal ostia.

Figure9. An 81-year old woman with an abdominal aortic aneurysm was treated with a suprarenal stent graft and followed-up at 36 months. A 10.2 mm stent migration was noted in the most recent CT MIP image (B) when compared to the previous one (A). VIE showed that the superior mesenteric artery (SMA) ostium was encroached by stent wire, but it’s position of encroachment shifted due to the movement of stent wires, which was caused by the longitudinal foreshortening of aneurysm sac. SMA ostium seems to be covered more than 50% by the stent wire due to overestimated thickness of wire diameter. Short arrows denote the SMA, while long arrows refer to the stent wires. (Reprint with permission from Ref 13)