Optimal scanning protocol of multislice CT virtual intravascular endoscopy in pre-aortic stent grafting: in vitro phantom study

Zhonghua Sun[1] PhD, Charlene Ferris[2] BSc

1. Discipline of Medical Imaging, Department of Imaging and Applied Physics, Curtin University of Technology, Perth, Western Australia
2. School of Health Sciences, University of Ulster, Shore Road, Newtownabbey, BT37 0QB, Northern Ireland, United Kingdom

Corresponding author:

Dr. Zhonghua Sun, Discipline of Medical Imaging, Department of Imaging and Applied Physics, Curtin University of Technology, Perth, Western Australia, GPO Box U 1987, Perth, Western Australia 6845

Tel: +61-8-9266 7509

Fax: +61-8-9266 4344

Email: z.sun@curtin.edu.au

Abstract

Objective: To investigate the optimal scanning protocol for multislice computed tomography angiography (MSCT) in pre-aortic stent grafting observed with virtual intravascular endoscopy (VIE).

Materials and Methods: The study was performed on a human abdominal aortic phantom which was housed in a perspex container, filled with contrast medium having CT attenuation similar to that used in the patient's abdominal CT scan. A series of scans were performed on a four-slice multislice CT scanner with the scanning protocols as follows: section thickness of 1.3mm, 3.2mm and 6.5mm, pitch value of 0.875, 1.25 and 1.75 with reconstruction intervals of 50% overlap. The degree of stair-step artifacts was measured at three different locations, superior mesenteric artery (SMA), renal ostium and the normal abdominal aorta. Standard deviation (SD) of the signal intensity measured on surface shaded images was used to determine the image quality. Radiation dose was also recorded in each scanning protocol.

Results: The VIE images showed that image quality was not dependant on pitch and section thickness in the visualization of renal ostium and SMA, whereas it was dependant on these two factors at the level of the normal aorta ($p<0.05$). It was noticed that when section thickness reached 6.5mm the SMA and renal ostia became distorted. Radiation dose measured in 1.3 mm protocols was significantly higher that those measured in other section thicknesses ($p<0.05$).

Conclusion: The scanning protocol of section thickness 3.2mm, pitch 1.25 with a reconstruction interval of 1.6 mm was recommended as it allows optimal visualization of VIE images of aortic ostia, generation of fewer artifacts and less radiation dose.

Key words: Computed tomography, virtual endoscopy, stent graft, image quality, artifact.

Introduction

Conventional surgical open repair is considered the gold standard to treat abdominal aortic aneurysm (AAA). The risk of perioperative death is more than 5% and may be as high as 65% in patients with severe pulmonary, cardiovascular or renal disease (1). A less invasive technique, endovascular stent graft repair has been developed over the past decade and has become an effective alternative to open surgical repair (2,3). Unlike conventional surgery, the success of endovascular repair cannot be ascertained by direct observation and mainly depends on medical imaging.

Helical CT angiography (CTA) has been widely used in clinical practice and reported to be the preferred modality in the evaluation of AAA both pre-and post-aortic stent grafting (4,5). The role of CTA has been greatly enhanced by the introduction of multislice CT (MSCT) due to its fast scanning, high spatial resolution and acquisition of nearly isotropic volume data (6). CTA-generated virtual intravacular endoscopy (VIE) is a rapidly evolving technology that permits interactive 2D and 3D visualization techniques not only for aortic branches but also for intraluminal stents (7). MSCT VIE has been recently investigated with regard to the optimal scanning protocol in post aortic stent grafting (8), however, to our knowledge, there has been no report of MSCT VIE in pre-aortic stent grafting. As MSCT is becoming more popular in clinical practice and replacing single slice CT in the preoperative planning of AAA, we aimed in this study to investigate the appropriate scanning parameter of MSCT VIE in AAA prior to endovascular stent graft repair. Determination of the optimal scanning protocol of our study was based on the objective assessment of image quality of VIE acquired from a variety of MSCT scans in terms of the presence of stair-step artifacts.

Materials and Methods

Human aorta phantom

The study was based on a human aorta phantom, which is physically required to be robust, dimensionally accurate and represent a human aortic aneurysm. The phantom was built based on a typical patient with an AAA (Fig1). The external structures to the aorta were manually edited from the image data set on a slice-by-slice basis. The bones and all the abdominal structures, except the superior mesenteric artery (SMA), renal arteries and aneurysm sac were excluded on the transverse scans. In order to make sure that the physical phantom was as accurate as the original CT data, we performed a series of measurements in the relevant areas of the phantom. Measurements of the aortic phantom were performed in the following positions: top and bottom of the aorta; proximal, middle and distal part of the SMA and bilateral renal arteries; length of the phantom and renal arteries. All these results were compared with those of axial CT data.

The phantom was built with medical rapid prototyping, which is the latest technique for manufacturing these models (9). Initially the phantom was to be built in one piece, but this made the removal of support structures inside the aorta and renal ostia difficult. Thus the phantom was built in two halves and fused together after removing support structures entirely to ensure a smooth internal surface. The phantom was put inside a perspex container, which was filled with iodinated contrast medium (300 mg/ml, Niopam 300, Bracco, UK) with the CT attenuation (200 HU) similar to that used in abdominal CT scanning.

CT scanner and parameters

The scanner used for this study was a Philips four-slice CT scanner (Mx 8000 Quad; Philips Medical Systems, The Netherlands). The detector collimation of the scanner is 4 x 1 /2.5 mm. The rotation time of the CT scanner was 0.5 second and the tube voltage was 120 kVp and current ranged from 200 mA to 240 mA. A field of view of 110 mm, matrix of 512 x 512 and 180 º linear interpolation algorithms were used to reconstruct the images, resulting in an in-plane resolution of 0.21 X 0.21mm.

The phantom was placed on the table of the scanner, parallel to the longitudinal axis. Image data were acquired at section thickness of 1.3mm, 3.2mm and 6.5mm, pitch value of 0.875, 1.25 and 1.75, and with reconstruction interval of 50% overlap.

After scanning, CT data were burned into CDs and transferred to a workstation equipped with Analyze V 5.0 (www.Analyzedirect.com, Mayo Clinic, USA) for data processing. A total of 9 data sets were generated. All data sets were reviewed in an unblinded fashion by an experienced radiologist familiar with axial CT and VIE images of the abdominal arteries.

Image analysis and assessment

Generation of VIE images of the renal ostium, SMA and the normal aorta were obtained from each dataset. A threshold range was chosen to remove the contrast medium from the aorta and creation of VIE images of the internal surfaces of the phantom was obtained. Detailed description of generating VIE images has been described elsewhere (10).

The degree of stair-step artifacts were based on the pixel intensity of each VIE image. Consistent settings in each image were required for greater accuracy. The "virtual eye" or camera position was kept at a 70° angle throughout the analysis of the images. Standard deviation (SD) of the pixel values was used to measure the degree of stair-step artifact observed on VIE images. A higher SD indicates more variation in the pixel intensity, therefore demonstrating greater existence of artifacts resulting in poor image quality. Similar to the methodology used in the post-stent grafting (8), a line profile was drawn across each VIE image, with an approximate value of 100 pixels being recorded. The measurements of SD were taken at three different locations, the SMA ostium, renal ostium and the normal abdominal aorta.

Statistical analysis

The results were analysed using SPSS 11.0 for Windows (SPSS, Inc) to determine the relationship between the SD, radiation dose and variable scanning parameters (section thickness, pitch and reconstruction interval). A p value < 0.05 was considered to be a statistically significant difference.

Three-factor experimental design was employed. The factors were section thickness, pitch value and reconstruction interval. The SD of signal intensity was measured at three features, namely SMA, renal ostium, and normal abdominal aorta. There was one determination of SD undertaken for each of the 9 cells defined by the factorial design. An analysis of variance of the resulting data, in accordance with the factorial design, was computed for each of the features.

Results

Accuracy of the aorta phantom

The phantom was built with a layer thickness of 0.354 mm and an in plane resolution of 0.8 mm. Figure 2 shows that there was a line in the middle of the phantom indicating where the two halves were joined (arrows). A small amount of epoxy resin was use to seal the phantom at the interface, which produced a smooth surface, simulating the inside of the aorta. Table 1 shows a series of measurements performed on both the computer phantom and axial CT images. The maximum difference for these comparisons was less than 0.5mm indicating that the aorta phantom was a very good representation of the original anatomical details.

Optimal scanning protocols of CT VIE

Table 2 shows the SD measured in all the scanning protocols in the study. It was noticed that the SD measured in the protocols with 1.3mm section thickness was higher than those measured in 3.2mm and 6.5mm section thickness, although this did not reach a statically significant difference ($p>0.05$). The SD measured in the SMA and the renal ostium was found to be independent of section thickness and pitch values ($p>0.05$). Also the SD measured in the normal aorta with 1.3mm section thickness was significantly higher than that measured with 3.2mm and 6.5mm section thicknesses ($p<0.05$). Similarly, radiation dose measured in 1.3mm protocols was significantly higher than that of the 3.2mm and the 6.5mm protocols ($p<0.05$), but it was irrelevant of pitch values.

Figure 3 shows the relationship of VIE image quality and the pitch value in the visualization of right renal ostium. Subjective evaluation of the renal ostium correlates well with objective assessment, which indicates VIE image quality is not dependent on pitch values. Figure 4 shows an example of VIE images relative to the section thicknesses with the same pitch value. It is clearly demonstrated that image quality observed in the SMA ostium was significantly affected by the apparent presence of stair-step artifacts when the section thickness increased to 6.5mm. However, this was not confirmed by the objective measurement of SD as it did not show significant difference ($p>0.05$).

Discussion

Helical CTA has been widely used in clinical practice and has been reported to replace digital subtraction angiography (DSA) in pre-aortic stent grafting of AAA in most of the situations (4, 11, 12). In the majority of patients, correctly performed CTA can reveal sufficient information needed for planning optimal surgical therapy

(13). And also a study has indicated the importance of this modality and how it derives from its ability to provide the most useful information from a single CT examination, especially when it is combined with modern computerised 3D post-processing, while DSA fails to provide these information (11).

Although these 3D postprocessings generated from original CTA dataset did not increase additional information, they do enhance our understanding of normal and abnormal anatomic structures, such as abdominal aorta and its branches as well as intraluminal aortic stents. This has been proved to be especially valuable in the detection of colonic polyps by CT virtual colonoscopy when compared to invasive conventional colonoscopy (14). Studies have also been carried out in the investigation of optimal scanning protocols for both single slice and MSCT virtual colonoscopy in colonic polyps (14-16). Our results generally corresponded to others with respect to the optimal scanning protocols of CTA in terms of the image quality observed on VIE, which is dependent on collimation or section thickness and irrelevant to pitch values. However, studies investigating the image quality of MSCT scanning protocols showed variable results in terms of the dependency of artifacts expression on CT parameters (17-19). Maintz et al (19) in their phantom study demonstrated that artifacts increased with increasing pitch and were less dependent on detector collimation or section thickness. This concurs with our findings to some extent, as noticed in the level of normal aorta. Moreover, it is agreed that thinner collimation does not mean to be the optimal scanning protocol as it results in a relative higher radiation dose, as observed in our study and others (20). Although thinner collimation produced the best VIE image quality due to fewer artifacts, the increase in image noise can cause image degradation, mainly in thin section protocols. This was apparently demonstrated in our study. The SD and radiation dose measured with a section thickness of 1.3 mm in all three levels were significantly higher than those measured with a section thickness of 3.2 mm and 6.5 mm as shown in table 2. Therefore, a section thickness of 3.2mm, pitch value of 1.25 with reconstruction interval of 1.6mm was considered to be the optimal scanning protocol in preoperative AAA because it allows optimal visualization of VIE images of the aortic ostium and generation of fewer artifacts as well as less radiation dose.

Clinical studies have shown that 2D axial images are insufficient to provide required information for preoperative planning of endovascular repair and most of the preoperative measurements were based on multiplanar reformation (MPR) and maximum-intensity projection (MIP) images (13). However, some potential roles do exist for CT VIE to play in the preoperative evaluation. One of these areas is the measurement of renal ostium diameter, which can be used as a reference to monitor the change of configuration following aortic stent grafting, particularly in these patients with AAA treated with suprarenal stent grafts (21). Another area would be in the preoperative planning of fenestrated stent graft, which is a recently designed technique to treat patients with complicated AAA (22). Traditional measurements of the proximal and distal aneurysm neck lengths and diameters can be obtained with MPR and MIP images. However, additional attention should be given to the aortic ostial diameters, their relative distances and orientations from which they arise from an aortic cross-section (21). Conventional 2D images and other 3D reconstructions fail to provide intraluminal views of the aortic branches and their spatial relationship, however, this is easily overcome with CT VIE. Figure 5 clearly demonstrates the 3D relationship between SMA and right renal ostium as well as the intraluminal distance between them. Technically it is quite challenging as fenestration to an endograft requires accurate planning and device construction based on high-quality 3D CT and angiography imaging. We consider that MSCT VIE may have a potential role to play in the preoperative planning of fenestrated stent grafts.

There are some limitations in the study, which should be addressed. Although the phantom used for the study was built from a typical patient data, there is no blood flow in the phantom which does not really simulate the real environment. Also the wall of the phantom has a higher attenuation than that of soft tissues of normal abdominal aorta, which may have caused some streak artifacts on VIE images. Blinded subjective assessment was not performed in this study, although we consider it would add strength to our results. Finally, only 9 datasets were included for analysis in our study, which lacks of robust assessment to some extent. The reason we chose these protocols is that the study was performed on a 4-slice CT scanner and submillimeter scanning (section thickness <1.0mm) is not routinely used in abdominal scanning because of increased image noise, lack of anatomical coverage and X-ray dose (20). Previous studies showed that pitch value should be less than 2.0 and reconstruction interval is 50% of the beam collimation or section thickness for acquiring acceptable helical CTA images (20, 23). More scanning protocols with a variety of section thicknesses and variable reconstruction intervals should be included to increase the impact of the study, especially if the study is performed on 16 or more slice CT scanners.

In conclusion, we have successfully tested a series of MSCT scans on a human aorta phantom and generated corresponding VIE images of the aortic ostia. For the purpose of visualizing aortic ostium and normal aorta with acceptable image quality observed on VIE, a scanning protocol of section thickness of 3.2 mm, pitch 1.25 and reconstruction interval of 1.6 mm is recommended as it allows fewer artifacts and less radiation dose when compared to other scanning protocols. Potential application of

MSCT VIE is recommended to the preoperative planning of fenestrated stent grafts.

Clinical validation of this technique in this area deserves to be investigated.

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References

1. Galland RB, Simmons MJ, Torrie EPH. Prevalence of abdominal aortic aneurysm in patients with occlusive peripheral vascular disease. Br J Surg 78 (1991), pp. 1259-1260
2. Cao P, Verzini F, Parlani G, et al. Clinical effect of abdominal aortic aneurysm endografting: 7-year concurrent comparison with open repair. J Vasc Surg 40 (2004), pp. 841-848
3. Prinssen M, Verhoeven EL, Buth J, et al. A randomized trial comparing conventional and endovascular repair of abdominal aortic aneurysms. N Eng J Med 14 (2004), pp. 1607-1618
4. Broeders IAMJ, Blankensteijn JD, Olree M, et al. 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 4 (1997), pp. 252-261
5. Armerding MD, Rubin GD, Beaulieu CF, et al. Aortic aneurysmal disease: Assessment of stent-grafted treatment-CT versus conventional angiography. Radiology 215 (2000), pp. 138-146
6. Rydberg J, Kopecky KK, Lalka SG, et al. Stent grafting of abdominal aortic aneurysms: pre-and postoperative evaluation with multislice helical CT. J Comput Assist Tomogr 25 (2001), pp. 580-586
7. Sun Z, Winder J, Kelly B, et al. Diagnostic value of CT virtual intravascular endoscopy in aortic stent-grafting. J Endovas Ther 11 (2004), pp.13-25
8. Sun Z, Gallagher E. Multislice CT virtual intravascular endoscopy for abdominal aortic aneurysm stent grafts. JVIR 15 (2004), pp. 961-970

9. Winder RJ, Sun Z, Kelly B, et al. Abdominal aortic aneurysm and stent graft phantom manufactured by medical rapid prototyping. J Med Eng Technol 26 (2002), pp. 75-78
10. Sun Z, Winder J, Kelly B, et al. CT virtual intravascular endoscopy of abdominal aortic aneurysms treated with suprarenal endovascular stent grafting. Abdom Imaging. 28 (2003), pp. 580-587
11. Beebe H, Kritpracha B. Imaging of abdominal aortic aneurysm: current status. Ann Vasc Surg 17 (2003), pp. 111-118
12. Beebe HG, Kritpracha B, Serres S, et al. Endograft planning without preoperative arteriography: a clinical feasibility study. J Endovasc Ther 7 (2000), pp. 8-15
13. Sun Z. Helical CT angiography of abdominal aortic aneurysms treated with suprarenal grafting. Cardiovasc Intervent Radiol 26 (2003), pp. 290-295
14. Johnson K, Johnson C, Anderson S, et al. CT colonography: determination of optimal CT technique using a novel colon phantom. Abdom Imaging 2004, 29: 173-176
15. Whiting BR, McFarland EG, Brink JA. Influence of image acquisition parameters on CT artifacts and polyp depiction in spiral CT colonography: in vitro evaluation. Radiology 217 (2000), pp. 165-172
16. Springer P, Stöhr B, Giacomuzzi S, et al. Virtual computed tomography colonoscopy: artifacts, image quality and radiation dose load in a cadaver study. Eur Radiol 10 (2000), pp. 183-187
17. Klingebeck-Regn K, Schaller S, Flohr T, Ohnesorge B, Kopp AF, Baum U. Subsecond multi-slice computed tomography: Basics and applications. Eur J Radiol 31 (1999), pp. 110-124

18. Wessling J, Fischbach R, Ludwig K, et al. Multi-slice abdominal CT in oncologic patients: influence of table feed and detector configuration on image quality and radiation exposure. Fortschr Roentgenstr 173 (2001), pp. 373-378
19. Maintz D, Fischbach R, Juergens KU, Allkemper T, Wessling J, Heindel W. Multislice CT angiography of the iliac arteries in the presence of various stents: in vitro evaluation of artefacts and lumen visibility. Invest Radiol 36 (2001), pp. 699-704
20. Sun Z, Winder J, Kelly B, Ellis PK, Kennedy PT, Hirst DG. Assessment of VIE image quality using helical CT angiography: in vitro phantom study. Comput Med Imag Graph 28 (2004), pp. 3-12
21. Sun Z. Zheng H. Effect of suprarenal stent struts on the renal ostia with ostial calcification observed in CT virtual intravascular endoscopy. Eur J Vasc Endovasc Surg 28 (2004), pp. 534-542
22. Greenberg RK, Haulon S, Lyden SP, et al. Endovasular management of juxtarenal aneurysms with fenestrated endovascular grafting. J Vasc Surg 39 (2004), pp. 279-287
23. Luboldt W, Weber R, Seemann M, Desantis M, Reiser M. Influence of helical CT parameters on spatial resolution in CT angiography performed with a subsecond scanner. Invest Radiol 34 (1999), pp. 421-426

Figure legends

Figure 1a shows a 3D surface shaded image of an infrarenal AAA selected for phantom design and construction. The aortic branches such as superior mesenteric artery, renal arteries are demonstrated clearly. Figure 1b is the computer model prototype after image processing and editing. It is noticed that the external surface of the phantom is rough and irregular as we only require the internal surface to be as smooth as possible. Figure 1c shows the rendered stereolithography data file which was used for building the phantom.

Figure 2 shows a human aorta phantom built with rapid medical prototyping. Normal aortic branches and cephalad of the aneurysm can be clearly seen on the image. Arrows indicate the fusion line in the middle of the phantom.

Figure 3. VIE images of the right renal ostium acquired with a section thickness of 1.3mm, pitch values of 0.875, 1.25, 1.75 and reconstruction interval of 0.6mm (a-c). The renal ostium remains the same configuration on these three images and image quality is independent of pitch values, based on subjective evaluation and objective assessment. Arrows show that the right renal ostium as observed on VIE images.

Figure 4. VIE images of the SMA ostium were acquired with section thicknesses of 1.3mm, 3.2mm and 6.5mm, pitch 1.25 and 50% of overlap (a-c). Subjective assessment showed that image quality depends on the section thickness, and SMA and renal ostium become distorted when the section thickness reached 6.5mm. Red arrows point to the SMA, while the yellow arrows refer to the stair-step artifacts present in renal and SMA ostia.

Figure 5. VIE image shows the 3D relationship between SMA and right renal ostium as well as the intraluminal distance measured between them. The image was

generated by looking at the SMA branch as the starting point towards the aortic aneurysm.