

3D stereoscopic visualization in fenestrated stent grafts

Abstract

Purpose: The purpose of this study is to present a technique of stereoscopic visualization in the evaluation of patients with abdominal aortic aneurysm (AAA) treated with fenestrated stent grafts compared to conventional 2D visualizations.

Materials and Methods: Two patients with AAA undergoing fenestrated stent grafting were selected for inclusion in the study. Conventional 2D views including axial, multiplanar reformation (MPR), maximum-intensity projection (MIP) and volume rendering (VR) and 3D stereoscopic visualizations were assessed by two experienced reviewers independently with regard to the treatment outcomes of fenestrated repair. Inter-observer agreement was assessed with Kendall's W statistic.

Results: MPR and MIP visualizations were scored the highest in the evaluation of parameters related to the fenestrated stent grafting, while 3D stereoscopic visualization was scored valuable in the evaluation of appearance (any distortions) of the fenestrated stent. VR was found to play limited role in the follow-up of fenestrated stent grafting.

Conclusion: 3D stereoscopic visualization adds additional information that assists endovascular specialists to identify any distortions of the fenestrated stents when compared with 2D visualizations.

Key words: fenestrated stent graft, stereoscopic visualization, two-dimensional visualization, follow-up

Introduction

Helical CT angiography has been reported to be the preferred modality for pre-operative planning and post-operative follow-up of endovascular stent graft repair of abdominal aortic aneurysm (AAA) (1). Three-dimensional (3D) CT imaging is a useful imaging modality that offers additional information of the anatomic structures and endovascular stent grafts, especially for assessment of the increasingly used technique, fenestrated stent grafts (2-4). Complex anatomic structures and fenestrated vessel stents make it difficult for observers to appreciate the inter-structure relationship based on 2D axial images, thus a number of 2D/3D reconstructions are commonly generated to improve visualization of fenestrated stent grafts and post-fenestration complications. Of these reconstructions, multiplanar reformation (MPR), maximum-intensity projection (MIP) and volume rendering (VR) are the most commonly used views to complement 2D axial images. Despite widely recognized value of these reconstructions, it is still difficult to appreciate the real 3D relationship between the aortic artery branches and fenestrated vessel stents due to lack of depth perception of the 2D images. To overcome the shortcoming of these displays for 3D context, stereoscopic visualization offers promise in this aspect.

There are various methods for generating and displaying stereoscopic views (5, 6). These include the use of polarizing filters to view separate right and left image pairs, complementary color (red/blue) image pairs and liquid crystal displays (LCD). Combining stereoscopic visualization with interactive views including adjustment of orientation and rendering parameters has the potential to improve viewing of complex anatomic structures such as aortic artery branches in relation to the fenestrated stent graft. The purpose of this study is to assess the performance of stereoscopic visualization

compared with conventional 2D views for evaluation of fenestrated stent grafts in the treatment of patients with AAA.

Materials and Methods

Patient data selection

Two sample patients with AAA undergoing fenestrated stent grafting were selected for inclusion in the study. Pre-operative planning was performed by a group of graft planners on a separate workstation equipped with Terarecon software (www.terarecon.com) installed at Cook R &D, Western Australia. Multislice CT (MSCT) datasets were obtained with a 64-detector row scanner (Toshiba Medical Systems, Kingsbury, UK) with the following parameter: beam collimation 64x0.5, pitch 1.0, reconstruction interval of 0.5mm, 120 kV, 140 mAs. The types of fenestration used in our study include scallop fenestration, large and small fenestrations.

Volume data review-conventional 2D/3D reconstructions

All of the DICOM (digital imaging and communication in medicine) data were transferred to a workstation at Cook R&D for generation of 2D axial and reconstructed visualizations including MPR, MIP and VR. Terarecon software allows the user to produce interactive 2D and 3D visualizations at any angles with regard to demonstration of the anatomic structures and fenestrated stent grafts. Reviewers can manipulate the volume data on the workstation and generate any views which they consider most useful for visualization or assessment of the structures.

3D stereoscopic visualization

All of the DICOM data were also transferred to another workstation equipped with Analyze V 7.0 (AnalyzeDirect, Inc., Lenexa, KS, USA) for generation of 3D volume data

required for stereoscopic visualization. Segmentation of anatomic structures and fenestrated stents was performed with a semi-automatic method. The segmented volume data containing aortic branches and stent grafts were saved in the STL (stereolithography) format which was transferred to another visualization system equipped with open source software (Visualization Toolkit, VTK, www.vtk.org) for stereo rendering and display of STL models.

A stereoscopic pair of images consists of two projections of the same 3D object acquired from two slightly different viewing angles. The pair of stereoscopic images is displayed so that only the left eye sees the left projection and only the right eye sees the right projection. As a result, the observer is able to reconstruct and appreciate the 3D object mentally including the depth dimension. Reviewers used LCD glasses for the stereoscopic display in our study (Fig 1). 3D stereoscopic views were presented to the two reviewers in a stereo visualization theatre by one of the authors (AS) with more than 10 years experience in stereoscopic visualization.

Image assessment

According to our experience in fenestrated stent grafting, we considered there are seven parameters that represent the treatment outcomes of fenestrated repair of AAA (table). Two reviewers (AB and KC) with more than 8 years' experience in fenestrated stent grafting assessed the 2D/3D image quality separately, while another two reviewers (AB and MLB) with more than 10 years' experience in fenestrated stent grafting evaluated the 3D stereoscopic visualization separately. The time interval between these two different assessments was 4 weeks, and the reviewers were blinded to the results of other assessment. The reviewers evaluated these visualizations based on a 5-point scale

scoring method with 1 indicating the least confident and 5 the most confident for using the visualization tool to assess the above seven parameters.

Statistical analysis

Statistical analysis of image scores was performed with SPSS (SPSS, V 16.0, Chicago, ILL) for analysis. Inter-reviewer agreement was determined by using the Kendall's W statistic with "0" indicating no agreement, and "1" perfect agreement among the reviewers. A p value less than 0.05 was considered statistically significant.

Results

Scallop, large and small fenestrations were placed into the celiac axis, superior mesenteric and bilateral renal arteries in these two cases. A second long stent (17.5 mm) was deployed in the left renal artery in patient 1 when the first one was found to be distorted at completion angiography (Fig 2). Patient 2 developed type I endoleak after fenestrated repair which was observed in both 2D and 3D images (Fig 3). All of the fenestrated vessels remained patent.

The table lists the scores of 2D/3D visualizations given by the reviewers. As shown in the table, MPR and MIP were scored the highest among all of the visualizations by two reviewers, and 2D axial view was scored valuable in the assessment of most of the parameters except in the modular overlap and skeletal problems (Fig 3). In contrast, VR was found to play limited role in the follow-up of fenestrated repair as both reviewers did not feel confident to use it as a follow-up imaging tool and it was scored 1 or 2 in most of the situations.

Both reviewers gave a score of 5 to the stereoscopic view in the detection of any distortions of fenestrated stent, and 3 or 4 in the assessment of modular overlap and

position of the fenestrated stent in relation to the target vessel. Reviewer 2 also felt that stereoscopic visualization is very useful in the identification of source of endoleak (Fig 4), although this was not supported by review 1 who gave a score of 2 in this aspect.

Statistical analysis showed that there is high concordance between reviewers in the evaluation of value of 2D, MIP/MPR and 3D stereoscopic views (Kendall's W 0.77-0.89, $p < 0.05$), and good concordance for evaluation of 3D VR (Kendall's W 0.585, $P < 0.05$).

Discussion

Stereoscopic displays are known to provide additional information in many non-medical as well as medical fields (7-11). A recent study using 3D ultrasound data for evaluation of fetal bony structures showed that stereoscopic viewing adds valuable information for identification of fetal bony structures when compared with conventional 3D imaging (8). Our results showed that stereoscopic visualization of 3D CT data provides additional information about any distortions of fenestrated stents as well as modular overlap of stent grafts.

Conventional 2D visualizations including MPR and MIP play a dominant role in the follow-up of fenestrated stent grafts, and this finding is consistent to what was reported in the literature (12-14). This was confirmed in our study as the reviewers felt very confident to use MPR/MIP for assessment of these parameters, while 2D axial view was only useful in some particular areas. Surprisingly, our results showed that the performance of 3D VR was very limited in the evaluation of fenestrated repair as it received a very low score in most of the situations. Interactive volume display allows the viewers to identify the locations of specific anatomic structures and can further be enhanced by using the depth cues, cut planes and shading. In some cases, however, it is

still difficult to appreciate all of the structural details either because there are so many or the overlapping overwhelms the viewer (8).

In our study, stereoscopic viewing improved visualization of overlapping structures and fenestrated stents. Moreover, one of the reviewers considered stereoscopic viewing valuable in assisting him to locate the source of endoleak, which was present in one of the patients. Identification of high-contrast structures such as the fenestrated vessel stents and endoleaks showed improvements with stereoscopic visualization when compared with conventional 2D views.

Stereoscopic viewing is not widely available for medical applications at the moment. However, a red/blue display can be accomplished on most displays with little additional hardware or computational requirements with satisfactory results being achieved for many displays and comparable stereoscopic effects. Moreover, red/blue glasses are much cheaper than the LCD ones. Computer monitors capable of displaying 3D stereoscopic views without wearing the 3D glass are available in the market, thus, stereoscopic visualization could be used on a practical basis as a complementary visualization to routine 2D views in the follow-up of patients after fenestrated repair.

One of the limitations of our study is that we only tested the stereoscopic viewing in 2 selected cases. Investigation of the application of stereoscopic viewing in more patients treated with fenestrated stent grafts would allow us to draw a robust conclusion. Another limitation is that not all of the seven parameters were represented in the selected cases. Evaluation of these parameters with both 2D and 3D visualizations would be more accurate to determine the diagnostic value of stereoscopic viewing in the follow-up of fenestrated stent grafting.

In conclusion, we presented a technique of 3D stereoscopic visualization compared with conventional 2D visualizations in the evaluation of patients treated with fenestrated stent grafts. Our results showed that stereoscopic viewing provides additional information regarding any distortions of the fenestrated stents. Stereoscopic visualization could be a complementary tool for follow-up of fenestrated stent grafting.

Table Scores of each visualization tool in evaluation of fenestrated stent grafting

Parameters	2D axial		MPR/MIP		VR		Stereoscopic view	
	R1	R2	R1	R2	R1	R2	R1	R2
1	2	2	5	5	4	4	4	3
2	5	4	5	5	2	1	1	1
3	5	4	5	5	2	1	3	4
4	3	3	4	5	2	2	5	5
5	2	1	4	3	1	5	3	1
6	4	5	4	4	1	1	2	5
7	4	4	4	4	1	1	1	1

1. Modular overlap/changes eg dislocations
2. Graft apposition/wall contact in the landing zones
3. Position of the fenestration stent in relation to the target vessel
4. Any distortions of the fenestration stents
5. Skeletal problems eg stent fractures
6. Sources of endoleak eg type I
7. Signs of infection eg fluid collection, gas bubbles

R1-reviewer 1, R2-reviewer 2

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Figure legends

Figure 1 LCD glasses are used to view CT volume data in a stereoscopic projection.

Synchronization hardware is required for stereoscopic viewing with LCD glasses.

Figure 2A is 2D axial showing the long left renal stent in patient 1. MIP images (B and C) especially the thin slab MIP (C) demonstrates more clearly the intraluminal length of the fenestrated stent. 3D VR shows the relationship between fenestrated stents and vessels, but fails to reveal the fenestrated stent position intraluminally.

Figure 3 Type I endoleak in patient 2 was visualized on axial CT images (A) and multiplanar reformatted images (B). The endoleak was also demonstrated on 3D VR (C) and MIP images (D and E represent left and right anterior oblique views) that were generated with the Analyze software with bony structures being removed. Arrows indicate the endoleak arising just below the right renal artery.

Figure 4 Stereoscopic views in patient 2 demonstrate the endoleak in relation to the aortic branches. Fig 4A is a coronal view, while 4B is a sagittal view showing the endoleak below the right renal artery (the reader needs red/blue glasses to appreciate the stereoscopic effect).