Optimal scanning protocols of 64-slice CT angiography in coronary artery stents: An in vitro phantom study

Abstract

Purpose: The purpose of the study was to investigate the optimal scanning protocol of 64-slice CT angiography for assessment of coronary artery stents based on a phantom study.

Materials and Method: Coronary stents with a diameter of 2.5 mm was implanted in thin plastic tubes with an inner diameter of 3.0 mm to simulate a coronary artery. The tubes were filled with iodinated contrast medium diluted to 178 HU, closed at both ends and positioned in a plastic container filled with vegetable oil (-70- to -100 HU). A series of scans were performed with a 64-slice CT scanner with the following protocols: section thickness: 0.67 mm, 1.0 mm, 1.5 mm, 2.0 mm, pitch value: 0.2, 0.3, 0.5 and reconstruction interval of 50% overlap of the section thickness. 2D axial and multiplanar reformatted images were generated to assess the visibility of stent lumen, while virtual intravascular endoscopy (VIE) was reconstructed to evaluate the artery wall and stent surface.

Results: Our results showed that a scanning protocol of 1.0 mm slice thickness with a pitch of 0.3 produced acceptable images with best demonstration of the intrastent lumen and stent surface with minimal image noise or artefacts. In contrast, submillimeter scans with 0.67 mm resulted in moderate artifacts which affected visualization of the coronary lumen, in addition to the increased noise. When the section thickness increased to 1.5 mm and 2.0 mm, visualization of the artery wall and stent surface was compromised, although the intrastent lumen was still visible.

Conclusion: Our in vitro study suggested that a scanning protocol of 1. 0 mm section thickness with pitch of 0.3 is the optimal protocol for evaluation of coronary artery stents as it allows generation of acceptable images with better visualization of stent lumen, stent surface and coronary artery wall.

Key words: Coronary artery disease, coronary stent, image quality, visualization, multislice CT

Introduction

Coronary artery disease (CAD) is one of the leading causes of death in the developed countries [1]. In recent years, CAD has been increasingly treated with coronary stent placement [2, 3]. While stent implantation has been shown to treat the CAD successfully, 20–35% of patients treated with bare-metal stents develop restenosis, and 5–10% of patients with drug-eluting stents develop restenosis [4, 5]. The incidence of in-stent restenosis indicates that the patients will be followed-up frequently to monitor the treatment outcomes, which is normally performed with invasive coronary angiography. This further raises concerns of patient safety and economic cost. Thus, a less invasive imaging technique which can be used as an effective alternative to invasive angiography for the follow-up of coronary stenting is highly desirable.

Over the past 10 years, multislice CT (MSCT) has been increasingly used as a non invasive technique in cardiac imaging [6, 7]. Although promising results have been achieved with MSCT imaging, there are still limitations of this technology which prevent it from becoming a reliable diagnostic tool to replace invasive angiography. Recently, the emergence of 64-slice CT with increased spatial and temporal resolution led to significant improvement in the diagnostic value of MSCT for the evaluation of coronary in-stent restenosis [8-12], although this still needs further confirmation as to whether it could be used as a reliable alternative to invasive coronary angiography. One of the main limitations of MSCT in imaging of coronary stents is the blooming artefact which interferes with visualization of the stent lumen, subsequently affecting evaluation of in-stent restenosis. In addition to the application of post-processing reconstruction algorithms, optimization of MSCT scanning protocols is one of the effective methods to improve visualization of stent lumen and minimize the blooming artefact. Thus, the purpose of our study was to investigate the appropriate MSCT scanning protocol in coronary stenting based on an in vitro phantom study.

Materials and Methods

Phantom design

A plastic container (Figure 1 A) was used to hold the coronary stent phantom in our study. The plastic material has a thickness of less than 0.3 mm with CT attenuation similar to that of normal artery wall (35-40 HU). A thin plastic tube (Figure 1A) with 3.0 mm in diameter was placed inside the container and used as a simulated coronary artery. Three commercially available coronary stents with a diameter of 2.5 mm were inserted into the simulated coronary artery "tubes" which were located at the phantom. The tubes were sealed at both ends and filled with contrast medium to simulate the CT enhancement, and positioned in the plastic container filled with vegetable oil (CT attenuation of -70 to -100 HU to simulate pericardial fat) (Figure 1B). The tubes with expanded stents were positioned in an orientation parallel to the z-axis of the scanner.

In order to produce the contrast medium with CT attenuation similar to that of routine coronary CT angiography, a series of experiments were performed to produce the attenuation of 180-200 HU, which is the acceptable diagnostic CT attenuation in a contrast-enhanced coronary CT imaging. For an adult patient, the volume of contrast medium required for a routine CT scan is determined by the body weight, which is 1.5

ml per kilogram. Thus it is calculated that a dilution of 4% of 0.8 ml contrast medium mixed with 50 ml normal saline produced a CT attenuation of 178 HU.

Stent characteristics

Three sample stents (Taxus Liberte, stainless steel) were collected from the agency of Boston Scientific company in Saudi Arabia as they were expired. The stent diameter was 2.5 mm and 16 mm in length for two of them and 3 mm in diameter and 24 mm in length for the remaining one. All of them are drug-eluting stents.

These stents were delivered into the simulated coronary artery through small diameter catheters and expanded directly after deployment. All of these stents placed inside the simulated coronary artery were self-expanding stents.

64-slice CT scanning protocols

The stents were placed in a transverse position (perpendicular to the scan direction). The stationary stents were scanned without use of an ECG-synchronized protocol. A series of scans were performed with a 64-slice CT scanner (Brilliance 64, Philips Medical Systems, King Fahad Specialist Hospital, Dammam Saudi Arabia) with the following protocols: section thickness: 0.67 mm, 1.0 mm, 1.5 mm, 2.0 mm, pitch value: 0.2, 0.3, 0.5, reconstruction interval: 50% overlap of the section thickness. Tube current and voltage were 120 kV, 230 mAs for all scans. There are altogether 12 datasets (4 section thickness x3 pitch values).

Image postprocessing and reconstruction

After CT scanning, all of the images were saved in the DICOM (digital imaging and communications in medicine) format and burned into DVD disks for post-processing and analysis. All of the DICOM images were later transferred to a workstation equipped with commercially available software Analyze V 7.0 (Analyzedirect, Mayo Clinic). 2D axial, multiplanar reformatted (MPR) and virtual intravascular endoscopy (VE) images were generated to demonstrate the coronary stents and coronary artery lumen. Generation of VIE images has been described elsewhere [13, 14]. Similar to our previous method, a CT number thresholding technique was used to generate intraluminal views of the coronary stents. An upper CT threshold of 100 HU was selected to remove the contrast medium while retaining the soft tissue, artery wall and stent. Particularly, VIE images were produced to visualize the surface of coronary artery wall and stent with regard to the smoothness or irregularity.

Data assessment-qualitative evaluation

A 3-point scale was used to assess the image quality with respect to visualization of the stent (coronary) lumen: score 1: excellent or good image quality (optimal depiction of the coronary stent lumen); score 2: moderate image quality (coronary stent lumen is visible but with significant stenosis due to presence of moderate blooming artefacts); and score 3: poor image quality (coronary stent lumen is hardly visible due to presence of severe artefacts). All images were evaluated by one reviewer. Evaluation was focused on 2D axial and MPR images based on the above mentioned scoring method.

Data assessment of images-quantitative evaluation

A region of interest (ROI) was placed on MPR images to measure the image noise, which is defined as the standard deviation (SD). A circular area of ROI was placed in the simulated coronary artery outside of the stent and it was chosen to be as small as possible without inclusion of the area outside the coronary lumen. We did not measure the ROI inside the stented lumen as the coronary stent used in our study is so small that the visible lumen does not allow accurate measurements within the stented area. The location of ROI was kept as almost the same as possible in all of the images. At each location, measurements of the SD were repeated 3 times to avoid intra-observer variation, and the mean value was calculated and used for analysis.

Statistical analysis

All of the data were entered into SPSS V 16.0 (SPSS Inc, Chicago, ILL) to determine the relationship between the SD 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. 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

Two of the placed stents were noticed to move out of the centre of the plastic tubes during the CT scans and the remaining one stayed inside the tube. Thus, only the central one was available for our analysis. Our results showed that the scanning protocols with a slice thickness of 1.0 mm received the lowest scores compared to other protocols, as shown in the table. For CT scans performed with a submillimeter thickness of 0.67 mm, only the protocol with a pitch of 0.5 was scored 1, while the remaining protocols were scored 3 due to presence of moderate or severe artefacts. When the slice thickness is more than 1.0 mm, image quality was affected to some extent, as observed in protocols with slice thicknesses of 1.5 mm and 2. 0 mm, which were scored 2, although the stent lumen was still visible (Figure 2).

SD was successfully measured in all of the images, with protocols of 0.67 mm section thickness generating the highest value, indicating the increased image noise arising from thinner section thickness (table). The SD was found to be dependent on section thickness ($p<0.01$) and independent of pitch values ($p>0.05$), as shown in Figure 3. VIE images were successfully generated in all of the datasets with clear demonstration of both the intraluminal surface of coronary wall and coronary stents in the MSCT protocols with a section thickness of 0.67 mm and 1.0 mm, regardless of pitch values (Figure 4 A, B). While for the remaining protocols acquired with a section thickness of more than 1.0 mm, the stent surface was displayed with presence of artefacts, but the artery wall could not be clearly shown (Figure 4 C, D).

Discussion

There are two findings arising from our study which we consider important for clinical application: first, the small coronary stent can be visualized with 64 slice CT with acceptable image quality when a scan protocol of 1.0 mm slice thickness was selected. Second, with aid of VIE visualization both the artery wall and stent surface can be clearly shown which we consider valuable for follow-up of patients treated with coronary stenting. Although our preliminary results were based on a simple phantom with only one type of stent (small diameter) tested, research findings are applicable to larger stents which are commonly used in the treatment of patients with CAD.

Imaging of coronary stents is challenging as image quality is not only influenced by the cardiac motion but also by the metal component of the stent implanted. Studies using earlier MSCT scanners such as 4 slice CT were unsatisfactory in the assessment of coronary stents or in-stent restenosis because of limited spatial and temporal resolution [15, 16]. With increased number of slice such as 16- and 64-slice scanners, improved diagnostic accuracy has been reported in imaging of coronary artery disease and coronary stents [8-12, 17, 18]. This has been confirmed by a number of systematic reviews or meta-analyses of diagnostic accuracy of multislice CT angiography for detection of coronary in-stent restenosis [19-22]. It is evident from these reports that MSCT is increasingly playing an important role in the follow-up of patients treated with coronary stents and serves as an effective less-invasive technique. Investigation of the effect of stent diameter and material on MSCT image quality still remains a hot topic, and the visibility of stent lumen largely depends on the type, diameter and material of the stent implanted.

Researchers reported that MSCT imaging of coronary stenting is mainly affected by the stent diameter, especially for those with a diameter less than 3.0 mm [17, 18, 23]. In our study a coronary stent with a diameter of 2.5 mm was examined, thus, we believe our results could be applicable to larger stents. When imaging the coronary stents using 64-slice CT, a thin slice thickness (0.6-0.75 mm) with a low pitch (0.1-0.2) is most commonly preferred in the reported literature [8-12]. However, our results do not corroborate the traditional belief that thinner slice thickness produces the best image quality, especially in the coronary stenting. We tested various CT protocols in the phantom study to asses the small coronary stent, and found out that MSCT protocols with 1.0 mm slice thickness resulted in the best image quality with minimal blooming artefacts. In contrast, 64-slice CT protocols with thin slice thickness (submillimeter) produced more apparent artefacts which interfered with visualization of the stent lumen. Our findings about the relationship between pitch and image quality are generally consistent to what has been advocated by others, with lower pitch value preferred for imaging coronary stents, except with the protocol of a section thickness 0.67 mm and pitch of 0.5, which leads to better visualization of the stent lumen than those with pitch values of 0.2 and 0.3. This could be explained by the fact that relatively lower noise was achieved with higher pitch value than that with lower pitch values, as observed in our experiments.

Maintz et al in their in vitro study consisting of 68 different coronary artery stents demonstrated that varying artefacts were expected from stents of different materials and construction [24]. According to their study, artefacts were present in all of these coronary stents resulting in variable visibility of the stent lumen, ranging from 3.3% to 73.3%. Although we did not evaluate the narrowing of the stent lumen in our study as only one type of stent was assessed, the presence of blooming artefacts affected visualization of the stent lumen in all of the images. More than 50% of lumen area narrowing was observed in all of the 64-slice CT protocols in our experiments.

It has been shown that the most severe artefacts were found with tantalum, gold or gold-coated stents, or covered stents compared with stainless steel stents [23]. Gilard et al [23] experienced no serious partial volume effect or beam hardening artefacts in their group of patients treated with stainless steel stents, and reported that the lumen was assessable in 93% of the cases. In contrast, Mahnken et al [25] showed that gold and gold-coated stents caused the most severe artefacts in their group. The stent used in our study is stainless steel stent, which could explain the relatively better visualization of the stent lumen, especially the lumen is still visible with scans performed with a section thickness of 2.0 mm.

Similar to our measurement of the image noise, evaluation of the coronary artery wall and stent surface by VIE images depends on the section thickness and is independent of pitch values. Our initial results provide insight into the potential value of VIE visualization in the follow-up of coronary stenting. Drug-eluting stents are increasingly being used in the clinical practice with the aim of preventing in-stent restenosis, and research has shown the decreased incidence of stent re-stenosis when compared to bare metal stents [26]. However, there is a growing concern that delayed endothelisation and incomplete neointimal healing might lead to adverse cardiac outcomes and death as a result of late or very late stent thrombosis [27]. The development of in-stent restenosis after implantation is due to the neointimal hyperplasia around the stent in the arterial lining, which increases the risk of blocking the artery again. We believe that VIE, as a unique visualization technique of presenting the endoluminal appearance of arterial wall and stent surface, could be used as a valuable tool to identify any intimal changes of coronary artery due to the tissue overgrowth before it could lead to the in-stent restenosis or thrombosis.

The phantom was designed to simulate conditions comparable to in vivo MSCT angiography. However, some limitation should be addressed. Scans of the stents were only performed perpendicular to the stent axis, which is one of the limitations. Usually coronary arteries follow an oblique course, and the proximal left coronary artery in some cases is even parallel to the axial plane. Schulte et al demonstrated the dependency of the image quality on stent distortion in relation to the imaging plane for coronary artery stents [28]. Stent lumen narrowing may be even more pronounced in oblique orientations and in vessels with curved shape or irregular walls than was observed in our study.

Second, our experiments were obtained with a static vascular model. Cardiac motion makes it more difficult to evaluate the stent lumen. Third, we tested one type of stent which consists of metallic component of drug-eluting stents. Different types of stents with variable materials or diameters have been tested by others, however, our focus is to study the effect of MSCT protocols on stent visualization. Finally, the study was observed by one reviewer, which could introduce biased opinion. Two or more observers involved in the assessment are essential.

In conclusion, a coronary artery phantom was successfully used to evaluate the 64-slice CT in detection of the coronary artery stent and investigate the effect of MSCT protocols on the visualization of stent lumen and image quality. A scanning protocol of slice thickness 1.0 mm, pitch 0.3 and reconstruction interval of 0.5 mm was recommended as the optimal one as it allows better visualization of the stent lumen with minimal artefacts. VIE visualization is considered as a potential tool for follow-up of coronary stenting as it allows demonstration of the intraluminal views of the artery wall and stent surface. Further studies based on a more realistic phantom and large cohorts of patients are needed to validate our results.

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Figure legends

Figure 1A is a plastic container used to hold the plastic tubes plastic tubes, while Fig 1B shows the plastic container filled with vegetable oil to simulate the pericardial fat. A coronary stent was deployed inside the simulated coronary artery (arrows in B).

Figure 2. 2D axial and MPR images of coronary stents acquired with different 64-slice CT protocols. Fig 2 A-L corresponds to the following protocols (section thickness/pitch/reconstruction interval) visualized on both MPR and 2D axial images: 0.67/0.2/0.33, 0.67/0.3/0.33, 0.67/0.5/0.33, 1.0/0.2/0.5, 1.0/0.3/0.5, 1.0/0.5/0.5, 1.5/0.2/0.75, 1.5/0.3/0.75, 1.5/0.5/0.75, 2.0/0.2/1.0, 2.0/0.3/1.0, 2.0/0.5/1.0.

Figure 3. SD measured with different section thicknesses.

Figure 4. VIE images of the coronary artery wall and stent surface acquired with 64-slice CT protocols of section thicknesses of 0.67 mm, 1.0 mm, 1.5 mm and 2.0 mm with a pitch of 0.3, and 50% reconstruction interval of the section thickness. As shown in the images, both artery wall and the stent surface were clearly visualised when the section thickness was between 0.67 and 1.0 mm. When the section thickness increased to more than 1.0 mm, the relationship between the stent lumen and the artery wall could not be assessed as only the lumen surface of the stent was displayed.