Inter-Scan Reproducibility of Geometric Coronary Artery Measurements Using Frequency-Domain Optical Coherence Tomography

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Summary

Frequency-domain optical coherence tomography (FD-OCT) is a novel technology which provides high-resolution cross-sectional images of coronary arteries. The aim of this study was to evaluate the inter-scan reproducibility of geometric FD-OCT measurements in the clinical setting. We examined 20 coronary lesions using FD-OCT. Following the FD-OCT image acquisition (1st pullback), and after the disengagement and re-engagement of the guiding catheter, an additional acquisition (2nd pullback) was performed using a new FD-OCT catheter. There was excellent correlation for minimum lumen area (r = 0.99, P < 0.001), lesion length (r = 0.99, P < 0.001) and lumen volume (r = 0.99, P < 0.001) between the 1st pullback and the 2nd pullback. The Bland-Altman test demonstrated good agreement between the 1st pullback and the 2nd pullback: the mean difference for minimum lumen area, lesion length, and lumen volume was 0.05 mm², 0.03 mm, and 0.70 mm³, respectively; and the lower and upper limit of agreement for minimum lumen area, lesion length, and lumen volume was -0.58 and 0.48, -0.36 and 0.42, and -13.4 and 12.1, respectively. FD-OCT showed an excellent inter-scan reproducibility for the geometric coronary artery measurements. Our findings emphasize the value of FD-OCT as a tool for clinical longitudinal studies of coronary artery disease. (Int Heart J 2013; 54: 64-67)

Key words: Intracoronary imaging, Coronary artery disease

Frequency-domain optical coherence tomography (FD-OCT) is a novel technology which provides high-resolution cross-sectional images of coronary arteries. High frame rate (100 frame/sec) and fast pull-back speed (20 mm/s) of FD-OCT allow for a clear visualization of coronary lumens and vessel walls. Various factors such as location of the image catheter, heart motion, timing of image acquisition (systole/diastole) and manual zero-offset may affect the OCT assessment. In vitro phantom models have demonstrated the accuracy of quantitative OCT measurement for luminal size and length. In a Corelab setting, several studies have disclosed excellent intra- and inter-observer agreement of OCT measurements. However, the inter-scan reproducibility of geometric OCT measurements remains unclear. Such information in regard to measurement consistency between the scans should be required to design longitudinal OCT studies. The aim of the present study was to assess the inter-scan agreement for geometric FD-OCT measurements in a clinical setting.

Methods

Study population: We enrolled consecutive 20 patients who underwent percutaneous coronary intervention with a single stent for a native coronary artery lesion. Patients were excluded if they had congestive heart failure with a left ventricular ejection fraction < 30 %, renal insufficiency with baseline serum creatinine > 2.0 mg/dL, or required primary angioplasty. In addition, those with left main coronary artery stenting, ostial right coronary artery stenting, or bifurcation stenting were excluded because of expected difficulty in FD-OCT analysis. This protocol was approved by the Wakayama Medical University Ethics Committee, and all patients provided informed consent before participation.

FD-OCT image acquisition: Percutaneous coronary intervention was performed using a 6 Fr guiding catheter, 0.014-inch guide wire, and a commercially available balloon and stent (XIENCE V; Abbott Vascular, Santa Clara, CA, USA), according to conventional methods. After coronary intervention, the stented lesion was assessed by C7-XR™ FD-OCT imaging system (LightLab Imaging/St. Jude Medical, Westford, MA,

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All patients received an intravenous injection of 5,000 IU heparin and intracoronary injection of 1.0–2.0 mg isosorbide dinitrate before the FD-OCT imaging procedure. The FD-OCT image acquisition was performed as previously reported. Briefly, a Z-offset calibration was performed manually prior to introduction of the FD-OCT catheter into the coronary artery. The 2.7 Fr FD-OCT catheter was advanced distally to the stented lesion over a 0.014 inch conventional angioplasty guide wire. To remove the blood during FD-OCT image acquisition, preheated contrast media at 37°C (Omnipaque® 350 Injection; Daiichi Pharmaceutical, Tokyo) was infused from the guiding catheter at a rate of 3.0 mL/sec in the right coronary artery and 4.0 mL/sec in the left coronary artery by an auto-injector pump (Mark V; Medrad, PA, USA). The FD-OCT image acquisition was performed using the automatic pull-back at a speed of 20 mm/s. Following the FD-OCT image acquisition (1st pullback), and after the disengagement and re-engagement of the guiding catheter, an additional image acquisition (2nd pullback) was performed using a new FD-OCT catheter. All FD-OCT images were digitally archived in the FD-OCT system console for off-line analysis.

FD-OCT image analysis: The FD-OCT images were analyzed using a proprietary off-line review system (LightLab Imaging/ St. Jude Medical). The Z-Offset was adjusted, if necessary, in all the pullbacks before the analysis. The target lesion was defined as the stented segment between the first and last frame in which struts were visible over a 270 degree vessel circumference. Lumen area was measured at every 1 mm cross section in the target lesion. Lumen contour was obtained automatically and additional manual correction was performed if necessary. Minimum lumen area was determined as the smallest lumen area in the measured frames within the target lesion. The length of the target lesion was calculated from the number of cross-sectional frames. Lumen volume was calculated using Simpson’s rule. A representative case with quantitative FD-OCT analysis is shown in Figure 1.

Statistical analysis: All statistical analyses were performed using the statistical software package SPSS version 11.0 (SPSS Inc., Chicago, IL). Continuous variables are presented as the mean ± standard deviation. The correlation between the measurements of the 1st pullback and the 2nd pullback was analyzed by simple linear regression. Values of \( P < 0.05 \) were considered statistically significant. The agreement between the measurements of the 1st pullback and the 2nd pullback was established by Bland-Altman analysis. The Bland-Altman plot depicted the differences of each pair of measurements versus their mean values with reference lines for the mean difference of all paired measurements. The limit of agreement was defined as the mean ± 1.96 standard deviations of the absolute difference.

RESULTS

The patient characteristics are summarized in the Table. No pullbacks of FD-OCT contained artifacts that did not allow a proper image assessment. Eventually, 20 sets of the 1st/2nd pullbacks were analyzed in the present study.

The regression and Bland-Altman analyses for minimum lumen area, lesion length and lumen volume are shown in Figure 2, Figure 3 and Figure 4, respectively. There was excellent correlation for minimum lumen area (\( r = 0.99, P < 0.001 \)), lesion length (\( r = 0.99, P < 0.001 \)) and lumen volume (\( r = 0.99, P < 0.001 \)) between the 1st pullback and the 2nd pullback. In addition, the Bland-Altman test demonstrated excellent agreement for the geometric FD-OCT measurements between the 1st pullback and the 2nd pullback: the mean difference for minimum lumen area, lesion length and lumen volume was 0.05 mm², 0.03 mm, and 0.70 mm³, respectively; and the lower and upper limits of agreement for minimum lumen area, lesion length and lumen volume were -0.58 and 0.48, -0.36 and 0.42, and -1.34 and 12.1, respectively.

Table. Patient Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n (%) or Mean ± SD</th>
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<tbody>
<tr>
<td>Age, years</td>
<td>65 ± 11</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>13 (65)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>11 (55)</td>
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<tr>
<td>Dyslipidemia</td>
<td>10 (50)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>5 (25)</td>
</tr>
<tr>
<td>Current smoker</td>
<td>8 (40)</td>
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<tr>
<td>Target imaging vessels</td>
<td></td>
</tr>
<tr>
<td>LAD</td>
<td>13 (65)</td>
</tr>
<tr>
<td>LCX</td>
<td>2 (10)</td>
</tr>
<tr>
<td>RCA</td>
<td>5 (25)</td>
</tr>
<tr>
<td>Stent profiles</td>
<td></td>
</tr>
<tr>
<td>Stent length, mm</td>
<td>18 ± 4</td>
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<tr>
<td>Stent diameter, mm</td>
<td>3.1 ± 0.4</td>
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</tbody>
</table>

Values are given as n (%) or mean ± standard deviation. LAD indicates left anterior descending coronary artery; LCX, left circumflex coronary artery; and RCA, right coronary artery.

Figure 1. Representative case with quantitative FD-OCT analysis. Coronary stent was placed in the mid left anterior descending coronary artery (arrow). Lumen area and lesion length were compared between the 1st pullback and the 2nd pullback of FD-OCT. FD-OCT indicates frequency domain optical coherence tomography.

Figure 2. Regression analysis and Bland-Altman analysis for MLA measurements. There was a direct correlation and excellent agreement for the FD-OCT measurements of MLA between the 1st and 2nd pullbacks. FD-OCT indicates frequency domain optical coherence tomography; MLA indicates minimum lumen area.
Figure 3. Regression analysis and Bland-Altman analysis for measurements of lesion length. There was a direct correlation and excellent agreement for the FD-OCT measurements of lesion length between the 1st and 2nd pullbacks. FD-OCT indicates frequency domain optical coherence tomography.

**Discussion**

The present study demonstrates an excellent inter-scan reproducibility for the FD-OCT measurement of minimum lumen area, lesion length and lumen volume. OCT is an intravascular imaging technique that provides high-resolution, cross-sectional images of the coronary artery wall. The first generation time-domain OCT (TD-OCT) has proven to be a powerful tool for visualization of coronary microstructure. Due to its superior resolution, TD-OCT has the ability to identify pathology that could be missed by intravascular ultrasound (IVUS). Furthermore, recent advances in OCT technology have allowed faster image acquisition (frame rate = 100 frames/second, pullback speed = 20 mm/second), precluding the complex procedure of TD-OCT imaging. In the second generation FD-OCT, a 5 cm length of a coronary artery can be scanned for less than 3 seconds. FD-OCT offers significant advantages in feasibility and patient safety as compared to TD-OCT. Thus, FD-OCT is rapidly being adopted by catheterization laboratories worldwide for clinical use and research purposes.

Several studies have investigated the accuracy of quantitative OCT measurements. When OCT was performed in a plexiglass phantom manufactured with a precision of 10 μm, the OCT measurement correlated extremely well with the real luminal dimension (relative standard deviation 1.8%, r = 1.000, intercept 0.01, slope 1.02). In addition, OCT measurement demonstrated a high correlation with IVUS in vivo ($R^2$ = 0.82, $P < 0.001$). However, the luminal area measured by OCT seems to be smaller than that by IVUS. One possible reason for this difference is the superior ability of OCT to visualize the lumen-intima interface compared with IVUS, therefore allowing OCT to estimate the true lumen dimensions and causing IVUS to overestimate. Another possible explanation for measurement difference between OCT and IVUS is the effect of the cardiac cycle. While IVUS with a pullback speed of 0.5 mm/sec acquires images over many cardiac cycles, FD-OCT with a pullback speed of 20 mm/sec cannot select a specifically systolic or diastolic image. The difference of lumen dimension between systole and diastole could bias the measurement by 12%. Because OCT is consistently found to have smaller lumen area measurements than IVUS, caution should be taken before using literature-validated IVUS parameters to assess lesion significance by OCT.

The reproducibility of the FD-OCT measurements is of great concern in the clinical and research applications of this technology. Image artifacts due to suboptimal vessel flushing, guidewire shadowing and systole/diastole cardiac motion could have an influence on the reproducibility of the OCT measurements. The Z-offset also plays an important role in the accurate measurement and reproducibility of OCT. A 1% change in the magnitude of the ideal Z-offset resulted in a 12–14% error in area measurements by OCT. A clinical study examined the inter- and intraobserver reproducibility of quantitative FD-OCT measurements. The relative difference for lumen area, stent area, and neointimal area was around 1%. In the present study, we demonstrated excellent inter-scan reproducibility of the FD-OCT measurements for lumen area, lesion length and lumen volume. The excellent agreement for the geometric FD-OCT measurements between the two pullbacks might have resulted from the high-resolution method and the optimal image acquisition. Our finding suggests that FD-OCT is a reliable imaging tool for the assessment of coronary artery disease, especially for longitudinal studies with repeated FD-OCT examinations.

There are several limitations. First, FD-OCT requires keeping the guide wire in the vessel during image acquisitions. The shadow from the guide wire, which disturbs the depiction of the lumen border, can affect measurements of lumen area. Second, although isosorbide dinitrate and preheated contrast media were used to prevent coronary spasm induced by the imaging procedure, a potential change in vascular tonus during repetitive pullbacks cannot be completely excluded. Third, the measurements are currently performed manually. The development of automated quantitative analysis could improve the reproducibility of FD-OCT measurement. Fourth, the measurements of stent apposition, tissue protrusion, dissection extent, or thrombus burden were beyond the scope of our study. Further studies are required to assess the reproducibility of FD-OCT for these measurements. Finally, the reproducibility of the FD-OCT measurement was assessed only in the stented lesions. Our results may not be applicable to the non-stented lesions.

In conclusion, FD-OCT showed an excellent inter-scan reproducibility for the quantitative measurement of minimum lumen area, lesion length and lumen volume. Our finding em-
phasizes the value of FD-OCT as a tool for clinical longitudinal studies of coronary artery disease.

**DISCLOSURES**

Dr. Kubo has received grant support and consulting fees from St. Jude Medical. Dr. Akasaka has received grant support and consulting fees from St. Jude Medical.

**REFERENCES**


