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An assessment of the quality of optical coherence tomography image acquisition

Elder Iarossi Zago¹, Abdul Jawwad Samdani¹, Gabriel Tensol Rodrigues Pereira¹, Armando Vergara-Martel¹, Mohamad Amer Alaiti^{2,3}, Luis Augusto Dallan¹, Patricia Ely Pizzato¹, Vladislav Zimin¹, Anas Fares¹, Hiram G. Bezerra¹

¹Cardiovascular Imaging Core Laboratory, Harrington Heart & Vascular Institute, University Hospitals Cleveland Medical Center, 11100 Euclid Avenue, Lakeside Building, Room 3113, Mailstop: Lakeside 5038, Cleveland, OH 44106, USA

²University of Texas Southwestern, Dallas, TX, USA

³VA North Texas Healthcare System, Dallas, TX, USA

Abstract

Optical coherence tomography (OCT) provides excellent image resolution, however OCT optimal acquisition is essential but could be challenging owing to several factors. We sought to assess the quality of OCT pullbacks and identify the causes of suboptimal image acquisition. We evaluated 784 (404 pre-PCI; 380 post-PCI) coronary pullbacks from an anonymized OCT database from our Cardiovascular Imaging Core Laboratory. Imaging of the region-of-interest (ROI—lesion or stented segment plus references) was incomplete in 16.1% pullbacks, caused by pullback starting too proximal (63.7%), inappropriate pullback length (17.1%) and pullback starting too distal (11.4%). The quality of image acquisition was excellent in 36.3% pullbacks; whereas 4% pullbacks were unanalyzable. Pullback quality was most commonly affected by poor blood displacement from inadequate contrast volume (27.4%) or flow (25.6%), followed by artifacts (24.1%). Acquisition mode was ‘High-Resolution’ (54 mm) in 74.4% and ‘Survey’ (75 mm) in 25.6% of cases. The 54 mm mode was associated with incomplete ROI imaging ($p = 0.020$) and inadequate contrast volume ($p = 0.035$). We observed a substantial frequency of suboptimal image acquisition and identified its causes, most of which can be addressed with minor modifications during the procedure, ultimately improving patient outcomes.

Keywords

Image acquisition; Optical coherence tomography; Intravascular imaging

Elder Iarossi Zago, elderzago@gmail.com.

Compliance with ethical standards

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Introduction

Intravascular imaging guidance during coronary procedures enables detailed evaluation of the lesion morphology and has been shown to improve procedural and clinical outcomes [1-5]. The utilization of optical coherence tomography (OCT) intravascular imaging has increased, owing in large part to technological advances made during the past few years, in which occlusion technique was replaced by contrast injection only. OCT generates high resolution cross-sectional images of the vessels, allowing for in-depth lesion analysis and plaque characterization [6-8], that aids in vessel preparation and precise stent size selection and deployment [9, 10]. Moreover, OCT has a crucial role in assessment of stent expansion, malapposition and edge dissection [11, 12]. Intravascular OCT imaging involves three steps: optimal image acquisition, image analysis and appropriate interpretation and decision making by the operator based on the obtained images. The first step, image acquisition, is the key to optimal use of OCT, as the remaining steps are dependent on analyzability and quality of the acquired images.

As opposed to other imaging modalities, OCT acquisition requires displacement of blood by injection of contrast media. Insufficient blood clearance during image acquisition can greatly deteriorate the quality of the images [5, 13, 14]. Other factors like a fixed pullback size, inappropriate positioning of the catheter, type of pullback trigger and tortuosity of the vessel can result in inadequacies in OCT image acquisition. These intricacies make the all-important step of Image acquisition quite challenging.

The purpose of our study was to assess the quality of OCT images acquired as part of multicenter clinical trials and identify the specific inadequacies in image acquisition that may impair image analysis and impact clinical decision.

Methods

We utilized an anonymized, retrospective, multicenter, multinational OCT database maintained at the Harrington Heart & Vascular Cardiovascular Imaging Core Laboratory at University Hospitals Cleveland Medical Center, Cleveland, OH, USA and approved by our Institution IRB. All the patients gave informed consent for the original studies and our institution IRB determined that a separate informed consent was not necessary for the purpose of this study. This study was performed in accordance to the 1964 Declaration of Helsinki and its later amendments. A total of 784 pullbacks from closed trials (with already published results) were included in our analysis; none of the trials that were included in the database for this study had pre-specified pullback characteristics, being left to the operator discretion (high resolution vs survey mode, manual vs automatic trigger, manifold vs power injection). Patients with stable angina, unstable angina, or NSTEMI were included. Both pre- and post-PCI OCT images were included and all images were acquired between 2010 and 2017 as per the respective study protocols. Exclusion criteria included: (1) OCT catheter failure, OR (2) other equipment malfunction impacting the image acquisition. Subjects with acute STEMI, urgent PCI, cardiogenic shock, restenosis, stent thrombosis, target left main stenosis, aorto-ostial or diffuse disease, severe angulation or calcification that prevent OCT catheter to be advanced were excluded.

Two independent physicians, trained and validated at our institution, with more than 3000 OCT pullbacks analyzed each and blinded to any patient information, trial, clinical presentation, were responsible for the analysis of all pullbacks. Each OCT pullback was analyzed in its entirety. The region of interest (ROI) was defined as the stented segment plus the proximal and distal references (5 mm each) in the case of post-PCI pullbacks; or the stented segment co-registered to the pre-PCI pullback, in addition to the references. We documented the frequency of incomplete image acquisition of the ROI and the reasons behind it, such as inappropriate pullback size, and positioning of the OCT catheter.

We developed a classification system to objectively assess the quality of each pullback, ultimately grading into Classes 1–4 (Fig. 1), with progressive decline of overall image quality (Class 1 being an excellent quality and Class 4 being mostly unanalyzable). We also documented the reasons for poor image acquisition such as residual blood, artifacts, lack of contrast volume or flow, artifacts and occlusive lesion etc. In addition, we utilized an already published methodology for quality assessment, which was responsible for the FDA approval of OCT and is based on the measurement of analyzable length [15]. In summary clear imaging length (CIL) is the cumulative sum of clear image frames, defined as OCT cross-sections with a visible boundary between the lumen and the vessel wall along a continuous arc of at least 270° around the center of the lumen. CIL was also expressed in percentage relative to the total pullback length. The length of stent visible within the CIL was identified as clear stent length (CSL, in millimeters), which was also expressed in percentage relative to the total stent length.

Continuous variables are presented as means and standard deviations. Categorical variables are presented as numbers and percentages. Chi square and binary logistic regression analysis were used for subgroup comparisons between categorical variables and a $p = \text{value of } < 0.05$ was considered significant. All tests were performed using SPSS (IBM) version 25.

Results

A total of 784 pullbacks were included in this study, out of which, 404 (51.5%) were pre-PCI images and 380 (48.5%) were post-PCI. In terms of vessels, left anterior descending (LAD) artery 471 (60.1%) was most common, followed by the right coronary artery 157 (20.0%), left circumflex 134 (17.1%) and diagonal 14 (1.8%). Acquisition mode was 'High Resolution' (54 mm pullback length) in 583 (74.4%) and 'Survey' (75 mm pullback length) in 201 (25.6%) cases. In terms of access site, 456 (58.2%) were femoral and 328 (41.8%) were radial cases.

Analysis of pullback completeness (Table 1)

The image acquisition of the lesion or stented segment only, excluding the references, was incomplete in 58 (7.4%) of cases; whereas the ROI was incomplete in 126 (16.1%). The most common reason for incomplete ROI imaging, was the pullback starting too proximal 79 (63.7%), thus missing the distal reference, followed by inappropriate pullback length selection (i.e. since the longer pullback length is available, it should have been selected in order to cover the lesion length) (17.1%) and pullback starting too distal 14 (11.4%), thus missing the proximal reference.

Image quality analysis (Table 1)

A total of 284 (36.3%) pullbacks were considered to have excellent quality (Class 1) throughout the pullback, while additional 409 (52.2%) pullbacks had excellent quality in the lesion or stented segment but not in the references (Class 2). On the other hand, 28 (3.6%) had problems in the lesion/ stented segment alone (Class 3) and another 62 (7.9%) of the cases had inadequate quality that affected the ROI (Class 4). The most common quality issue was residual blood due to inadequate contrast volume in 128 (27.4%) cases or contrast flow in 120 (25.6%), followed by artifacts in 113 (24.1%) pullbacks. Quality was affected by catheter not properly flushed in 12 (2.6%) pullbacks. The CIL was found to be $84.0 \pm 18.7\%$ and the CSL was noted to be $95.8 \pm 15.5\%$.

Subgroup comparison based on pullback length (Table 2)

A comparison between pullback lengths or modes (adjusted for access site) revealed that 54 mm pullbacks had a significantly higher frequency of incomplete ROI compared to the 75 mm pullbacks (18.2% vs 10%; $p = 0.020$). Regarding pullback quality, there was a higher frequency of inadequate contrast volume in the 54 mm pullbacks (30.4% vs 19.7%; $p = 0.035$).

Subgroup comparison based on access site (Table 2)

There was no statistical difference between the femoral and radial access in terms of the completeness of ROI. More pullbacks with Class 1 quality were seen in the case of femoral access (41.7% vs 28.7%; $p = 0.001$), whereas Class 2 quality pullbacks were more frequent in the case of radial access (48.5% vs 57.5%; $p = 0.032$). Similar but not statistically significant pattern was seen in the case of Class 3 and 4 quality (Table 2).

Discussion

To the best of our knowledge, in addition to providing a review of parameters and techniques for optimal image acquisition, this is the first study assessing the inadequacies of optical coherence tomography image acquisition using a new objective classification (Table 1; Fig. 1). The analysis revealed a significant number of incomplete and poor quality OCT images, and provided an insight toward understating underlying mechanisms of poor OCT image acquisitions. This in turn, can provide guidance for improvement of OCT image acquisition.

It is worth highlighting that our study included OCT images from varied operators, at different centers, as part of distinct clinical trials, in which specific protocols of image acquisition were followed to generate the best quality of images for offline analysis. Given that the operators were participating in OCT based clinical trials, we considered them experts in this technology. Despite that, we noted a significant frequency of suboptimal images, which leads us to assume that in general practice the prevalence might be even higher, potentially resulting in increased contrast usage, higher radiation exposure and longer procedure time, thereby limiting the overall impact of OCT imaging on PCI.

We found that the rate of incomplete OCT images (Fig. 2) affecting the ROI was 16.1%. The resulting loss of analyzable length can lead to failure of identification of important

pathology in the lesion and the references. In turn, stent planning (in the case of pre-PCI pullbacks) and analysis of stent expansion, malapposition and edge dissection (in the case of post-PCI pullbacks) could be severely impaired [16, 17]. Our data identifies the most common causes of incomplete OCT pullbacks and emphasizes the importance of optimal OCT catheter positioning relative to the lesion and appropriate pullback size selection.

Even though two-thirds of pullbacks in our sample had quality issues, only a fraction of these cases were deemed unanalyzable (4%). Nonetheless, the remaining cases had some degree of quality related problems that still affected the image interpretation to variable extent. Our study shows that careful displacement of blood is crucial for optimal image acquisition as about 32% of all images were affected by residual blood, caused by either inadequate contrast volume or flow, resulting in less than ideal image quality (Fig. 3b).

The ILUMIEN OPTIS system has two modes for image acquisition: 'Survey' mode and 'High Resolution' mode. The 'Survey' mode provides a rapid pullback of 75 mm over 2.1 s at 180 frames per second (i.e., in 5 frames/mm). The 'High Resolution' mode images a 54 mm segment at the same frame rate over 3 s (i.e., 10 frames/mm), having twice the frame density [18]. Our analysis showed that the 54 mm 'High Resolution' mode was heavily preferred (74% vs 26%) over the 75 mm 'Survey' mode resulting in significant higher frequency of incomplete ROI in the 54-mm pullbacks (18.2% vs 10%; $p = 0.02$). We assume that the reason for this preference (of 54 mm mode) relates to its name in the software ('High Resolution') that suggests greater resolution and better image quality. It is worth mentioning that practically, the resolution and image quality between the two modes are exactly the same, with the main difference being in the frame density and image acquisition time. We believe that for clinical decision making, it is more important to have a complete image of ROI than to have a higher frame density (0.1 mm vs 0.2 mm between the frames) and hence, there might not be enough reason to pursue 54 mm pullbacks in routine clinical practice.

Our sub-group comparison revealed higher frequency of inadequate contrast volume in the 54 mm mode compared to the 75 mm mode (30.4% vs 19.7%; $p = 0.035$). This finding is explained by the fact that the 54 mm ('High Resolution') pullbacks take a longer time to acquire, resulting in more contrast usage (and hence the volume issues) and higher radiation exposure. These factors provide additional basis to favor the 75 mm 'Survey' mode for general purpose OCT acquisition.

Based on the literature [2, 13, 19-28], the best practices to avoid residual blood and to achieve excellent image quality include proper engagement of the guide catheter in the coronary artery, avoidance of guide catheters with side holes, optimal synchronization between flushing and OCT catheter pullback (the OCT pullback should not be started before the distal lumen is completely cleared of blood), use of power injections as they are more reliable in providing a blood-free lumen and use of higher-viscosity flush solutions as they provide superior imaging quality compared to the lower-viscosity ones.

We observed a substantial frequency (14% of all cases) of artifacts such as sew-up artifact, out of screen images, fold-over artifact and non-uniform rotational deformity. However,

these artifacts only affect a few frames and have a minor effect on the overall quality and analyzability of the pullback. On the other hand, blood in the catheter, which results from failure to flush the catheter before imaging the vessel (Fig. 3c), can affect the entire pullback and in turn have a greater impact on analyzability by blocking the source light [29]. In our study, this completely avoidable phenomenon was seen in a relatively minor number of pullbacks.

On comparison based on access site, there was no difference in terms of completeness of pullbacks between femoral and radial sites, however, femoral access seems to have an impact on overall quality of the pullbacks, with a higher frequency of Class 1 quality pullbacks. On the other hand, there was a higher rate of artifacts in the femoral group. Further studies will be needed to confirm these findings.

By providing a detailed insight into the inadequacies of OCT acquisition and identifying the most common causes of suboptimal images, our findings can have significant implications in improving the overall quality and impact of OCT. We re-emphasize a standardized image acquisition protocol/technique based on published guidelines [2] and adequate training of the operator regarding proper catheter positioning, appropriate pullback size selection, and optimal use of contrast. Further studies to correlate image quality with training and experience of the operator, and to assess the impact of improved quality of OCT on procedural decision making and clinical outcomes are needed.

Limitations

Our study has a few limitations. Firstly, it is a retrospective study with its inherent limitations. Secondly, because of the study design, we do not know about the experience and training of the operator with regards to OCT and were unable to correlate the inadequacies in image acquisition with such factors. Third, our database does not include ST-elevation myocardial infarction (STEMI) cases. Fourth, the study does not include images from high risk PCI procedures such as chronic total occlusion (CTO), ostial lesions or left main lesions. Fifth, due to the nature of this study, the OCT acquisition procedure was not controlled, which impact the interpretation of causes of poor image qualities. Lastly, only the Abbott OCT system were included in our study.

Conclusion

Our study identified a significant frequency of cases with suboptimal image acquisition, and its causes, most of which are preventable with minor changes during the procedure. Better education and training on image acquisition will reduce the number of pullbacks necessary to adequately image a vessel, reduce contrast usage and lead to better imaging data quality, ultimately improving procedural decision-making and patient outcomes.

Abbreviations

OCT	Optical coherence tomography
LAD	Left anterior descending

ROI	Region of interest
PCI	Percutaneous coronary intervention
CIL	Clear imaging length
CSL	Clear stent length
STEMI	ST segment elevation myocardial infarction
CTO	Chronic total occlusion

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Fig.1.

Class 1 has excellent quality throughout ROI, other classes have quality issues (shaded red) in reference only (Class 2), stented segment/lesion only (Class 3) or the entire ROI (Class 4).

a Pre stent and **b** post stent

Fig. 2.

A 54 mm pullback (yellow line) where the operator did not capture the ROI (red dash line). A potential 75 mm pullback (blue dash line), and minimal advancement of the OCT catheter would meet the required length to include the complete ROI

Fig. 3.
Cross-sectional images of an excellent image acquisition (**a**); residual blood in the catheter (**b**) and catheter not flushed (**c**)

Table 1**Pullback completeness and quality analysis**

Variable	n = 784
Pullback completeness analysis	
Incomplete stent/lesion, n (%)	58 (7.4)
Incomplete distal reference, n (%)	99 (12.6)
Incomplete proximal reference, n (%)	30 (3.8)
Incomplete region of interest (ROI), n (%)	126 (16.1)
Reason for incomplete pullback	
Pullback started too proximal, n (%)	79 (63.7)
Pullback started too distal, n (%)	14 (11.4)
Inappropriate pullback length, n (%)	21 (17.1)
Others, n (%)	12 (9.5)
Pullback quality analysis	
Clear image length (CIL), mm, mean (SD)	49.8 (13.3)
Clear image, % (SD)	84.0 (18.7)
Clear stent length (CSL), mm, mean (SD)	23.2 (10.0)
Clear stent, % (SD)	95.8 (15.5)
Classification of pullback image quality	
Class 1: excellent quality throughout the pullback, n (%)	284 (36.3)
Class 2: quality issue with the references only, n (%)	409 (52.2)
2A: minor issue affecting only the reference, n (%)	278 (35.5)
2B: moderate issue affecting only the reference, n (%)	92 (11.7)
2C: major issue affecting only the reference, n (%)	39 (5.0)
Class 3: quality issue with the lesion/stented segment only, n (%)	28 (3.6)
3A: minor issue, n (%)	6 (0.8)
3B: moderate issue, n (%)	18 (2.3)
3C: major issue, n (%)	4 (0.5)
Class 4: quality issue with both the lesion/stented segment and references, n (%)	62 (7.9)
4A: minor issue, n (%)	6 (0.8)
4B: moderate issue, n (%)	25 (3.2)

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Variable	n = 784
4C: major issue (not analyzable), n (%)	31 (4.0)
Reasons affecting quality	
Inadequate contrast volume, n (%)	128 (27.4)
Inadequate contrast flow, n (%)	120 (25.6)
Catheter not flushed, n (%)	12 (2.6)
Artifact (sew-up, out of screen etc.), n (%)	113 (24.1)
Occlusive lesion, n (%)	7 (1.5)

Table 2

Comparison between sub-groups based on pullback length and access site

Variable	54 mm, n = 583, n (%)	75 mm, n = 201, n (%)	p value	Femoral, n = 456, n (%)	Radial, n = 328, n (%)	p value
Access—femoral	375 (64.3)	81 (40.3)	—	—	—	—
Access—radial	208 (35.7)	120 (59.7)	—	—	—	—
Pullback length (54 mm)	—	—	—	375 (82.2)	208 (63.4)	—
Pullback length (75 mm)	—	—	—	81 (17.8)	120 (36.6)	—
Pullback completeness analysis						
Incomplete stent/lesion	55 (9.4)	3 (1.5)	0.002	38 (8.3)	20 (6.1)	0.685
Incomplete distal reference	84 (14.4)	15 (7.5)	0.032	68 (14.9)	31 (9.5)	0.077
Incomplete proximal reference	25 (4.3)	5 (2.5)	0.300	19 (4.2)	11 (3.4)	0.722
Incomplete region of interest (ROI)	106 (18.2)	20 (10.0)	0.020	85 (18.6)	41 (12.5)	0.076
Classification of pullback image quality						
Class 1: excellent quality throughout the pullback	221 (37.9)	63 (31.5)	0.379	190 (41.7)	94 (28.7)	0.001
Class 2: quality issue with the references only	293 (50.3)	116 (58.0)	0.160	221 (48.5)	188 (57.5)	0.032
Class 3: quality issue with the lesion/ stented segment only	23 (3.9)	5 (2.5)	0.289	15 (3.3)	13 (4.0)	0.468
Class 4: quality issue with both the lesion/ stented segment and references	46 (7.9)	16 (8.0)	0.767	30 (6.6)	32 (9.8)	0.098
Reasons affecting quality						
Inadequate contrast volume	102 (30.4)	26 (19.7)	0.035	73 (29.6)	55 (24.9)	0.605
Inadequate contrast flow	83 (24.7)	37 (28.0)	0.698	57 (23.1)	63 (28.5)	0.236
Catheter not flushed	7 (2.1)	5 (3.8)	0.402	5 (2.0)	7 (3.2)	0.605
Artifact (sew-up, fold-over, out of screen etc.)	91 (27.1)	22 (16.7)	0.115	75 (30.4)	38 (17.2)	0.006
Occlusive lesion	4 (1.2)	3 (2.3)	0.616	2 (0.8)	5 (2.3)	0.282

Bold values indicate $p < 0.050$