LIMITATIONS OF THE MANUAL PULLBACK IN INTRACORONARY ULTRASOUND IMAGING

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Abstract — **Intravascular ultrasound (IVUS) may provide highly accurate information about the cross-sections of coronary and other vessels. By pulling the transducer back inside of the vessel, a continuous stream of cross-sectional data is obtained. However, the images have to be assigned to actual locations and in their proper orientations to allow reliable analyses. In this paper, we focus on the errors introduced by the catheter pullback, which is still performed mostly manually and unsupervised in clinical routine. However, even in idealized in-vitro studies several effects occur. We could measure a real pullback speed of 1.14±0.34 mm/s where a constant speed of 1 mm was instructed. Absolute orientations and relative twists of the IVUS images were loaded with RMS errors of 24.03° and 5.01°, respectively, between different pullbacks of the same artery. Especially, these errors have to be considered for in-vivo assessments to avoid possible distortions of volumetric and other quantifications.**

Keywords — **Coronary Arteries, Intravascular Ultrasound, 3-D Reconstruction, Catheter Pullback, Biplane Angiography**

I. Introduction

In the assessment of coronary artery disease, intravascular ultrasound has evolved to a complementary method to selective contrast angiography. While accurate information about the plaque location and composition can be obtained [1], a significant lack of current IVUS systems is their inability to produce geometrically correct spatial reconstructions of the vessel. It is still quite common to perform a 3-D reconstruction by stacking up the slices into equidistant frames, neglecting both possible vessel curvature and artifacts in catheter movements during the pullback. The first problem can partially be solved by fusion of the IVUS data with biplane angiography, i.e. reconstructing the catheter path in 3-D, calculating the twisting of the catheter during pullback analytically, and afterwards matching the IVUS frames to their real 3-D locations in the geometrically correct orientations [2].

However, these measurements can only be as accurate as the data they are based on. It is therefore necessary to analyze and minimize the error sources that are introduced in the acquisition step. While the prevailing opinion remains that a constant manual pullback is performable in sufficient accuracy for clinical assessments, others are using automated devices that control and adjust the pullback with respect to ECG and respiratory cycles [3]. This paper focuses on the effects of the manual pullback, neglecting other well-known artifacts like non-uniform rotational distortions caused by the bending of mechanically driven transducers [4], [5], [6].

II. Methods

For the assessment of errors due to the manual pullback, we used two fresh cadaveric pig hearts with markers that were visible in both angiography and IVUS images. These markers provided artificial landmarks for estimating the real pullback speed as well as rotational movements of the catheter.

A. Data Acquisition

1) Preparation and Equipment: Each of the cadaveric pig hearts was supplied with eight wire clips (straightened paper clips of 1 mm in diameter), which were placed between the myocardium and the right coronary artery (Figs. 1, 2). After immersing the heart into a cylindrical container filled with water at body temperature, the RCA was catheterized and pressurized with saline at 100 mmHg. For IVUS imaging, a sheathed mechanically driven IVUS catheter was used (MicroView,™ 2.9 F, 30 MHz; CVIS, Sunnyvale CA, USA). Images were recorded on S-VHS tape with a rate of 30 frames/s. For both hearts, angiograms were acquired with a biplane Philips device in 9" mode and frontal/lateral orientation. Selected images were digitized using a Nicon Coolscan™ in 512 × 512 pixel resolution. All angiograms were rectified for pincushion and sigmoidal distortions using the algorithm presented in [7].

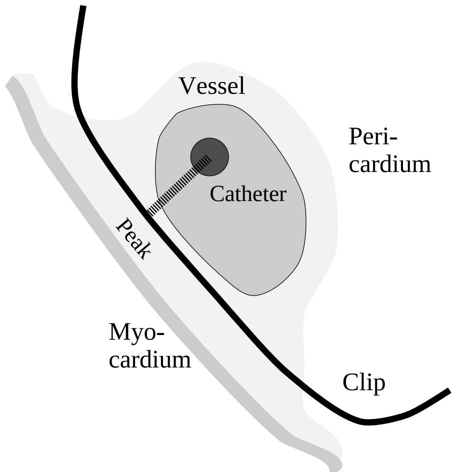

Figure 1: Clip used as an artificial landmark; the clip is inserted straight between the vessel and the myocardium and reflects the ultrasound signal perpendicular to the clip, thus causing a peak in the IVUS image.

2) Imaging Protocol: After preparation of the respective heart, the IVUS catheter was inserted under fluoroscopic control up to the starting point, and the sheath was fixed at the ostium of the coronary artery. The IVUS core was moved to the most distal location within the artery. The IVUS catheter was then manually pulled back three times in each heart by approximately 120 mm, repositioning its tip back to the initial location after each pullback. The pullbacks were performed by a highly experienced operator (S. C. DeJong), who was asked to maintain a constant pullback speed of 1 mm/s. Immediately before the pullback series started, a pair of reference angiograms was taken showing the catheter in its starting position. Aside these reference angiograms, the pullbacks were monitored under single-plane fluoroscopy.

B. Evaluation

1) Pullback Speed: First, the catheter trajectory as well as the clips were geometrically reconstructed from the biplane angiograms using a well-established system (German Heart Institute of Berlin [8], [9]). The calibration of the system was performed using a ball phantom, and the imaging geometry was refined using the catheter tip as well as the end points of the clips as reference. After obtaining the 3-D model, the minimum distances of the clips to the catheter were determined and retained as 3-D vectors. For each of these matches, the time-stamp of the IVUS image containing the respective echo was determined. Since the length of the catheter path between two adjacent clips was known from the 3-D model, the average pullback speed between each pair of clips could then be calculated from their time-stamps.

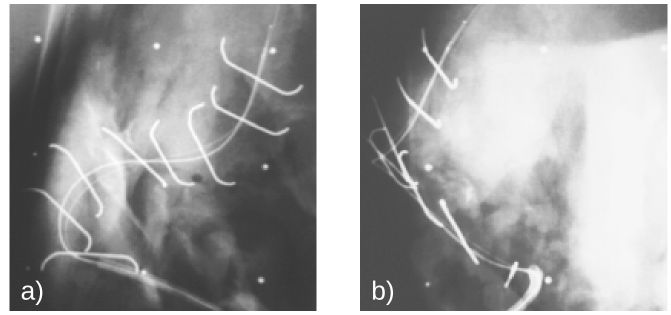

Figure 2: Angiograms of one of the hearts with clips and IVUS catheter; a) frontal view, and b) lateral view.

2) Variability in Rotation: This analysis is based upon the assumption that the movements of the IVUS core within the sheath are reproducible, at least in an idealized system. Thus, if the peak of a single clip appears in a specific sector of the IVUS image, it should always appear in this sector again after movement of the catheter tip to a different location and back. We split this measurement into two tasks. First, the deviation of a peak to the virtual peak of a reference pullback was calculated; second, the relative twist between pairs of adjacent clips was compared to the twist of the reference pullback. The reference pullback was calculated from the mean orientations of the echoes over all three pullbacks. Since all pullbacks should match the reference pullback in an ideal system, the 2-D difference angles were considered as the imaging errors.

3) Multiple Images of the Same Echo: In a separate step, the variations of the echo orientation caused by a specific clip within the same acquisition were analyzed. Those clip echoes were chosen for which their peaks were visible for at least one second. Within each set, the range of variation was determined as the angle of the sector covered by the echo during acquisition.

III. Results

1) Pullback Speed: Despite the fact that a constant pullback speed of 1 mm/s was aimed for, relatively high deviations could be measured (Tab. 1). The local minimum pullback speed over all series was 0.55 mm/s, the maximum was 2.33 mm/s.

2) Variability in Rotation: The absolute orientation within each pullback showed standard deviations of up to 8.82° compared to the reference pullback (Tab. 2). The differences between the pullbacks were much higher; a maximum of 79.4° could be measured between the initial orientations of pullbacks A and B in the first heart (Fig. 3). Additionally, the relative twist was analyzed with respect to the reference pullback (Tab. 3). The moderate standard deviation should not obscure the fact that locally a high twisting error may be introduced; between the first and the second clips in heart #1, the twisting

Pullback		n	*Mean*	$\pm SD$
			(*in* mm/s)	
Heart #1	Pullback A	6	1.02	0.24
	Pullback B	6	1.43	0.25
	Pullback C	7	1.31	0.42
	all Pullbacks	19	1.26	0.36
Heart #2	Pullback A	7	0.84	0.29
	Pullback B	7	1.03	0.25
	Pullback C	7	1.23	0.18
	all Pullbacks	21	1.03	0.29
		40	1.14	0.34

Table 1: Average pullback speed measured in n segments between adjacent clips.

Pullback		n	*Mean*	$\pm SD$
			(*in* °)	
Heart #1	Pullback A	7	−44.11	3.94
	Pullback B	7	+20.89	4.23
	Pullback C	7	+23.22	2.96
	all Pullbacks	21	±0.00	31.43
Heart #2	Pullback A	8	+11.39	8.82
	Pullback B	8	−18.73	3.63
	Pullback C	8	+7.34	5.51
	all Pullbacks	24	±0.00	14.79
		45	±0.00	24.03

Table 2: Deviation of the absolute orientation from the reference pullback at n clips.

Pullback		n	*Mean*	$\pm SD$
			(*in* °)	
Heart #1	Pullback A	6	+1.57	6.62
	Pullback B	6	−0.77	6.82
	Pullback C	6	−0.80	3.61
	all Pullbacks	18	±0.00	5.97
Heart #2	Pullback A	7	+3.52	3.67
	Pullback B	7	−1.40	2.31
	Pullback C	7	−2.12	3.28
	all Pullbacks	21	±0.00	4.02
		39	±0.00	5.01

Table 3: Deviation of relative twist from the reference pullback between n pairs of adjacent clips.

differred by as much as 27.5° between pullbacks A and B (Fig. 3). Please note that since the reference pullback has been derived from the mean orientation over all pullbacks, the total mean error is zero, and the total standard deviation equals the root mean square (RMS) error in both cases. The 8th clip of heart #1 was discarded in this study, because it was visible only in one out of the three pullbacks.

3) Multiple Images of the Same Echo: For 4 out of 46 matches, 3 acquisitions of the same echo within the same pullback, and for further 2 matches, 2 acquisitions have been performed. The mean width of the covered sector was 6.41° (RMS 8.23°), with a maximum width of 15.30°.

IV. Discussion

The high variance in the pullback speed proved that the manual pullback is not acceptable for high-quality assessments such as 3-D reconstructions and volumetric quantifications. On the other hand, these artifacts are avoidable with moderate effort, e.g. by using a motorized pullback device. The problem of ECG and respiratory gating occur in either case. The variances in the orientation of the peaks indicate that the orientation of an image can be determined only with some uncertainty. Especially, the initial orientation at pullback start is completely arbitrary and has to be identified according to landmarks or other references. However, the manual pullback may introduce further artificial axial rotation of the images if the catheter core is twisted against the sheath, which can easily happen, especially when the catheter is reinserted. While an automated pullback may suppress these errors sufficiently, the entire system still remains sensitive to changes of the catheter path, e.g. if the catheter or the imaging machine are slightly moved during pullback. Since the automated pullback avoids the need of manual intervention at pullback time, these errors may be minimized as well.

V. Conclusion

We could show that the manual pullback, as it is still commonly performed in clinical routine, is not feasible to allow proper data acquisition for simple localization tasks as well as for complex quantitative analyses. Thus, we recommend the use of an automated pullback device with ECG gated data acquisition, and a fixation of the entire catheter path from the device to the patient. In combination with biplane angiography, the real locations of the IVUS frames as well as the spatial orientations of plaque fragments can be determined with high accuracy, providing optimum results for clinical analyses.

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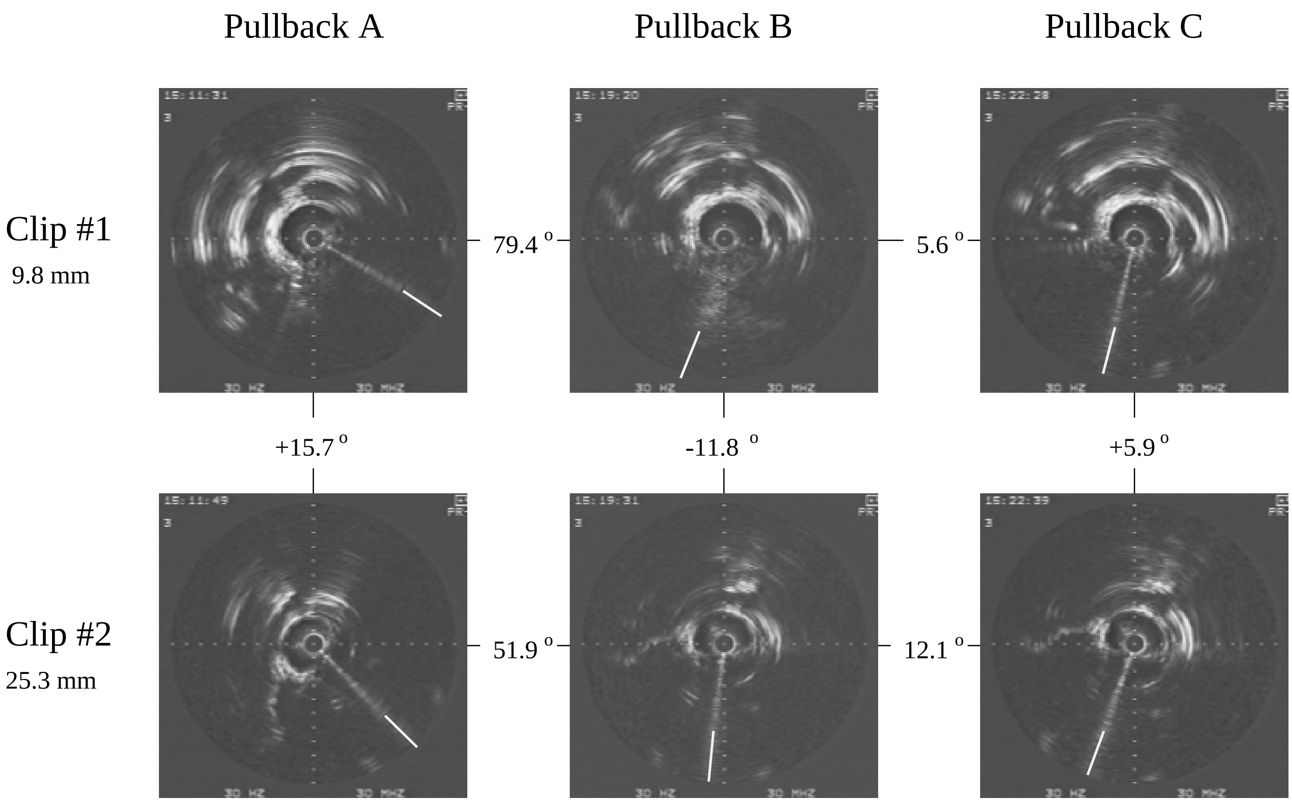

Figure 3: Variances between the first two clips of heart #1 with distances from pullback start indicated (echoes marked in outer sections by bright lines); from left to right, the pairwise difference angles between the pullbacks are shown; in vertical direction, the relative twists between the clip echoes are given.

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