Patient Specific Optimal Catheter Selection for the Left Coronary Artery

Sami ur Rahman[1], Stefan Wesarg[1], and Wolfram Völker[2]

[1] Interactive Graphics Systems Group, Fraunhoferstr. 5, 64283, Darmstadt, Germany
{srahman,stefan.wesarg}@gris.tu-darmstadt.de
[2] Universitaetsklinikum Würzburg, Oberduerrbacher Str.6 / Haus A1, 97080, Würzburg
Voelker_W@medizin.uni-wuerzburg.de

Abstract. During coronary artery angiography, a catheter is used to inject a contrast dye into the coronary arteries. Due to the anatomical variation of the aorta and the coronary arteries in different humans, one common catheter cannot be used for all patients. The cardiologists test different catheters for a patient and select the best one according to the patient's anatomy. To overcome these problems, we propose a computer-aided catheter selection procedure. In this paper we present our approach for patient specific optimal catheter selection for the angiography of the left coronary artery (LCA). It involves segmentation of the aorta and coronary arteries, finding the centerline and computing some geometric parameters. These parameters include curve angle of the LCA, LCA contralateral wall curve length, and the aorta cavity length. We then consider catheters for the LCA and compute the angles and lengths of the two curves as well as the distance between these curves. We suggest a catheter that is the closest one with respect to the patient's arteries geometry. This solution avoids testing of many catheters during catheterization. The cardiologist already gets a recommendation about the optimal catheter for the patient prior to the intervention.

1 Introduction

Coronary angiography is an examination of the blood vessels of the heart. It is performed to investigate the presence of any obstruction in the coronary arteries. Due to the anatomical variation of the aorta and coronary arteries in different humans, one common catheter cannot be used for all patients. The cardiologists test different catheters for a patient and select the best one according to the patient's anatomy. This procedure is time consuming and there is a slight chance of cancer from excessive exposure to radiation. It is also possible that a catheter -not matching the internal anatomy- punctures the artery and causes internal bleeding. It will be more helpful for the cardiologists to know in advance the optimal catheter before they actually start angiography. Literature related to optimal catheter selection discusses the general concepts about the shape of the aorta and coronary arteries and suggestions about suitable

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Lecture Notes in Informatics, Band P192
ISBN 978-3-88579-286-4

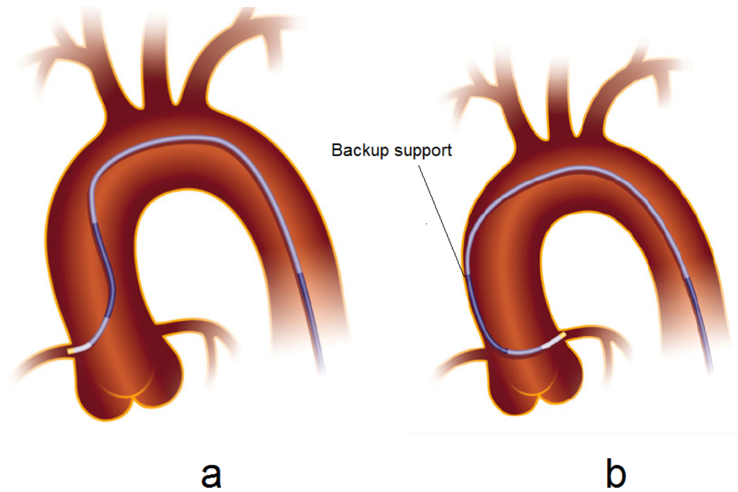

Fig. 1. Catheter placed along the centerline in Right Coronary Artery (a), Back-up support at the contralateral wall in Left Coronary Artery (b)

catheters, but it lacks discussion about patient specific catheter selection. For example Schneider [1] and Kirks [2] discuss the very general cases and the recommended catheters. Kimbiris [3] focuses on the anomalous aortic origin of the coronary arteries. Brinkman [4] published results of a study about the variability of human coronary artery geometry. A general discussion about the guiding catheter selection for the right coronary artery angioplasty is given by Myler [5] and for the left coronary artery by Voda [6]. In some other studies, results related to best catheter selection after testing a series of catheters are given. Sarkar et al. [7] have tested 79 catheters on 24 patients which represents an average of three catheters per patient. We have done some preliminary work dealing with catheter recommendation based on patient specific image data [8]. There, we have discussed how an optimal catheter can be selected for the Right Coronary Artery (RCA). For this, we exploited the clinical confirmation that a catheter placed along the aortic and coronary artery centerline is an optimal one in case of a normal RCA (Fig. 1 (a)). In case of the LCA this assumption is not valid. For stable catheter position in LCA, it is important that it should have a co-axial position and a back-up support at the contralateral wall (Fig. 1 (b)). In this work we present a method for computing the suitability of catheters used for left coronary angiography for specific patient anatomy. To the best of our knowledge no one has suggested catheter selection procedure for LCA based on patient specific image data so far.

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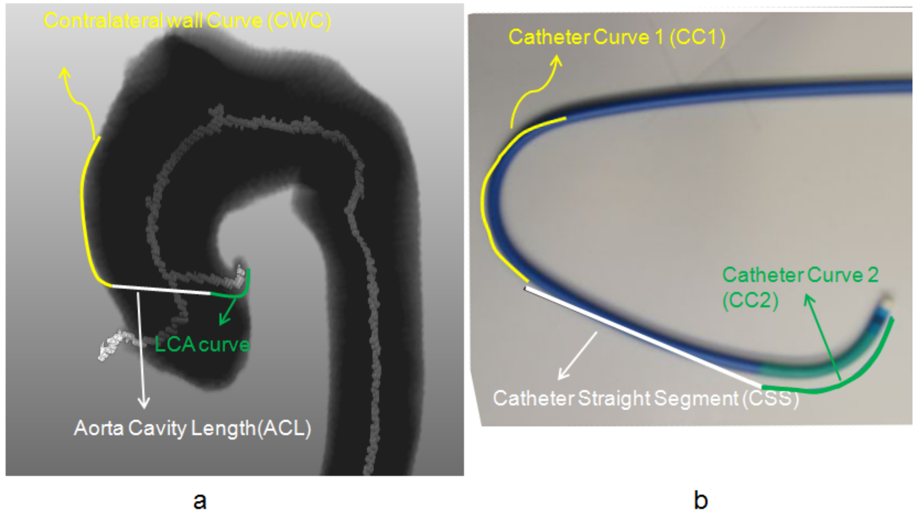

Fig. 2. Parameters for the arteries (a), parameters for the catheters (b)

2 Method

We developed a procedure where the cardiologist gets a recommendation about the optimal catheter for the LCA prior to the intervention. We consider the two conditions (co-axial position and back-up support) for optimal catheter in case of normal LCA. The prerequisites for our approach are the segmented images of the aorta and coronary arteries as well as information about the geometry of the catheters. Although there is a large number of catheters used for LCA angiography we have restricted ourselves to the commonly used catheters that provide back-up support for the normal LCA. In this work we are considering back-up support from the contralateral wall of the LCA. Our method can be described as follows. We consider the angle and length of the two curves of catheters (green and yellow curves in Fig. 2 (b)). We call the yellow curve *Catheter's Curve 1* (CC1) and the green curve *Catheter' Curve 2* (CC2). CC1L is the *length of CC1*. CC2A is the *angle of CC2*. The distance between CC1 and CC2 (white segment in Fig. 2 (b)) is referred to as the *Catheter's Straight Segment Length* (CSSL). From patient image data (Fig. 2 (a)) we consider the following parameters:

- The yellow curve is the *Contralateral Wall Curve* (CWC).
- The green curve as *LCA curve* (LCAC).
- The *length of CWC* (CWCL).
- The *angle of LCAC* (LCACA)
- The *distance between CWC and LCAC* (white line in Fig. 2 (a)) is referred as the Aorta Cavity Length (ACL).

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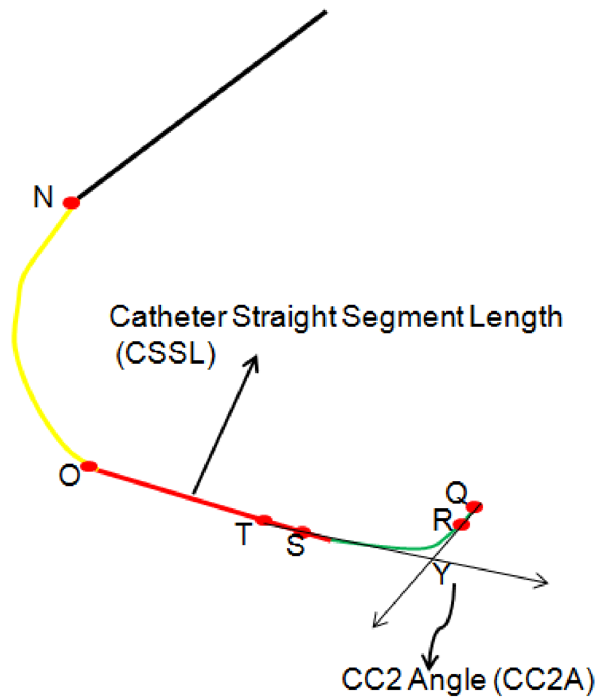

Fig. 3. Catheter's parameters computation

2.1 Catheter's curves computation

Computing curve angles and lengths of catheters is straight forward. We take photos of the catheters and extract the centerline of the catheters. We then consider the two curves (yellow and green curves in Fig. 3). The yellow curve provides back-up support at the contralateral wall of the aorta. The distance from point N to O is considered as CC1 Length (CC1L). Catheter's Curve 2 Angle (CC2A) is computed using points Q, Y and T. This angle has to be matched with the LCACA. The Catheter Straight Segment Length (CSSL) is the length between the points O and S. This length will be matched to the ACL.

2.2 Arteries curves computation from the patient's image data

Curves computation of the LCA is more difficult and is done as follows. We need to segment aorta and LCA, get the centerline, find the LCACA,CWCL and ACL. We have described our automatic segmentation technique in [9]. However, the algorithm for optimal catheter computation is independent from segmentation schemes and any segmentation scheme that extracts the aorta and the coronary arteries can be used. In Fig. 4 (a) the segmented arteries and the centerline are shown. During left coronary angiography the catheter follows the centerline

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Lecture Notes in Informatics, Band P192
ISBN 978-3-88579-286-4
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inside the descending aorta and the aortic curve. It then follows the tangent path at the maximum curvature point of the aortic curve, hits the contralateral wall, moves along the contralateral wall and then bends towards the LCA. In Fig. 4 (b) the green line shows such a path. Although the catheter may sometimes deviate from this path, we will show below that it will not have significant effect on our overall results.

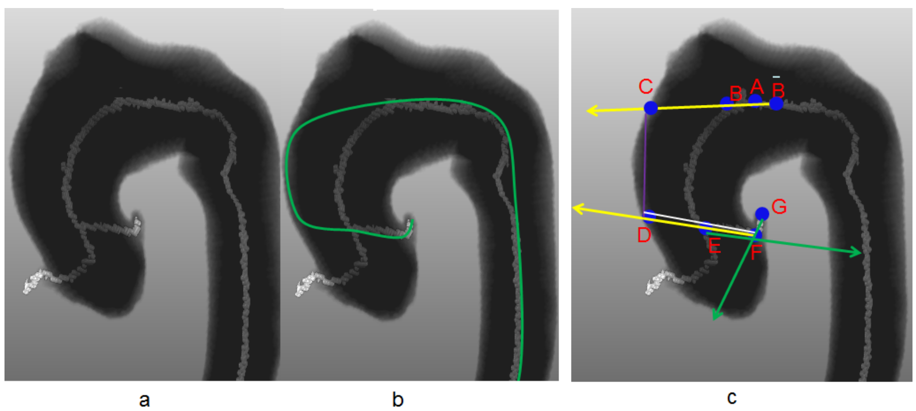

Fig. 4. Arteries parameters computation

In Fig. 4 (c) the different points are shown that are used for the curves computation of the arteries. Point A is the point where the aortic curve has maximum curvature. Points B and $\bar{B}$ are the adjacent points of A on the centerline. The catheter is supported by the contralateral wall in the area between point C and D. Point C can be computed using the tangent line at point A. This tangent line can be estimated by a line that passes through points B and $\bar{B}$. The tangent line is extended until it touches the contralateral wall. This point is marked as point C. Point D can be computed in the same way using points E and F. Point E is the branching point in the centerline. Point F is the position of the LCA ostium and G is the tip of the LCA. The method to find points E and G are explained in our paper [8] and the ostium position in our paper [9].

CWCL: The CWCL is taken as the distance between point C and D in Fig. 4 (c). This length shows the area where the catheter is touching the contralateral wall and gets back-up support.

LCACA: The LCACA is computed using the two green lines (Fig. 4 (c)). First we compute the intersection point F of these two lines and then the angle between points E, F and G.

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ISBN 978-3-88579-286-4

ACL: The most important parameter is the ACL, i.e. the length between the LCA branching point F and the point D. This length is compared with the CSSL. We want to emphasize that all these computations are done automatically.

2.3 Optimal Catheter Selection

After computing parameters for all the catheters and for the given patient's image data, our next step is to define a quantitative measure for the optimal catheter selection. We propose the following cost function. The optimal catheter is given as the minimum of all the costs CC_i computed for all considered catheters i.

$$OC = \arg\min_i \{CC_i\} \tag{1}$$

where i is the i^{th} catheter and

$$\begin{aligned} CC_i = &\{W1 * ((CSSL)_i - ACL)\} + \\ &\{W2 * ((CC2A)_i - LCACA)\} + \\ &\{W3 * ((CC1A)_i - CWCA)\} \end{aligned} \tag{2}$$

$W1$, $W2$ and $W3$ are weights assigned to each term of the formula. The strongest criteria for the catheter selection is the best matching of CSSL and ACL and $W1$ is a weight coefficient for this term. The best match of this parameter will guarantee that the catheter has a suitable CSSL for the given patient's ACL. Therefore, highest weight should be given to $W1$. The next important criteria for the optimal catheter selection is the difference between CC2A and LCACA. $W2$ is a weight coefficient for this term and it gets next highest value. The weight coefficient for the difference between CC1L and CWCL is $W3$ and this term represent the back-up support. Back-up support is important but before looking at this it should be assured that the catheter has already reached the LCA at the correct angle. Therefore we give the smallest weight to $W3$. In our result section we present experiments for finding optimal values for $W1$, $W2$ and $W3$.

3 Results

Although there is a large number of catheters available in the market, for left coronary angiography we have restricted our experiments to eleven different catheters in our initial experiments. Most of them are used by our clinical partner. We have used MRI data of eight different patients. The data is provided by our clinical partner. Using a Fast Marching Method for segmentation, followed by skeletonization of aorta and LCA [8, 9] we have built patient specific aorta models. We have computed the ACL, LCACA and CWCL. All these points are computed automatically. We use the formula given in Eq. 2 to find the optimal catheter.

Proper selection of values for $W1$, $W2$ and $W3$ is important for the optimal catheter selection. In our experiments (Table 1) we have used different values for

ISBN 978-3-88579-286-4

Table 1. Comparing the suggested optimal catheters using different weights of $W1, W2, W3$ in Eq. 2

S.No	W1	W2	W3	No. of patients with suitable CSSL
1	.3	.3	.3	2/8
2	0.4	0.3	0.3	3/8
3	0.6	0.3	0.1	4/8
4	0.7	0.2	0.1	4/8
5	0.8	0.15	0.05	6/8
6	0.85	0.1	0.05	8/8

$W1, W2$ and $W3$. We started by assigning equal weights to all coefficients and found that in the suggested optimal catheters, only two out of eight patients had appropriate CSSL. We then changed the weights and assigned higher weight to W1 ($W1 = 0.4$, $W2 = 0.3$, $W3 = 0.3$). These values improved result for one further patient. Using $W1 = 0.6$, $W2 = 0.3$, $W3 = 0.1$, we found that four out of eight suggested optimal catheters had also optimal CSSL. Changing the values to $W1 = 0.7$, $W2 = 0.2$, $W3 = 0.1$ didn't change the result for CSSL. Increasing $W1$ to 0.80 and $W2 = 0.15$, $W3 = 0.05$ gave results where six out of eight patients had optimal CSSL. For $W1 = 0.85$, $W2 = 0.10$, $W3 = 0.05$ we found that all optimal catheters had also optimal CSSL.

Since we have not found similar work, we cannot compare our results with other approaches. However, the results have been judged by an experienced cardiologist. In Fig. 5 results of top three optimal catheters are shown for two patients. The rest of the patients have similar results.

4 Discussion and Conclusion

Knowing which one is the best catheter prior to coronary angiography significantly reduces the exposure time to radiation. An optimal catheter selection dramatically reduces the risk of artery punctures and internal bleeding. In this paper we have proposed a method for selecting the optimal catheter for the left coronary angiography. This work along with our previous work [8] provides a solution for arteries with normal take off. To the best of our knowledge no similar work has been published and we are the first to introduce a method for selecting a catheter which provides co-axial position and maximum back-up. We have considered three parameters (LCACA, ACL, CWCL) from the patient's image data that should be checked against the three parameters (CC1L, SSL and CC2A) of the catheters. We have formulated our suggested solution as a minimization of a cost function. The cost for each catheter is computed by finding the difference between the values of these parameters. We select a catheter with a minimum cost value being the closest one to the patient's arteries geometry. This solution

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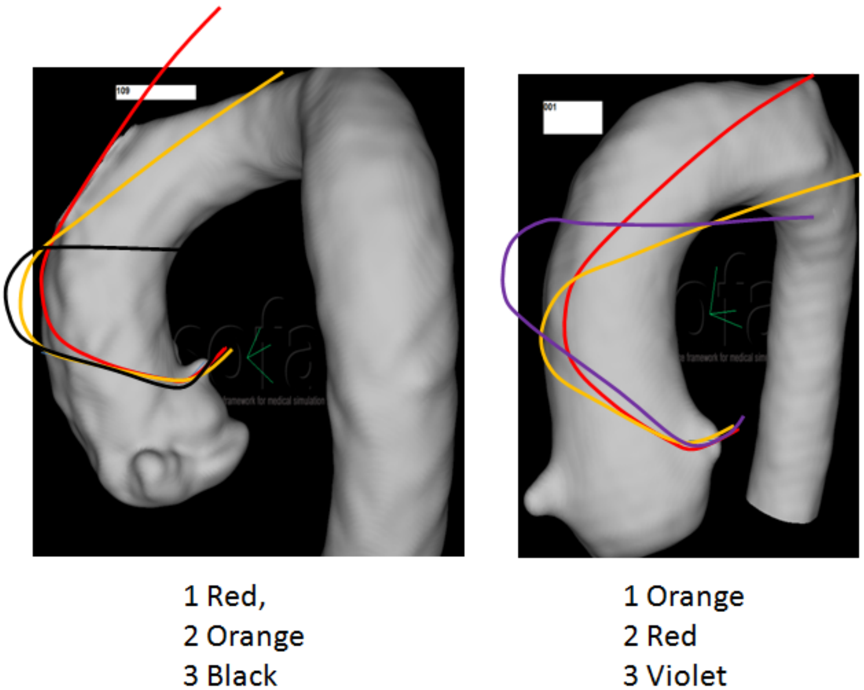

Fig. 5. Suggested optimal catheters ranking

avoids testing of many catheters during catheterization. The cardiologist already gets a recommendation about the optimal catheter for the patient prior to the intervention. It takes less than a minute to compute the optimal catheter.
Clinical evaluation of the method is in progress. In our future work we will focus on the cases where the coronary arteries have abnormal take-off. We will also focus on cases where the aorta itself is not normal. If there are lesions in the aorta we have to modify the technique for curve computation. In our current work we are considering only the 2D centerline, but aorta and coronary arteries diameter also play a role in the best catheter selection. There are also 3D catheters which are interesting for future work. We also have to look at the deformable nature of catheters and have to investigate the variability of catheter positioning inside the patient's arteries. Our ultimate goal is to select the optimal catheter for right as well as left coronary artery even for anomalous cases.

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