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OPTIMAL CATHETER SELECTION FOR ANOMALOUS RIGHT CORONARY ARTERIES (RCA)

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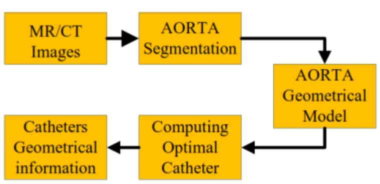
Graphical abstract



Abstract

Coronary artery angiography is a procedure in which a catheter is used to inject a contrast dye into the coronary arteries. However, in different humans a common catheter cannot be used due to the anatomical variation of the aorta and coronary arteries. Therefore, a cardiologist has to test different catheters on a patient and selects the one that best suits the patient. The whole process is time consuming and there is minor possibility of cancer due to the extreme exploitation to rays. To overcome the mentioned problems, we propose a computer-aided catheter selection procedure. In this paper, we present novel approach for patient specific optimal catheter selection for the angiography of the coronary arteries with high take off (anomalous RCA). It involves segmentation of the aorta and coronary arteries, nding the centerline and computing some important geometric parameters. These parameters include computing coronary arteries curve angle (CACA), distance of the Ostium from the aortic valves (DOAV) and the aorta diameter (AD) near the Ostium. Afterwards tip angle of the catheter (CTA), catheter curve two depth (CC2D) and catheter curve two width (CC2W) are computed. Finally, we compare CACA with CTA, DOAV with CC2D, AD with CC2W and suggest a catheter that is the closest to the patients arteries geometry. This solution avoids testing of many catheters during catheterization.

Keywords: Angiography; aortic geometry; insight segmentation and registration toolkit; optimal catheter; right coronary artery; patient specific angiography.

1.0 INTRODUCTION

Aorta is the longest artery in human; it starts from the left ventricle of the heart and extending down to the abdomen. The aorta distributes oxygenated blood to all parts of the body. During angiography generally, the aorta is used to push the catheter inside the human body. There is anatomical difference in all humans, so a single catheter cannot be used for all patients.

After examining the different kind of catheters, the cardiologists used the best catheter for a specific person. The experiment results in three catheters per patient. There are approximately 300 types of catheters available in market [1]. Therefore it is hard for cardiologists to decide which one will be best for the specific patients. Sarkar *et al.* [2] test 79 catheters on 24 patients to search the optimum catheter for patients. This process is time consuming, risky and can result in other diseases like cancer [3].

Our work will suggest a computer-aided catheter selection procedure. Which basically will take the input of two Magnetic Resonance Image (MRI) provided by the clinical partner. This work will take MR Images and apply image processing techniques, i.e. noise removal, image sharpening, object recognition, segmentation [3]. These images will be then ready to compute specific parameters, which will then compare by the catheters.

The article is organized as follows: Section II describes a detailed literature review and state of the art approaches; Section III describes the requirements and methods; experimental results are described in Section IV, while future work and conclusions are provided in Section V and Section VI.

2.0 BACKGROUND AND RELATED WORK

While doing the search on such special cases of handling the aorta Campeau proposed [4] the trans-radial method of caricaturization using the radial artery from the wrist approach to the heart and coronary arteries. This approach is becoming the alternative approach for angiography. He took some initial steps and did trans-radial attempts for catheterization. This patient friendly method was refined by Kiemeneij and Laarman [5] and [6].

Kim [7] discusses about the novel catheter (5F Tiger-II), which is specially manufactured for engaging left and right arteries from the right trans-radial artery approach. They randomized the 160 patients among the standard Judkins and the 5F Tiger II catheters. The Tiger II was associated with a significantly shorter 40% total procedure time and 33% less fluoroscopic time for angiography. There was not a considerable variation between the Tiger II and Judkins catheters for left coronary angiography. For the right coronary angiography, 100% were done with the Tiger II and 95% with the Judkins catheters. There were no medical complications in any group, so the procedural success rate was 100%.

Schneider [8] and Kirks [9] recommends the catheters after evaluating certain general cases, Kimbiris [10] focuses on the anomalous aortic origin of the coronary arteries. Brinkman [11] published results of a study about the variability of human coronary artery geometry.

Metz *et al.* [12] proposed the Evaluation of Four versus Five French Catheters for Trans-femoral Coronary Angiography. He analysed the technical characteristics, quality of angiography and medical assessment of the puncture site for 100 randomly selected patients.

Brown *et al.* [13] proposed use of five French Catheters for Cardiac Catheterization and Coronary Angiography. Many centers tried using the five French catheters and mentioned that: "The smaller arterial puncture site may decrease both recovery time and the number of complications". The post-catheterization recovery time was reduced by one hour from routine of eight hours. He concludes that five French catheters are ideal for most heart catheterization and are now used regularly in casual cardiac catheterization.

3.0 PROPOSED SOLUTION

In this paper, we have discussed high take off approach for patient specific optimal catheter selection for the angiography of the coronary arteries. It involves segmentation of the aorta and coronary arteries, finding the centerline and computingsome geometric parameters. These parameters include computing coronary arteries curve angle (CACA), Distance of the Ostium from the Aortic Valves (DOAV) and the aorta diameter (AD) near the Ostium as in Fig.1. Considering catheters we have computed the tip angle of the catheter (CTA), catheter curve two depth (CC2D) and catheter curve two width (CC2W) as depicted in Fig.2. A comparison mechanism was then formed comparing CACA with CTA, DOAV with CC2D and AD with CC2W. Afterwards catheter closes to the patient's arteries geometry was suggested. 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. Interlocking is a safety critical hence it requires advanced formal modeling techniques and step by step.

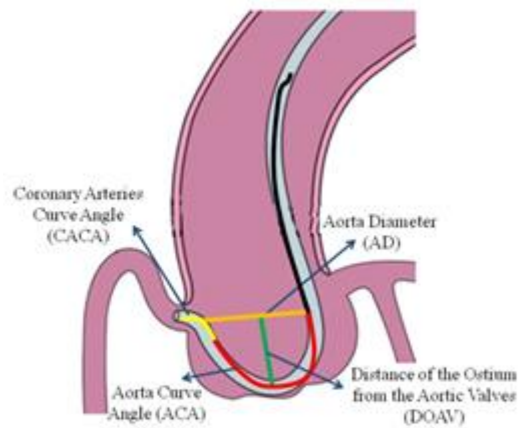


Figure 1 Presenting basic parameters of aorta

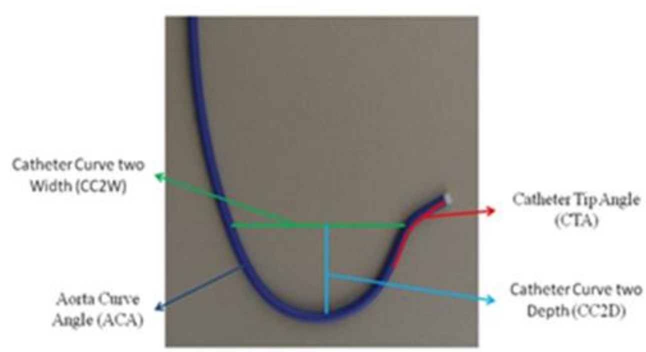


Figure 2 Presenting basic parameters of cathete

3.1 Formal Statistic Model

There are four points (dots on the yellow curve line A, B, C and D in Fig.3) starting and ending points are already known by computing RCA curve using the concept given in [14]. Tangent line is calculated by using the known RCA curve. Mathematically, to draw a straight-line minimum two points are required, so considering the first two blue dots in aorta (point A and B) and draw a straight line towards the bottom (line AE in Fig.3). Then considering the next two points (point D and C) and draws a line in the direction of the LCA (line DF in Fig.3). These lines intersect each other at the point P. Now it is easy to calculate required RCA angle by three points (∠ DPE).

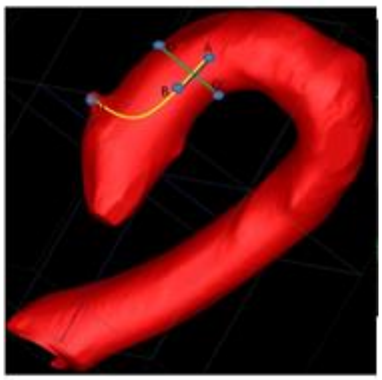


Figure 3 Calculating the coronary arteries curve angle

3.2 Distance of the Ostium from the Aortic Valves (DOAV)

The coronary arteries take off depends on the distance between the Ostium (branching point) and the aortic valves. There are three types of origins for coronary arteries (Table 1).

Table 1 Take off's of the coronary arteries

Sr. No.	Take off Types	Distance from aortic valves
1	Normal Take off	1 – 1.5 cm
2	High Take off	> 1.5 cm
3	Low Take off	< 1.5 cm

Further, this paper will provide all the necessary information for both take offs i.e. for high take off and for low take off (abnormal origin of RCA) and selection of the optimal catheter for arteries with high take off as in high take off, catheter gets back-up from the aortic valves Fig.3.

An abnormal takeoff needs a different kind of information. The first one is the angle of the RCA; this is the angle from the end of an aorta to the start of RCA. This can be seen more clearly in Fig.3, a green curve line. Yellow line is the RCA curve. To calculate the DOAV, a line is drawn using two points A and B towards the aortic valves. Then computing the last non-zero pixel on the line, line EA (Fig.3). DOAV calculated using the distance formula for the line PE. Here P is the intersection of the line AE and line DF.

3.3 Aorta Diameter (AD)

Aorta diameter is an important parameter for optimal catheter selection. The idea is, calculate the slope of the line AB (black line in Fig.4).

Figure 4 Calculating the slope of aorta

By using two points, point A and point B, slope of line AB can be calculated by using following slope formula;

$$m = \frac{x - x'}{y - y'} \qquad (1)$$

where (x, y) are the coordinates of point A and (x', y') coordinates are of point B. Our focus was to calculate the perpendicular of line AB. Mathematically perpendicular line has following relation with slope;

$$m = -{}^{1}/_{m'} \qquad (2)$$

Here m is the slope of the line AB and m' is the slope of perpendicular line OO' (Fig.4). By using slope of line OO' (perpendicular to line AB) following conditions has to be satisfied;

$$x - x' = m'(y - y') \qquad (3)$$

Basically the requirement is to search a perpendicular line on point A. Slope m' will be the slope of line OO' and point A's coordinates will become $(x\ y)$. Two times, two finite loops calculate the non-zero location in binary image. One is for point O and another for point O'.

3.4 Calculating the Radius of the RCA

For this purpose, there is the ITK gradient image filter to get the gradient images Fig.5 (b). Calculation was done by taking start form point B in Fig.6 (c) or point B in Fig.5 (b).

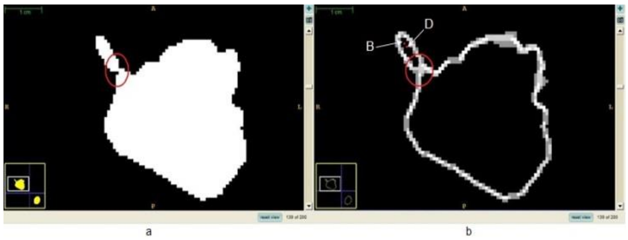


Figure 5 Given aorta on axial plan (a), gradient on axial plan (b)

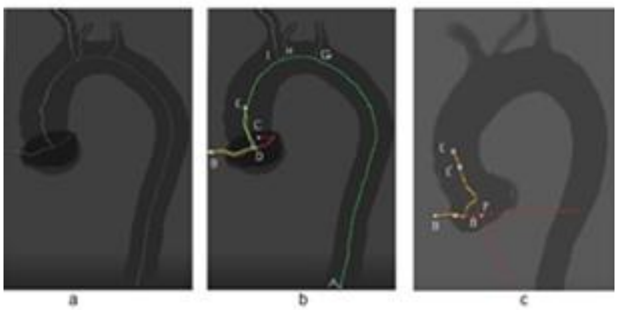


Figure 6 Segmenting and extracting the center line of aorta (a), calculating the thin line from point a to b, line from point b to c and finally from point b to e (b), calculating the angle of rca (c)[1]

For every point of centerline image (center of gradient or binary image) algorithm is calculating the line of equation, using the second next pixel. Let's say a point D is the second next pixel of point B. Then equation (1) can give the slope (m) of the small line;

$$x - x' = m' / (y - y') \quad (4)$$

In equation (4) (x, y) is the location of point B and (x', y') location is of point D (Fig.5, b). Basically nearest pixel is needed, but if nearest pixel is found then possibility of wrong selection is high. For correct pixel, slope of perpendicular line of point B is needed. Mathematically if two lines are perpendicular to each other, then relation between slopes can be defined as;

$$m = 1 / m' \quad (5)$$

Here m' is the slope of perpendicular line. Now any pixel location (x', y'), which will satisfy the following equation, will be the nearest and perpendicular to that specific pixel;

$$pointB\ (x) - x' = 1/m'\ pointB(y) - y' \quad (6)$$

$$m' pointB\ (x) - x' - pointB(y) + y' = 0 \quad (7)$$

By using equation (6) or equation (7), form point B to point B'; all distances calculated pixel by pixel from yellow line of Fig. 6(C) till gradient line of Fig.5(b). The minimum distance is the radius of the RCA. In equation (6) or equation (7), pointB(x) is x-coordinates of pointB and pointB(y) is y-coordinates of point B location.

By using above strategies, final data was ready to represent the angle approximation in Fig.7. Above all methods are explained according to the aorta, but in Fig.7 every parameter is shown from the catheter perspective. CACA approximation can be seen in Fig.7(a), DOAV and AD are in Fig.7(b).

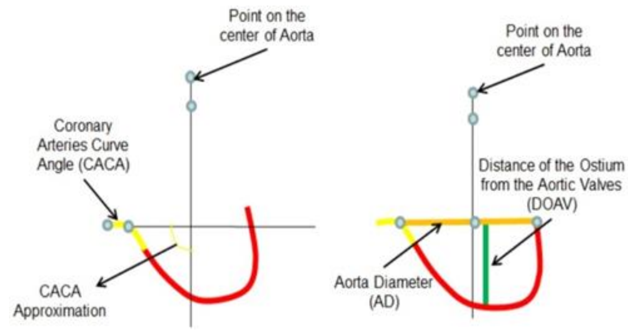


Figure 7 Pictorial representations of CACA (a), DOAV And AD (b)

3.5 Best Catheter Selection

After calculating all necessary parameters from the given patient's data; it's time to select and determine the optimal catheter. We follow the same cost function as Rahman [3] did. With adding the thickness of RCA (RRCA); i.e the diameter of RCA, Right Coronary artery curve angle (RCACA), Distance of the Ostium from the Aortic Valves (DOAV) and Aorta Curve angle (ACA). Calculated catheter will be the exact (ideally) as the geometry of patient's aorta and RCA. Best catheter is given as the minimum of all the costs BC*i* computed for all the considered catheters i as calculated in equation (8);

$$BC = minPCi \quad (8)$$

Here *i* is the nth catheter;

$$PCi = A + B \quad (9)$$

$$A = 0.4 * ans\left((CRCAC)i - RCACA\right) + 0.3 * abs\ ((CCA)i - ACA) \quad (10)$$

$$B = 0.2 * ans\left((CDOAV)i - DOAV\right) + 0.1 * abs\ ((TCT)i - RRCA) \quad (11)$$

Strongest criteria for the catheter selection is CRCAC & RCACA and CCA & ACA. Therefore, we gave the strongest selection criteria to CRCAC & RCACA; we gave forty percent for this difference which will ensure the RCA angle. Second highest criteria is CCA & ACA; we gave thirty percent for this difference (in equation (10)) which will ensure the internal geometry of aorta. Furthermore, we gave twenty and ten percent to DOAV & CDOAV and TCT & RRCA (see equation (11)). The selected catheter will be the optimum catheter for the patient.

4.0 EXPERIMENTAL RESULTS

The images of all patients had resolution of 200x200x200.

4.1 Patient One

DOAV of a patient one (from U to U') is approximately 13 mm (green thick line). CACA is approximately 90° (red curve in Fig.8 (A)) and radius of RCA of this patient is measured as 1.75 mm.

RU'R' is obliged Aorta Curve Angle (ACA) (green curve). But an approximation of this angle is done by taking 2RU'U (red curve). This half ACA is 57° so ACA is 114° and width is computes as 43 mm from R to R' (Fig.8 (B)).

Computing AD was a basic errand. The problem in this task was the orientation of the aorta. As shown in Fig.8 (C) (green line) the normal aorta diameter (AD) is 30 mm. To take care of this issue, computing the orientation of the aorta by taking point B, this point is five pixels away from point A (Fig.8 (C) red line). This orientation calculates the slope of the line AB and gives the orientation (slope) of the aorta. Using this slope information, the AD is approximately 28 mm.

In Fig.8 (C) red thin line is showing the error in calculation and green thick line showing exact diameter of an aorta.

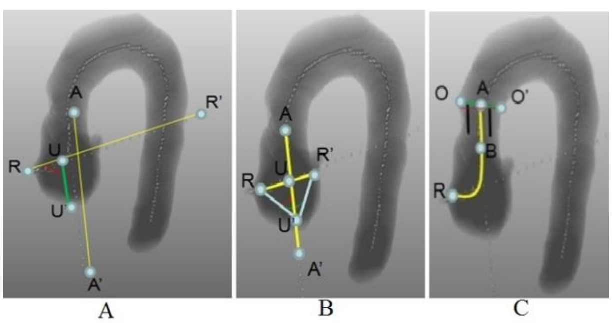


Figure 8 Calculating The DOAV And CACA Of patient one (a), calculating The ACHA Of the patient one (b), calculating The ACHA of the patient one (C)

4.2 Patient Two

DOAV of patient (from U to U') is approximately 17 mm (green thick line). CACA is approximately 105° (red line in Fig.9 (A)) and radius of RCA is measured as 1.11 mm.

RU'R' is obliged Aorta Curve Angle (ACA) (green curve). This angle is approximated by taking 2RU'U (red curve). This half ACA is approximately 54°, therefore ACA is approximately 108° (Fig.9 (B) B green curve) and catheter width from R to R' is calculated as 35 mm.

In Fig.9 (C) the normal aorta diameter (AD) is 34 mm. But, after calculating the orientation of the aorta and calculating the slope of the line AB this diameter is now approximately 28 mm. Red thin line is showing the error in calculation and green thick line showing the actual diameter of aorta.

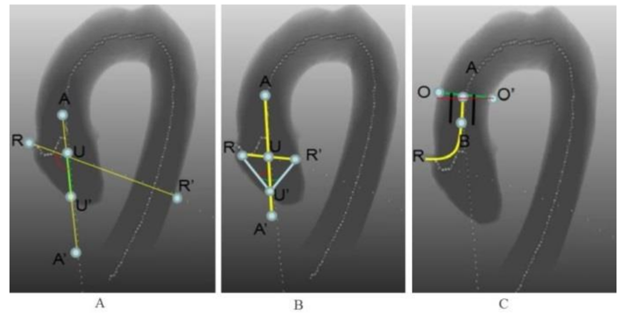


Figure 9 Calculating The DOAV And CACA Of patient two (A), calculating The ACHA of the patient two (B), calculating The ACHA Of The patient two (C).

4.3 Patient Three

DOAV of this patient (from U to U') is approximately 11 mm (green thick line). CACA is approximately 101° (red line in Fig.10 (A)) and radius of RCA of patient is measured as 0.79 mm.

RU'R' is required Aorta Curve Angle (ACA) (green curve). This angle is approximated by taking 2RU'U (red curve). This half ACA is approximately 48°, therefore ACA is approximately 96° and catheter width from R to R' is calculated as 39 mm (Fig.10 (B)).

The normal aorta diameter (AD) is 35 mm. But after calculating the orientation of the aorta by calculating the slope of the line AB this diameter is now approximately 32 mm. In addition to that red thin line is showing the error in calculation and green thick line showing exact AD (Fig.10 (C)).

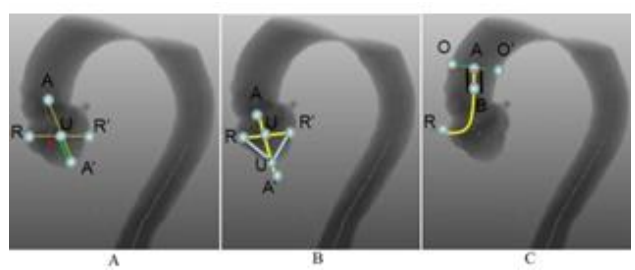


Figure 10 Calculating The DOAV And CACA Of patient three (A), calculating the ACHA Of the patient three (B), calculating The ACHA Of The patient three (C)

5.0 FUTURE WORK

The work can be extended to cases where the RCA has an anterior origin (as in Fig.11). The cases where the aorta itself is not normal can be investigated. According to Mr Wang [15] the most common reason for sudden death is the anomalous origin of coronary arteries. If there are lesions in the aorta, then the existing techniques will need some modification. In this work only 2-D centerline considered, but aorta and coronary arteries diameter also play an important role in the selection of best catheter. There are also 3-D catheters, which are interesting for future work. The deformable nature of catheters can be considered and the investigation of the variability of catheter positioning inside the patient's arteries will be interesting.

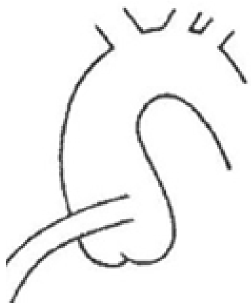


Figure 11 Anterior origin of right coronary artery

6.0 CONCLUSION

Solution for the high takeooff of RCA along with some basic necessary parameters calculation is presented. This work introduced some basic parameters and their calculations, which can identify the origin of RCA. These parameters are calculated by the aorta root calculation. The result of this work will help in the selection of catheter.

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