# A Method for Computer-Assisted 3D Reconstruction of Coronary Arteries Using Angiography Images (Scientific Report)

# Bilgisayar Destekli Bir Metod Yardımıyla Anjiyografi Görüntülerini Kullanarak Koroner Arterlerin 3 Boyutlu Görüntülenmesi (Bilimsel Rapor)

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**ABSTRACT** In this paper, we present a simple method for the 3D reconstruction and visualization of coronary arteries in angiography. We developed an algorithm to manually select vessel borders around the stenotic region. We select twenty cross sections around problematic region. Cross section points are used for 3D reconstruction. In 3D, each cross section defines a circle with a diameter of the length of the cross section and origin at the midpoint of two cross section corners. Relative information about a vessel diameter can be known from circle diameters around corresponding region. Therefore, obtained circles are used for visualizing the change in vessel diameter along the selected part of the vessel. Creating tubular structure by joining these circles in 3D was realized by a Matlab program. Created tubular structure represents the final 3D reconstruction of blood vessel. We applied selection and 3D visualization procedure for two images which belong before and after percutaneous coronary intervention. As shown in the result, the coronary artery was successfully reconstructed in 3D from angiography images.

**Key Words:** Coronary stenosis; coronary vessels

**ÖZET** Bu çalışmada, anjiyografi görüntülerini kullanarak koroner arterlerin üç boyutlu biçime dönüştürülmesi ve görüntülenmesine yönelik basit bir metod sunmaktayız. Stenoz bölgesindeki damar çeperlerini manuel olarak seçmek için bir algoritma geliştirdik. Problemli bölge etrafında yirmi adet kesit seçtik. Kesitleri oluşturan noktalar üç boyutlu görüntü meydana getirilmesi için kullanıldılar. Oluşturulan her kesit üç boyutta çapı kesit boyu kadar olan, merkezi de kesitin iki köşe noktasının orta kısmına denk gelen bir çembere karşılık gelecektir. Bir damar çapı hakkındaki bilgi göreceli olarak karşı gelen bölge civarındaki çember çaplarından bilinebilir. Böylece elde edilen çemberler kullanılarak seçilen damar kısmı boyunca çap değişiklikleri görsel olarak elde edilebilir. Üç boyutta bu çemberlerin birleşimi ile tüp yapısının oluşturulması bir Matlab yazılımı ile gerçekleştirilmiştir. Oluşturulan tüp yapısı kan damarının, sonuç olarak elde edilen, üç boyutlu temsilidir. Damar çeperi seçilmesi ve damarın üç boyutta görüntülenmesi işlemlerini perkütan koroner girişim öncesi ve sonrasına ait iki görüntü için uyguladık. Sonuçlarda görüldüğü gibi, anjiyografi görüntülerinden yararlanılarak üç boyutlu koroner arter rekonstrüksiyonu başarılı bir şekilde gerçekleştirilmiştir.

**Anahtar Kelimeler:** Koroner arter stenozu; koroner damarlar

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Accurate assessment of coronary artery anatomy is the most important for coronary artery disease. Angiography, some ultrasound, computed tomography (CT) and magnetic resonance imaging (MRI) techniques are used cardiology practice for assessing arterial morphology.[1-6] Coronary angiography is an X-ray examination of the blood vessels. It shows the coronary artery in a two dimensional (2D) way. Although 2D coronary images couldn't give complete information of arteries and lesions, 3D reconstruction should be used. Herein, we report the case of a 65-year-old man who presented with chest pain and who was treated at coronary care unit with the final diagnosis of right coronary artery stenosis detected by conventional coronary angiography. Then we present a simply method for the 3D reconstruction and visualization of coronary arteries in angiography.

## MATERIAL AND METHODS

A 65-year-old man with a past history of myocardial infarction (7 days before), hyperlipidemia and hypertension was admitted for evaluation of his chest pain. His initial blood pressure and heart rate were 130/80 mmHg and 78/min, respectively. Respiratory rate was 16/min. Fourth heart sound was clearly audible. An electrocardiogram (ECG) on admission was poor R-wave progression and T wave negative in the inferior leads (DII, DIII, aVF). The patient was transferred to the coronary care unit and he was treated with nitroglycerin, diltiazem, aspirin, and heparin. The symptoms completely resolved within 45 minute. Transthoracic echocardiography performed mild hypokinesis of the inferior wall, with a calculated ejection fraction of 0.50. Chest X-ray showed no abnormality. Coronary angiography performed on the 2nd day of hospitalization. At the projection of left anterior oblique (LAO) a significant stenosis (80%) in the second segment of the right coronary artery (RCA) was clearly identified (Figure 1a). In the meantime, a bare stent was implanted successfully (Figure 1b). TIMI 3 flow was achieved finally without procedural complications. The patient was discharged 3 days after admission on prescribed aspirin and clopidegrel was suggested for at least 6 months. One month later, he performed an exercise stress test successfully, with no evidence of ischemia.

### 3D RECONSTRUCTION PROCEDURE

Written informed consent was obtained from the subject. This study describes a simple method for the 3D reconstruction of coronary arteries. Two angiograph images [before and after percutaneous coronary intervention (PCI)] which belong to same patient were used in this report (Figure 1a, 1b). We developed an algorithm to manually select vessel borders around the stenotic region. Manual border determination was done under the control of a cardiology expert. We select forty points to determine twenty cross sections (two points for one cross

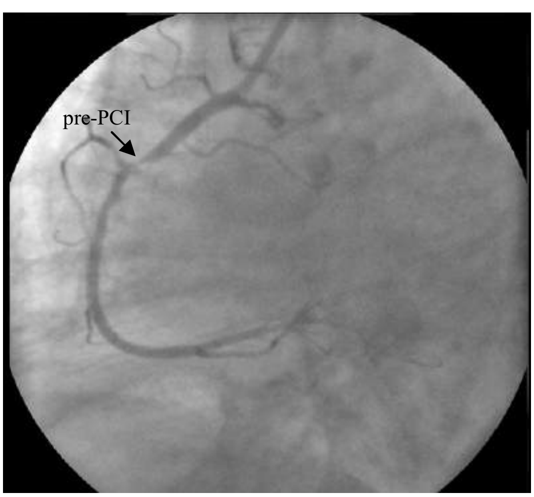


**FIGURE 1A:** Right coronary artery angiographic image of pre-percutaneous coronary intervention (pre-PCI)

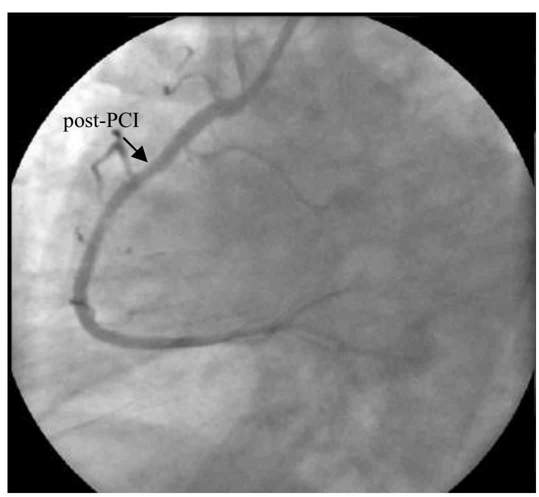


**FIGURE 1B:** Right coronary artery angiographic image of post-percutaneous coronary intervention (post-PCI).

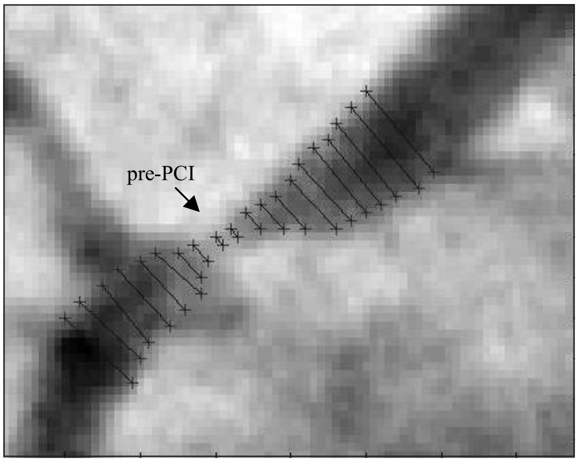


**FIGURE 2A:** Selected cross sections of angiographic image of pre-percutaneous coronary intervention (pre-PCI). For each cross section, two points were used. (Zoomed and cropped for better view)

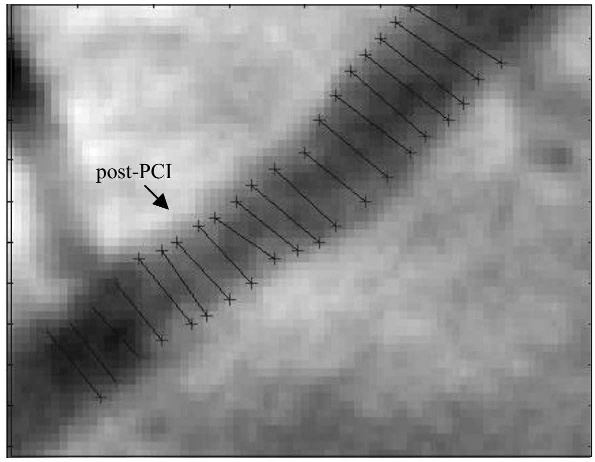


**FIGURE 2B:** Selected cross sections of angiographic image of post-percutaneous coronary intervention (post-PCI). For each cross section, two points were used. (Zoomed and cropped for better view).

section) around problematic region. This part of the process is shown in Figures 2a, 2b.

Selected cross section points give us three types of information: (i) relative position according to first selected cross section, (ii) diameter information of vessel, (iii) direction information of vessel. Middle points of cross sections give us the information for relative position. They are calculated by the formula:

$$YM_n = \frac{(Y_{1n} + Y_{2n})}{2} \qquad (1)$$

Each diameter ($r_n$) is calculated from lengths of cross points by Euclidian distance in two dimensional space,

$$\frac{\sqrt{(X_{1n} - X_{2n})^2 + (Y_{1n} - Y_{2n})^2}}{2} \qquad (2)$$

Direction is slope of the line between two consecutive middle points. It is defined by the formula:

$$d_n = \frac{(YM_n - YM_{n+1})}{(XM_n - XM_{n+1})} \qquad (3)$$

Cross section points are used for 3D reconstruction. In three dimensions, each cross section

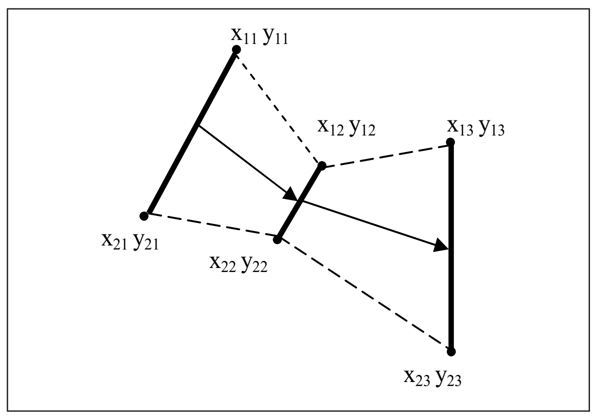


**FIGURE 3A:** Selected points (xmn and ymn) and their corresponding cross sections. Arrows between middle points of two consecutive cross sections state direction of vessel.

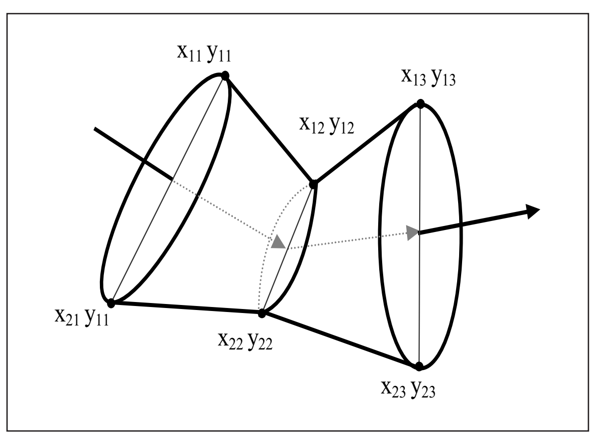


**FIGURE 3B:** 3b. 3D Tubular plotting of (a), the tube is created by circular cross-sections which were created by using the points in (a).

**TABLE 1:** Proposed 3D reconstruction algorithm in Matlab code.

```
IM=imread('vessel.png');
IM=double(IM);
[H W]=size(IM);
imagesc(IM);colormap(gray(256));
q=0;
inp=input('will you select points?=');

if(inp)   % manual point selection
    for i=1:q
        plot(x1(i),y1(i),'r+');
        plot(x2(i),y2(i),'r+');
        line([x1(i) x2(i)],[y1(i) y2(i)]);
    end
    while 1
        hold on;
        [n1X n1Y b]=ginput(1)
        if(b==27)
            break;
        end
        n1X=fix(n1X);
        n1Y=fix(n1Y);
        plot(n1X,n1Y,'r+');
        [n2X n2Y]=ginput(1);
        n2X=fix(n2X);
        n2Y=fix(n2Y);
        plot(n2X,n2Y,'r+');
        line([n1X n2X],[n1Y n2Y]);
        q=q+1
        x1(q)=n1X;
        x2(q)=n2X;
        y1(q)=n1Y;
        y2(q)=n2Y;
        r(q)=sqrt((n2X-n1X)^2+(n2Y-n1Y)^2)/2;
    end
    save crs x1,y1,x2,y2,r,q
end
load crs x1,y1,x2,y2,r,q;
close all;

%% 3D reconstruction
figure;
x=((x1+x2)/2-(x1(1)+x2(1))/2)/10;
y=((y1+y2)/2-(y1(1)+y2(1))/2)/10;
z=linspace(0,0,q);
[X,Y,Z]=tubeplot(x,y,z,r,linspace(0,0,q),20,[0 0 1]);
cmap=[zeros(256,1)+1  zeros(256,1)+0.5 zeros(256,1)+0.3];
surf(X,Y,Z,'FaceColor','flat','FaceLighting','phong'); colormap(cmap);
shading flat; axis equal.
```

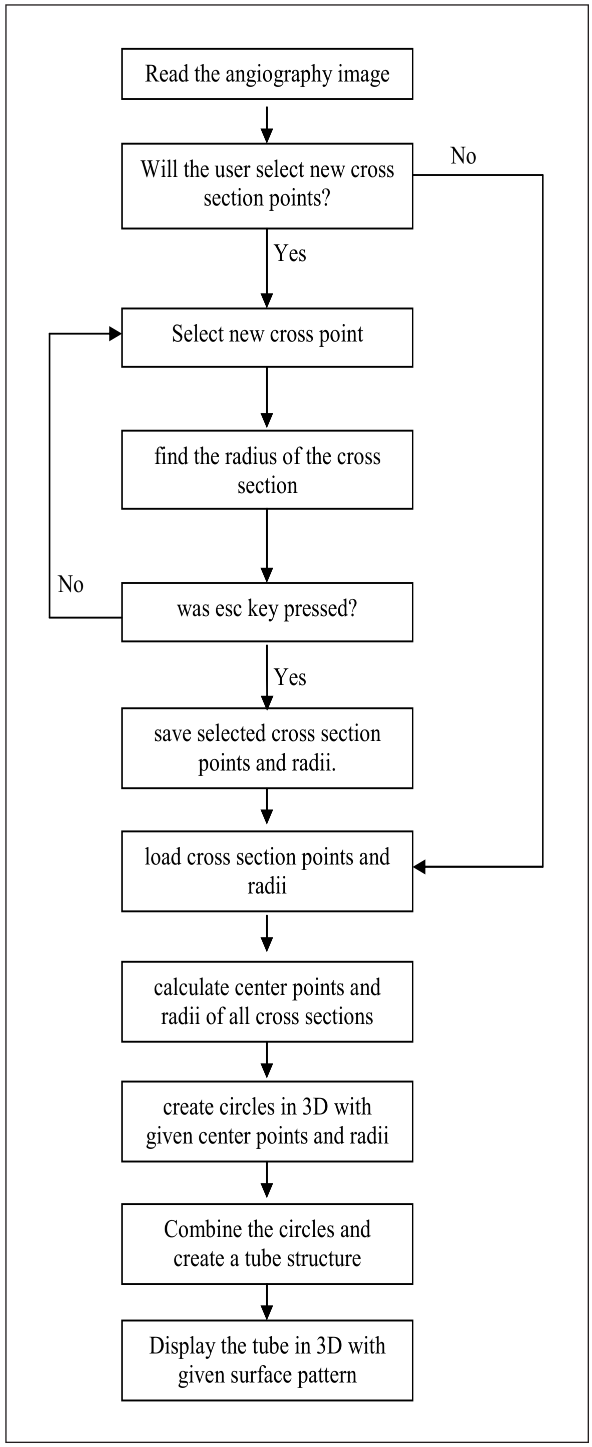


**FIGURE 4:** Block diagram of the proposed algorithm. Algorithm allows the user to select the points by the "mouse clicks" and asks questions to the user at some points, interactively.

defines a circle whom center point is middle point of cross section and radius is half of cross sections length. Joining 3D circles creates a tube. A simple

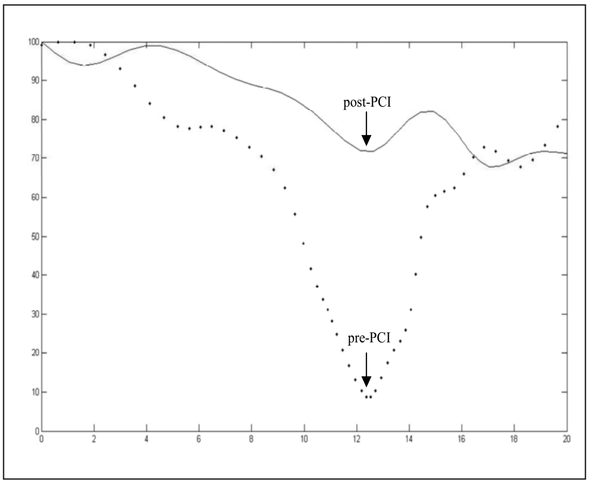


**FIGURE 5:** Relative diameter of pre-PCI (dashed line) and post-PCI (solid line). Here, maximum diameter value of vessel was selected 100 % and other relative diameter values were found by determining the ratios between any diameter and maximum diameter value.

3D plot for this procedure is given in Figure 3a, 3b. This tubular structure represents final 3D reconstruction of blood vessel. Joining circles and creating 3D tube mesh points was done by a freely available Matlab® code.

Our algorithm is given below (Table 1). This algorithm is a computer programme that belong us. It is written and run in Matlab 7.0 ®. It first asks user whether (s)he will select cross section points or use points saved before. In manual selection operation, user can create any number of cross sections till 'esc' key pressed from keyboard. Point positions ('x1' 'y1' 'x2' 'y2' in code) and diameters ('r' in code) are saved to use later. The proposed algorithm was shown as a block diagram in Figure 4.

## RESULTS

Figures 1a and 1b are angiographs of a patient before and after PCI. Narrowing of the artery is stated in Figure 1a under the arrow. Manually selected points and corresponding cross sections for pre-PCI and post-PCI are seen on Figures 2a and 2b. In order to show the result of PCI operation in a two dimensional plot, diameters of selected cross sections were calculated and plotted in the same graph (Figure 5). Diameter information is relative according to maximum diameter value and gives information of length in percentage. So, the values can change between zero and a hundred. Figures 6a and 6b give a look through proximal lumens in order to show the length from inside of vessels. Final result of 3D reconstruction is given in Figures 7a and 7b. 3D object is rotated in order to give a look from distal or proksimal region.

## DISCUSSION

In this study, an algorithm for 3D reconstruction of blood vessels is presented. We decided to determine vessel border manually. Automatic segmen-

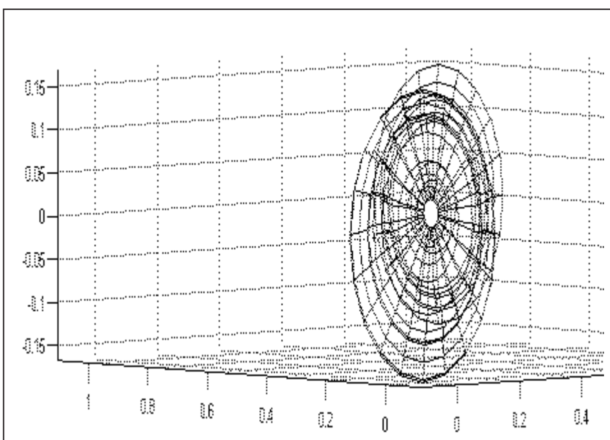

**FIGURE 6A:** View from lumen of right coronary artery before PCI.

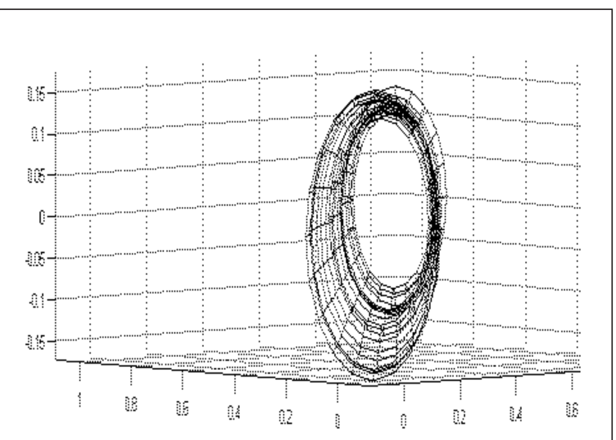

**FIGURE 6B:** View from lumen of right coronary artery after PCI.

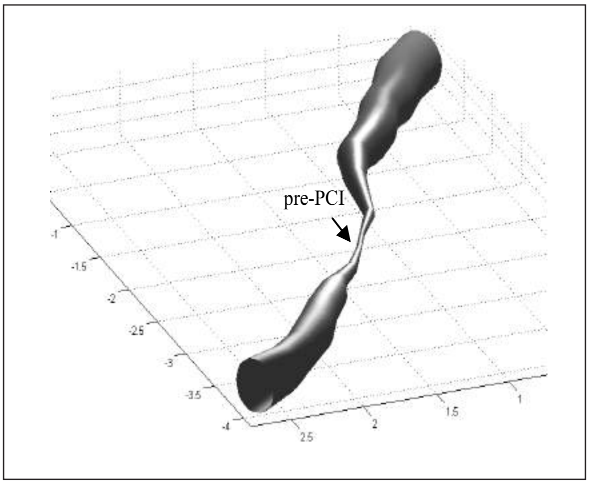


**FIGURE 7A:** 3D reconstruction of pre-percutaneous coronary intervention (pre-PCI)

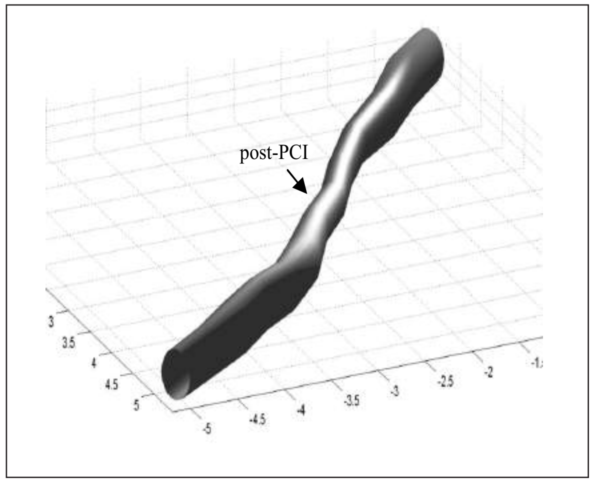


**FIGURE 7B:** 3D reconstruction of post-percutaneous coronary intervention (post-PCI).

tation of vessel is a challenging problem and can give unreliable results due to errors in orientation (angle, translation, etc.) which results in significant artefacts such as streaking and blurring. Therefore, we only want to show the elimination of stenosis visually, it is not a must for us to develop an automatic segmentation algorithm.[7] Also because of being manual, this work may be used as a ground truth for automatic vessel reconstruction algorithm. In this work we assumed that third dimension (depth) is not considerably changing for this part of artery so we used angiographic images which belong to only one perspective (RCA for LAO position). This assumption gives us quite comfort because manual selection of cross sections wouldn't be so convenient if there were more angiographic images. Also using only one perspective made us to assume that vessels cross section is always circular. While these assumptions gave us practicality, result 3D images emphasized the effect of PCI successfully.

In conclusions, the proposed method makes easy to understand technical bases of MRI or multi slice CT analysis as well as enable us to evaluate two dimensional images as three dimensional images. The user can benefit from the method freely and practically. Method increases visual quality especially for educational purposes. Also, the method is important for cardiologists and surgeons because of supplying three-dimensional image of the vessel and the lesion. In order to distribute, it requires a simple installation and short education procedure.

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