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CARDIOVASCULAR IMAGING

ORIGINAL ARTICLE

# Cross-sectional area measurement of the coronary arteries using CT angiography at the level of the bifurcation: is there a relationship?

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**PURPOSE**
Our aim was to determine whether there is a correlation between cross-sectional areas of the left main coronary artery (LMCA), left anterior descending artery (LAD), and circumflex artery (CX) in normal cases using coronary CT angiography.

**METHOD**
Examinations of 180 patients (119 men and 61 women) were selected among 2248 consecutive coronary CT angiography studies. Cross-sectional areas of LMCA, LAD, and CX were measured at the level of bifurcation. Correlation between age, height, and body mass index and coronary artery cross-sectional areas was investigated and possibility of formulating a correlation between the cross-sectional areas of LMCA, LAD, and CX was explored.

**RESULTS**
Mean cross-sectional areas of LMCA, LAD, and CX were found as 17.4±3.9 $mm^2$, 12.5±3.1 $mm^2$, and 10.5±3.0 $mm^2$, respectively. While cross-sectional areas of LMCA and LAD were significantly larger in men, no significant difference was found between the sectional areas of CX in men and women. A multiple regression analysis was conducted to elucidate the relationship between the cross-sectional areas of LMCA LAD, and CX. Our analysis showed that the relationship between LMCA, LAD, and CX cross-sectional areas can be formulated as follows: LMCA=3.870 + 0.718×LAD + 0.434×CX.

**CONCLUSION**
There is a correlation between the cross-sectional areas of LMCA, LAD, and CX at the level of bifurcation, and this correlation can be expressed with a formula.

Coronary artery disease is the leading cause of death worldwide. Thus, coronary artery imaging is one of the most commonly used diagnostic methods. Recently, coronary computed tomography angiography (CCTA) has become another widely used method in coronary artery imaging since it is a noninvasive technique that is easy to perform (1, 2).

One of the major advantages of CCTA is that it allows for the measurement of not only two-dimensional diameters but also cross-sectional areas of the vascular structures. Thus, it is possible to calculate the degree of narrowing caused by atherosclerotic plaques in case of obstruction. It is also possible to predict the symptoms that may arise in a patient in relation to the obstruction and determine the treatment that can be performed using CT angiography.

Atherosclerotic plaques are commonly seen adjacent to vascular bifurcations (3, 4). Left main coronary artery (LMCA) length is variable, and it is shorter in comparison with other main coronary arteries. Therefore, atherosclerotic plaques can occupy the whole vessel in some cases. In such cases, it is difficult to determine the degree of narrowing caused by the plaque since it is not possible to understand the reference artery diameter. Similarly, normal dimensions of the arteries might not be understood in cases of plaque build-up that occupy the long segment starting from the left anterior descending artery (LAD) and circumflex artery (CX) origin. Recently developed multidetector computed tomography (MDCT) technology provides valuable information in terms of understanding three-dimensional anatomy of coronary bifurcation and measuring the angle and vessel cross-sectional area (5, 6). This information is considerably important for the diagnosis and treatment of bifurcation lesions.

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Some studies aimed to elucidate the correlation between the diameters of coronary arteries at bifurcation levels using Murray's law or Finet's formula (7, 8). However, no study aiming to evaluate the relationship between the cross-sectional areas of the coronary arteries at the level of LMCA bifurcation is found to date. In this study, we aimed to investigate whether there is a correlation between LMCA, CX, and LAD cross-sectional areas in normal cases and explore the possibility of explaining the relationship with a formula, which may then be used to estimate the reference cross-sectional area of a stenosed coronary artery when the other two arteries are normal.

## Methods

### Study design

Images of CCTA studies in 2248 cases with suspected or known coronary artery disease performed between January 2008 and December 2014 were retrospectively re-evaluated. The indications of CCTA were chest pain, abnormal electrocardiography (ECG) changes, patients with high-risk for coronary artery disease, follow-up of patients with coronary artery bypass surgery and preoperative coronary artery assessment in patients undergoing cardiac surgery. A total of 2068 cases were excluded for the following reasons: presence of coronary artery origin abnormalities, absence of LMCA, presence of atheromatous changes, coronary artery luminal dilatation due to various reasons, presence of ramus intermedius artery, presence of metal artifacts such as surgical clips or pacemaker leads leading to difficulty in evaluation, altered coronary anatomy due to operation, studies performed without use of nitroglycerine, or inability to follow the coronary artery courses due to motion artifacts. Thus, 180 cases made up the study population (119 men and 61 women; age range, 19–84 years; mean age, 49.1±13.1 years).

**Main points**

- In cases with diffuse atherosclerotic plaques, it may be hard to determine the degree of narrowing due to difficulty in identifying the reference artery diameter.
- Recent multidetector computed tomography technology provides valuable information in terms of measuring vessel cross-sectional area.
- A correlation is available between left main coronary artery and left anterior descending artery and circumflex artery cross-sectional areas at bifurcation level, and this correlation can be formulized.
- It is possible to calculate each of three coronary artery cross-sectional areas with a formula in an overwhelming majority of the cases.

### CT protocol

Approval for this study was obtained from the local institutional review board. All CT examinations were performed using 64-detector or 320-detector scanners (Brilliance-64, Phillips Medical Systems or Aquilion ONE, Toshiba Medical Systems). A bolus of 60–120 mL iodine contrast agent, either iomeprol (Iomeron 400, Bracco) or iohexol (Omnipaque 350, GE Healthcare), followed by 40–50 mL saline solution, was injected into an antecubital vein through an 18G–20G catheter at a flow rate of 5–6 mL/s using an automated power injector (Medrad Envision CT). Contrast agent administration was controlled by a bolus-tracking technique. A circular region of interest was selected in the descending aorta at the level of the tracheal carina, and image acquisition was started 5–6 s after the signal attenuation reached the predefined threshold of 150 or 180 HU. In our department, administration of intravenous beta-blocker drug instead of oral tablet form is preferred prior to the CCTA studies due to its fast onset and clinical feasibility. Thus, a beta-blocker drug (5–20 mg, Beloc ampul 5 mg/mL, AstraZeneca) was given intravenously before the CT angiography if the heart rate was >70 beats per min. In the absence of contraindications, 0.4 mg of sublingual nitroglycerine spray (Nitrolingual pump spray, Farma-Tek) was administered just before scan initiation.

For the 64-detector CT scanner, data were acquired using the retrospective ECG gating with the following parameters: 64×0.625 mm detector collimation, 0.4 s gantry rotation time, pitch of 0.2–0.4 adapted to the heart rate, 120–140 kVp tube voltage, and 600–900 mA tube current. For the 320-detector CT scanner, data were acquired with the prospective ECG gating using the following parameters: 320×0.5 mm detector collimation, 0.35 s gantry rotation time, 100–135 kVp tube voltage, and 400–600 mA tube current. Tube voltage and current were adapted to body mass index (BMI) and thoracic anatomy in all cases. The effective reconstruction slice thickness was 0.9 mm for 64-detector CT scanner and 0.5 mm for 320-detector CT scanner.

### CT image reconstruction and analysis

All examinations were interpreted on a three-dimensional workstation (EBW, Philips Medical Systems) using multiplanar reformatting (MPR) technique. First, presence of atherosclerotic plaque in the coronary arteries was investigated, and no measurement was made in cases with coronary plaque (Fig. 1). Second, presence of ramus intermedius branch that arises from LMCA was investigated, and the cases with ramus intermedius branch were excluded based on the prediction that those cases would cause errors in measurements. Thus, sectional area measurements that the device performed automatically were primarily acquired in axial images created in line with the artery course in 180 cases included in the study. Measurement of cross-sectional areas of each coronary artery is shown on a representative case in Fig. 2. In the event that an error was noticed in automatic measurements, manual corrections were made. Measurements were made from artery segment just before the bifurcation for LMCA, and from artery segment right after the bifurcation for LAD and CX.

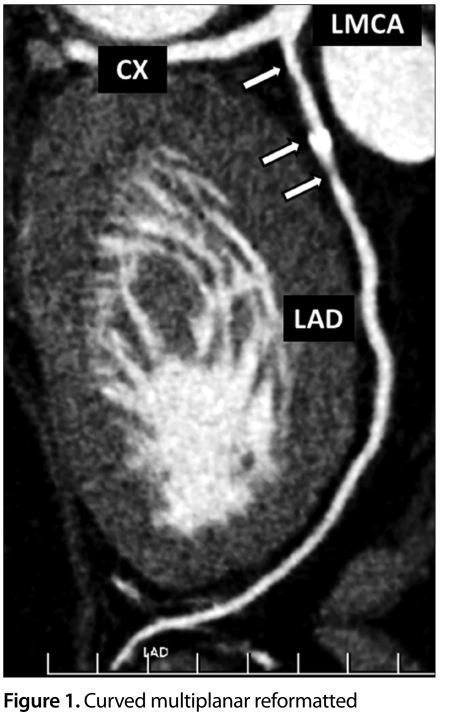



**Figure 1.** Curved multiplanar reformatted coronary CT angiography image shows long-segment atheromatous plaques *(arrows)* in the proximal part of the left anterior descending artery (LAD). In cases with diffuse atheromatous changes in a long segment of a coronary artery, it is difficult to determine the reference vessel dimensions in order to detect the degree of stenosis. Left main coronary artery (LMCA) and circumflex artery (CX) are normal in this case.

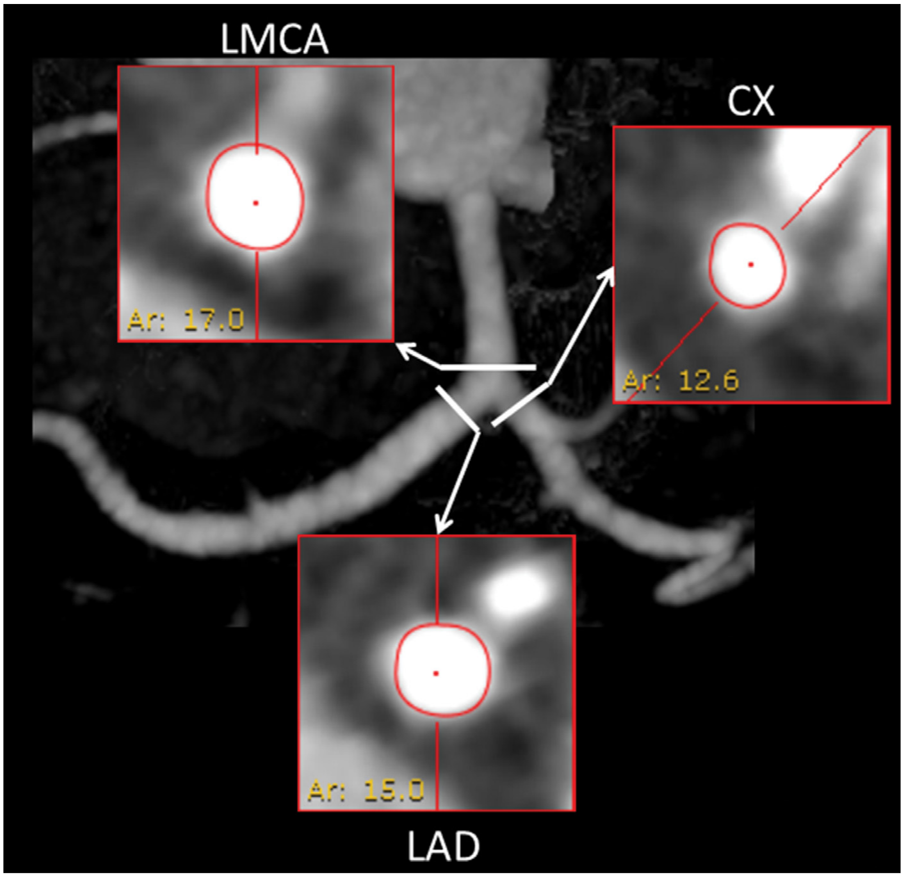



**Figure 2.** Cross-sectional areas of the three coronary arteries at the point of left main coronary artery (LMCA) bifurcation. The cross-sectional area measurements were performed in the plane perpendicular to the long axis of the vessel immediately before and after the bifurcation. CX, circumflex artery; LAD, left anterior descending artery.

**Table. Regression analysis showing the relationship between LMCA, LAD, and CX**

| | b | SEB | β | *P* |
|---|---|---|---|---|
| Constant | 3.870 | 0.714 | | <0.001 |
| LAD | 0.718 | 0.065 | 0.581 | <0.001 |
| CX | 0.434 | 0.068 | 0.336 | <0.001 |

LMCA, left main coronary artery; LAD, left anterior descending artery; CX, circumflex artery; SEB, standard error of B.
Regression formula, LMCA=3.870 + 0.718×LAD + 0.434×CX.

### Statistical analysis

Statistical analyses were made using the SPSS software version 15.0. Normal distribution of the variables was ensured using visual (histograms, probability plots) and analytical methods (Kolmogorov-Simirnov and Shapiro-Wilk's tests). Normally distributed variables were presented using means and standard deviations. Correlation between LMCA, LAD, and CX cross-sectional areas was investigated using Pearson correlation coefficient. Student t test was used to compare LMCA, LAD, and CX cross-sectional areas. Multiple linear regression analysis was used to develop a model to elucidate the relationship between LMCA, LAD, and CX cross-sectional areas. The model fit was assessed using appropriate residual and goodness-of-fit statistics ($R^2$= 0.460, $P$ < 0.001). A series of regression analyses were run to compare the fitness of the model between genders; Fisher's Z test was performed and $R^2$ values were compared. A 5% type-I error was accepted as the level of statistical significance.

## Results

The mean sectional areas of LMCA, LAD, and CX were found as 17.4±3.9 mm², 12.5±3.1 mm², and 10.5±3.0 mm², respectively. In subgroup analysis of genders LMCA, LAD, and CX cross-sectional areas were calculated as 15.9±3.9 mm², 11.2±2.9 mm², 10.0±3.1 mm² in women and 18.1±3.6 mm², 13.1±3.1 mm², 10.7±2.9 mm² in men, respectively. We compared cross-sectional areas of arteries among both genders and found no statistical difference for CX ($P$ = 0.094), while LMCA and LAD cross sectional areas were larger in men ($P$ < 0.001, for both).

No correlation was found between coronary artery cross-sectional areas and patients' age (LMCA, r= -0.114, $P$ = 0.127; LAD, r=0.080, $P$ = 0.283; CX, r= -0.006, $P$ = 0.939). Similarly, there was no significant correlation between cross-sectional areas and BMI (LMCA, r= -0.071, $P$ = 0.346; LAD, r= -0.079, $P$ = 0.294; CX, r= -0.017, $P$ = 0.824). A weak positive correlation was observed between patient height and cross-sectional areas (LMCA, r=0.229, $P$ = 0.002; LAD, r=0.271, $P$ < 0.001; CX, r=0.156, $P$ = 0.037).

There was a strong correlation between LMCA cross-sectional area and LAD and CX cross-sectional areas (r=0.779, $P$ < 0.001 and r= 0.678, $P$ < 0.001, respectively) (Fig. 3). Regression analysis revealed the following formula (Table):

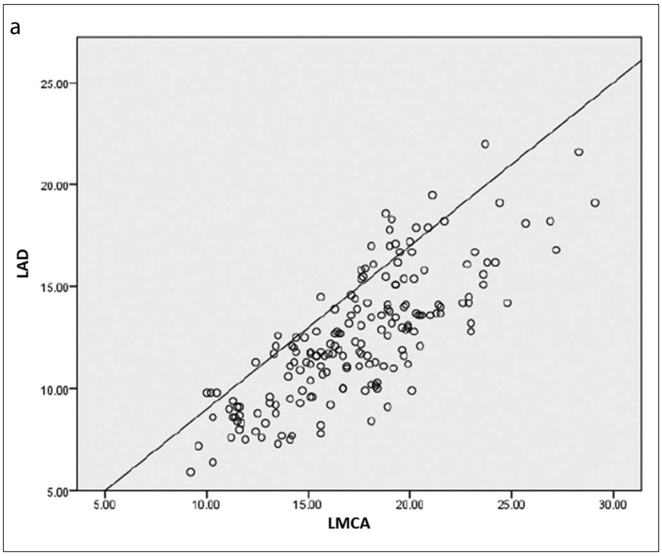
LMCA=3.870 + 0.718×LAD + 0.434×CX

With this formula, we were able to calculate each of three coronary artery cross-sectional areas in an overwhelming majority of the cases. The coefficient of determination of the model was $R^2$=0.706 ($P$ < 0.001) for male patients and $R^2$=0.637 ($P$ < 0.001) for female patients. Comparison of the fitness of the model with Fisher's Z test between genders revealed that there was no significant difference between the respective $R^2$ values, Z= -1.19, $P$ = 0.234. Thus, no difference was observed between men and women in terms of functioning of the formula.

## Discussion

In this study, LMCA, LAD, and CX cross-sectional areas were measured at the bifurcation level and their intercorrelation was investigated. The study revealed a correlation that can be formulated between the cross-sectional areas of these three arteries.

Knowing the dimensions of a coronary artery is crucial for appropriate stent sizing. Either undersizing or oversizing can predispose the patients to a higher rate of in-stent restenosis. Moreover, life-threatening complications may occur in such cases. On the other hand, coronary artery size is related to outcomes after percutaneous coronary intervention, and poorer outcomes are expected in patients with small cross-sectional coronary artery areas (9).



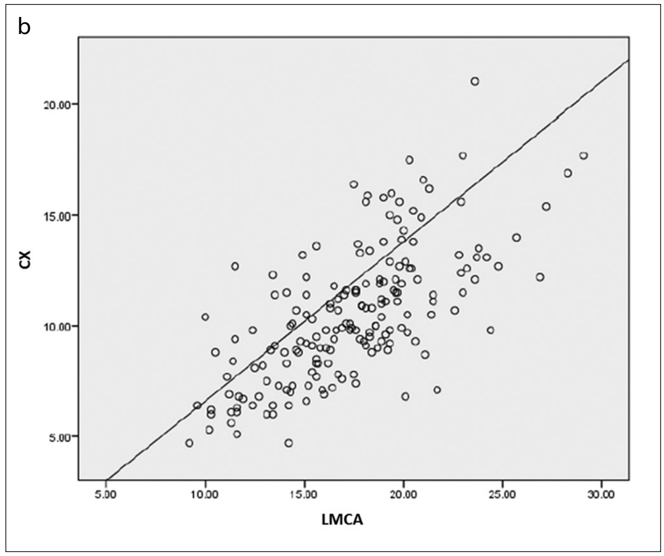




**Figure 3. a, b.** Scatterplot graphs between **(a)** left anterior descending artery (LAD) and left main coronary artery (LMCA) and **(b)** circumflex artery (CX) and LMCA cross-sectional areas reveal strong correlation (r= 0.779 and r=0.678, respectively).

Studies investigating cross-sectional areas of coronary arteries were mainly carried out with the purpose of investigating LMCA. In our study, we found mean LMCA cross-sectional area as 17.4±3.9 mm$^2$. In an MDCT study, Zeina et al. (10) reported distal LMCA sectional area as 14±5 mm$^2$, which is smaller than ours. In their study no preimaging sublingual nitroglycerine was administered to the patients. Nitroglycerine used in our study could cause different degrees of coronary vasodilation, which could explain the difference between these two respective studies. However, Christensen et al. (11) found LMCA cross-sectional area as 12.4±4.4 mm$^2$, which is smaller than both of the aforementioned measurements, even though they used MDCT with sublingual nitroglycerine administration. Similar size difference was also observed for cross-sectional areas of LAD and CX in proximal segments, which were measured as 12.5±3.1 mm$^2$ and 10.5±3.0 mm$^2$ in our study and 8.5±3.5 mm$^2$ and 7.4±3.5 mm$^2$ in Christensen et al. (11), respectively. We believe that this difference might be attributed to patient demographics.

While some studies reporting differences between female and male coronary artery cross-sectional areas are available, studies reporting the opposite are also found in the literature (10, 12, 13). Zeina et al. (10) reported LMCA cross-sectional area as smaller in women compared with men. In a small group of patients made up of 19 men and seven women MacAlpin et al. (12) found no significant difference in normal coronary artery cross-sectional areas between genders. In our study, we found LMCA and LAD cross-sectional areas to be significantly larger in men compared with women ($P < 0.001$), while no significant difference was detected between genders with regard to CX cross-sectional areas ($P = 0.094$).

In our study, no significant correlation was revealed between patient age and coronary artery dimensions, similar to the findings in studies by Hutchins et al. (14) and Zeina et al. (10). Some other studies found a slight increase in coronary arteries with age (15, 16), while one study reported that coronary artery size decreased with age and suggested that it may result from the decreased response to nitroglycerine, i.e., age-related decrease in vasodilation of the arteries (17).

No significant correlation was found between coronary artery cross-sectional area and BMI in our case group, while a positive but weak correlation was found between cross-sectional area and patient height. Leung et al. (17) reported no significant correlation between coronary artery dimensions and weight, height, or body surface area, while Zeina et al. (10) reported significant correlation between LMCA cross-sectional area and height, weight, and body surface area in males only.

In this study, our primary aim was to determine a correlation that could be formulated between LMCA, LAD, and CX dimensions at the level of bifurcation. In fact, geometry of the ideal bifurcation is described by Murray's law, which states that the cube of the radius of a parent vessel equals the sum of the cubes of the radii of the daughters. Both studies using this law at the LMCA branching level reported that it was successful in defining coronary artery diameters (7, 18). However, coronary artery diameters were used in this formula. Currently, coronary artery cross-sectional areas are easily measured with MDCT and potential narrowing degrees can be defined in a more objective manner. Therefore, we formulated the correlation between cross-sectional areas of coronary arteries instead of diameters. In our study, we observed that the formula worked well for both women and men. Although the formula appears somewhat long and complex in its current form, it can be simplified using more cases in future studies.

Our study had some limitations. First, we measured post-vasodilation dimensions instead of the actual dimensions of the coronary arteries, since we included nitroglycerine-administered cases. Nitroglycerine is administered in most intravascular ultrasound and CCTA studies, which are used in coronary artery imaging in addition to catheter angiography. Therefore, our results can be compared with the results obtained via other methods. Although nitroglycerine affects and dilates all normal coronary arteries, theoretically, the ratio between the cross-sectional areas of the coronary arteries should not be changed. Second, we did not compare the accuracy of our measurement results with a different method such as intravascular ultrasound. Third, LMCA cross-sectional area was only measured at the distal segment of the bifurcation level and not at the proximal and middle segments. Fourth, we excluded the cases with ramus intermedius branch, even though they met all the requirements, in order to achieve standardization in the formula that we would create. Future studies may investigate if the formula works in cases with trifurcation instead of bifurcation or identify if there is a correlation that can be defined with a different formula. Finally, nitroglycerine might result in different degrees of dilation in abnormal arteries in comparison with normal arteries. Therefore, the formula that we created might not function properly on arteries with visible focal atheromatous changes.

In conclusion, the recent use of MDCT allows easy measurement of coronary artery cross-sectional areas. LMCA, LAD, and CX cross-sectional areas are correlated at the bifurcation level, and this correlation can be formulated.

## Conflict of interest disclosure

The authors declared no conflicts of interest.

## References


1. Ozturk E, Kantarci M, Durur-Subasi I, et al. How image quality can be improved: our experience with multidetector computed tomography coronary angiography. Clin Imaging 2007; 31:11–17. [CrossRef]
2. Koşar P, Ergun E, Oztürk C, Koşar U. Anatomic variations and anomalies of the coronary arteries: 64-slice CT angiographic appearance. Diagn Interv Radiol 2009; 15:275–283.
3. Rachev A, Stergiopulos N, Meister JJ. Theoretical study of dynamics of arterial wall remodeling in response to changes in blood pressure. J Biomech 1996; 29:635–642. [CrossRef]
4. Kimura BJ, Russo RJ, Bhargava V, McDaniel MB, Peterson KL, DeMaria AN. Atheroma morphology and distribution in proximal left anterior descending coronary artery: in vivo observations. J Am Coll Cardiol 1996; 27:825–831. [CrossRef]
5. Kantarcı M, Doğanay S, Karçaaltıncaba M, et al. Clinical situations in which coronary CT angiography confers superior diagnostic information compared with coronary angiography. Diagn Interv Radiol 2012; 18:261–269.
6. Kawasaki T, Koga H, Serikawa T, et al. The bifurcation study using 64 multislice computed tomography. Catheter Cardiovasc Interv 2009; 73:653–658. [CrossRef]
7. van der Waal EC, Mintz GS, Garcia-Garcia HM, et al. Intravascular ultrasound and 3D angle measurements of coronary bifurcations. Catheter Cardiovasc Interv 2009; 73:910–916. [CrossRef]
8. Schoenenberger AW, Urbanek N, Toggweiler S, et al. Deviation from Murray's law is associated with a higher degree of calcification in coronary bifurcations. Atherosclerosis 2012; 221:124–130. [CrossRef]
9. Saucedo JF, Popma JJ, Kennard ED, et al. Relation of coronary artery size to 1 year clinical events after new device angioplasty of native coronary arteries (A new approach to coronary intervention [NACI] registry report). Am J Cardiol 2000; 85:166–171. [CrossRef]
10. Zeina AR, Rosenschein U, Barmeir E. Dimensions and anatomic variations of left main coronary artery in normal population: multidetector computed tomography assessment. Coron Artery Dis 2007; 18:477–482. [CrossRef]
11. Christensen KN, Harris SR, Froemming AT, et al. Anatomic assessment of the bifurcation of the left main coronary artery using multidetector computed tomography. Surg Radiol Anat 2010; 32:903–909. [CrossRef]
12. MacAlpin RN, Abbasi AS, Grollman JH, Eber L. Human coronary artery size during life. Radiology 1973; 108:567–576. [CrossRef]
13. Dodge JT Jr, Brown BG, Bolson EL, Dodge HT. Lumen diameter of normal human coronary arteries. Influence of age, sex, anatomic variation, and left ventricular hypertrophy or dilation. Circulation 1992; 86:232–246. [CrossRef]
14. Hutchins GM, Bulkley BH, Miner MM, Boitnott JK. Correlation of age and heart weight with tortuosity and caliber of normal human coronary arteries. Am Heart J 1977; 94:196–202. [CrossRef]
15. Ehrlich W, de la Chapelle C, Cohn AE. Anatomical ontogeny of man: A study of the coronary arteries. Am J Anat 1931; 49:241–282. [CrossRef]
16. Neufeld HN, Wagenvoort CA, Edwards JE. Coronary arteries in fetuses, infants, juveniles and young adults. Clin Invest 1962; 11:837–844.
17. Leung WH, Stadius ML, Alderman EL. Determinants of normal coronary artery dimensions in humans. Circulation 1991; 84:2294–2306. [CrossRef]
18. Zhou Y, Kassab GS, Molloi S. On the design of the coronary arterial tree: A generalization of Murray's law. Phys Med Biol 1999; 44:2929–2945. [CrossRef]