SCIENTIFIC BASIS OF a New Hypothesis: Is the Cavitation Phenomenon the Mechanism for Formation of Plaques in Coronary Arteries? Protocol of a New Study.

Thach Nguyen [1,2,3], Thao Dang [3], Truong Thanh Vien [1], Ai Vu[1,], Quoc Bui [1], Thy Dang [1], Advait J. Soni [4,] Hiral Patel [3], Vy NT Le [4], Pham Minh Tri [4], Kim HB Truong [4], Bui Pham Thai Hoa [4], Phuoc Thanh Luong [4], Lê Diệu Anh[3,] Nguyễn Bảo Trân Châu [3] Cát Hoàng Anh[3] Nguyễn Trọng Hoàng [3]Ernest Talarico [4], Gianluca Rigatelli [5], Duane Pinto [6] and Michael Gibson [7].

[1] Cardiovascular Research Department, Methodist Hospital, Merrillville IN

[2] Medical Education Department, St Mary Medical Center, Hobart IN

[3] Tan Tao University, School of Medicine, Long An Vietnam

[4] Anatomy Department, Indiana University Northwest, Gary IN

[5] Endoluminal Interventions, Rovigo Hospital, Rovigo, Italy,

[6] Beth Israel Deaconess Medical Center, Harvard Medical School, Boston MA

[7] Baim Clinical Research Institute, Harvard Medical School, Boston MA

ABSTRACT

In current literature, there is no confirmed mechanism for the formation and growth of atherosclerotic plaques. In reference to each individual person, the entire arterial tree is exposed to atherogenic effects of systemic risk factors and yet only a few arteries develop plaques. These plaques are observed in the coronary arteries in which they are clustered in the proximal segment of the left anterior descending artery (LAD), left circumflex (LCX), and the proximal and segments of the right coronary artery (RCA). Why is there such a pattern of spatial distribution? As seen in fluid dynamics and industrial hydraulics, the damage on the inside surface of pipes is proved to be caused by cavitation or collapse of air bubbles, a natural phenomenon that could also be similarly seen in a pattern of lightness and darkness. Could the cavitation or the ruptures of the bubbles be the mechanism of formation

Correspondence

Thach Nguyen, MD FACC FSCAI
Tan Tao University, School of Medicine
Long An, Vietnam
Email: thach.nguyen@ttu.edu.vn

of cholesterol plaques? In coronary arteries, during diastole with distal negative suctioning, if the pressure in some areas of the coronary vasculature decreases below the vapor pressure of most likely diluted nitrogen, the nitrogen molecules would congregate together and form bubbles. They explode when they are pushed in the area where the coronary pressure recovers above the vapor pressure of nitrogen. These explosions create jet waves breaking the endothelial integrity allowing chemotaxis and infiltration of LDL cholesterol molecules lipid-laden plaques ultimately leading to cholesterol formation (prominently seen in patients with hypercholesterolemia) across the intima triggering atherosclerosis.

Methods: Coronary angiograms with 1 or 2 lesions were selected. The anatomical configuration promoting formation of plaques were classified as the following: **Mechanism** 1: **Long contrast hangover versus short to no contrast hangover** because in the area with long contrast hangover, the speed was low and the dynamic pressure was high, so the bubbles could explode. **Mechanism 2: Large branch versus smaller branch** In the case of LAD and LCX, the larger arteries have less lesion than the smaller arteries because more air bubbles (or empty spaces) were formed in smaller arteries due to preferential flow towards the large arteries. **Mechanism 3: Curved segment versus straight segments** More bubble rupture happened around the curved segments of a bifurcation area. **Mechanism 4: Primary versus secondary flow at bifurcation** In flow at bifurcation, more cavitation happens proximal to a branch with secondary flow (most of the times, it is the sidebranch because of smaller size) than in primary flow (because of the large size of the main branches). The reason is because the preferential flow is usually the primary flow. There are exceptions in which the smaller side branches receive the primary flow because of straight line transition from the main vessel to the side branch even the side branch is smaller. **Mechanism 5: At the apex of a curve with a sidebranch** In this case, two risk factors are affecting the coronary segment: The curvature of the segment and presence of a side branch. **Mechanism 6: In case of smooth proximal and mid segments, no large sidebranch,** the lesion happened in distal segment **Results:** The data of 70 patients were collected.

Conclusion: The mechanism of formation of coronary lesions is most likely due constant injuries from explosion of air bubbles, breaking the endothelial integrity and allowing infiltration of cholesterol molecules in the vasculature.

INTRODUCTION

In current literature, there is no confirmed mechanism for the formation and growth of atherosclerotic plaques. In reference to each individual person, the entire arterial tree is exposed to atherogenic effects of systemic risk factors and yet only a few arteries develop plaques. These plaques are observed in the coronary arteries in which they are clustered in the proximal segment of the left anterior descending artery (LAD), left circumflex (LCX), and the proximal and segments of the right coronary artery (RCA). (1) Why is there such a pattern of spatial distribution? As seen in fluid dynamics and industrial hydraulics, the damage on the inside surface of pipes is proved to be caused by cavitation or collapse of air bubbles, a natural phenomenon that could also be similarly seen in a pattern of lightness and darkness. Could the cavitation or the ruptures of the bubbles be the mechanism of formation of cholesterol plaques? In coronary arteries, during diastole with distal negative suctioning, if the pressure in some areas of the coronary vasculature decreases below the vapor pressure (P) of most likely diluted nitrogen, the nitrogen molecules would congregate together and form bubbles. (Figure 1)

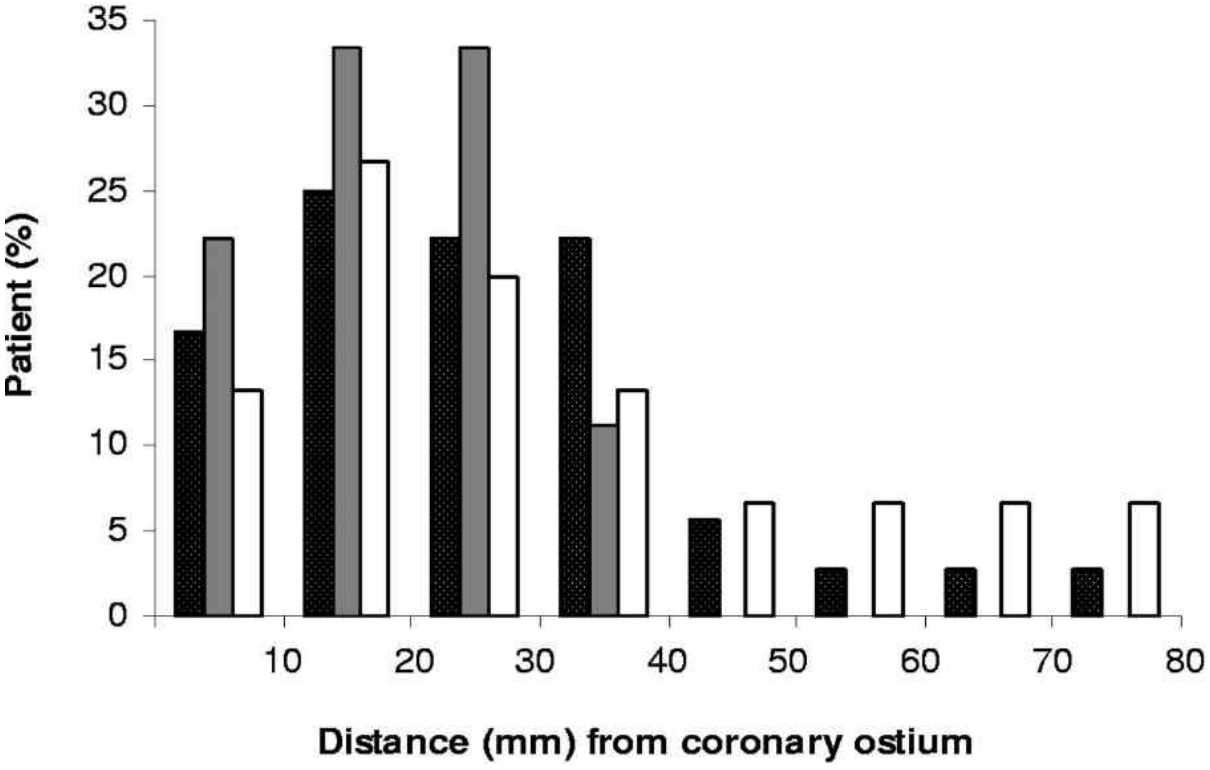

Figure 1. *Distance from the coronary ostium to the lesion: The majority of the lesions stayed in the range of 15mm to 25mm from the ostium*.

Once the plaques are formed, they are covered by a thin cap. What continues to crack these soft caps exposing the cholesterol core below, attracting platelets to form a white thrombus, obstructing the blood flow and causing acute coronary syndrome, critical limb ischemia, transient ischemic attack? (Figure 2) (2) After the acute process subsides, fibrosis occurs, making the cap thicker and the arterial lumen narrower. This is the pathological mechanism of the progression of coronary artery disease.

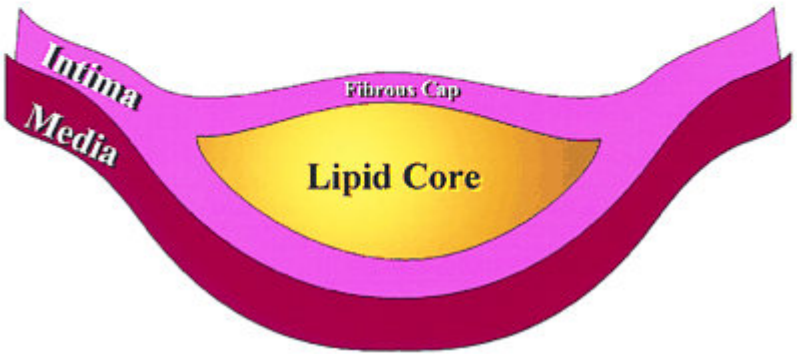

Figure 2. *A cholesterol plaque with a fibrous cap(lipid-laden plaque). This cap can have its thickness increased or decreased according to the pathological situation. (adapted from reference 2)*

In the field of domestic or industrial hydraulics, the damage on the inside surface of pipes is proved to be caused by cavitation or collapse of air bubbles. (3) Could the cavitation phenomenon happen in the human arteries or specifically the coronary arteries? Could the cavitation phenomenon be the first mechanism triggering the cascade of formation of cholesterol plaques? The goal of this study is to explain and confirm the mechanism of formation of cholesterol plaques based on the hydraulic principle of cavitation or air bubble collapse.

BACKGROUND

Basis for a Scientific Rationale **Cavitation in Pipes** In the investigation of damage to the inside surface of domestic or industrial pipes, cavitation or explosion of air bubbles is the confirmed culprit. In flowing liquid, the cavitation phenomenon occurs when the air bubbles are formed as the local dynamic fluid pressure (DP) decreases to a level lower than the vapor pressure (VP) of the gas diluted in the liquid. As the bubbles are carried along the flow, if the DP stays low, these bubbles will grow further in size, become vulnerable and explode.

When these bubbles enter an area with local DP higher than the VP inside the bubbles, they will implode. (Figure 3) (3)

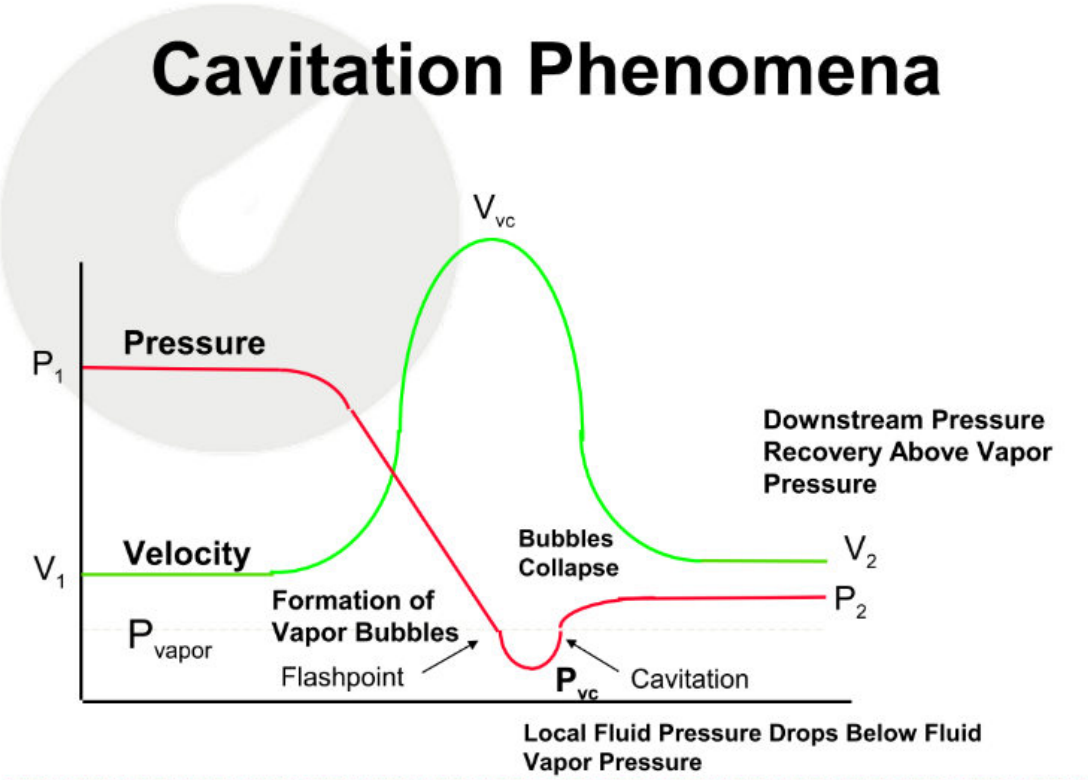

Figure 3. *Cavitation and Bubble Formation.* When the local dynamic pressure from the inlet becomes lower than the vapor pressure in the liquid then the bubbles form. When these bubbles move to an area with local dynamic pressure higher than the vapor pressure then the bubbles will burst.

During these explosions or collapses, as the molecules of the fluid rush in to fill the void, they create small but powerful micro jets or shock waves. (Figure 4) (3) When these shock waves impact against the surfaces of the pipes, or components of the valves inside the pump, the materials of construction of the valves or pipes can be work-hardened and fatigued. As the surfaces become brittle and less resistant to local fracture, they are also subject to erosion with time.

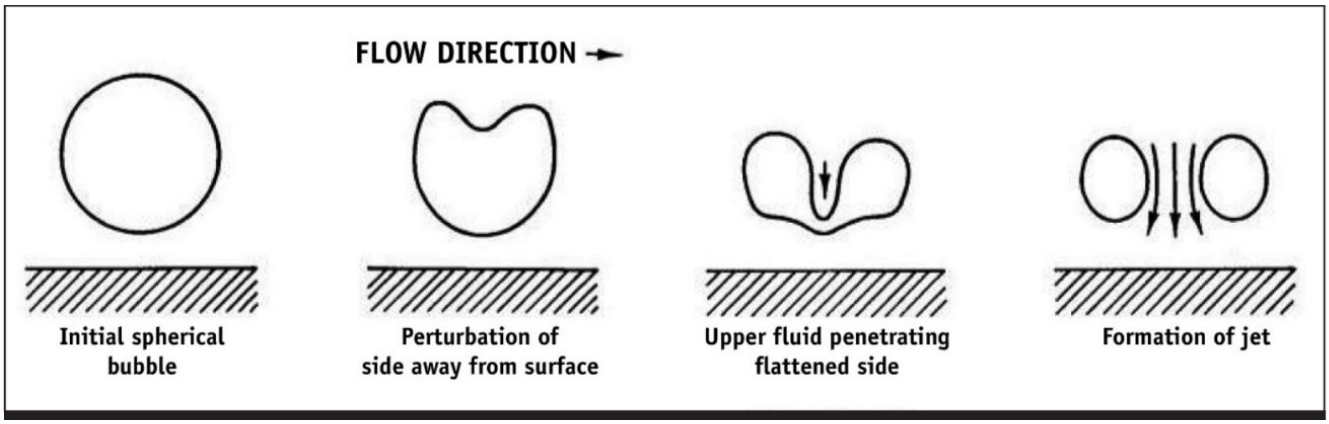

Figure 4. *Bubble Formation and Implosion***.** Formation of a bubble and its burst creating micro-jets (Adapted from reference 3)

Evidence of Cavitation in the Coronary Arteries In the process of injury and formation of cholesterol plaques, is there a possibility that the cavitation phenomenon happens in the aorta, coronary and peripheral arteries? The presence of different areas of LOW and HIGH dynamics pressure along the inside surfaces of these arteries are suspected to be the sources triggering the birth, sustaining the growth and hastening the explosions of the air bubbles. Because the time to form cholesterol plaques in human arteries is very long (50, 60 years or more), it is very difficult to document or to image the formation of bubbles and their collapse. The shortest time for formation of cholesterol plaques is >10 years seen in children with hereditary hypercholesterolemia. (4)

One of the ways to indirectly prove the cavitation phenomenon on the formation of atherosclerotic plaques is to match the locations of HIGH dynamic pressure and low VP in the coronary arteries with the presence of mild to moderate cholesterol plaques. In this methodology, many lesions need to be excluded and are listed in table 1.

Table 1. Lesions Excluded in this Study

1. Very severe lesion: Once the lesion becomes too severe, it could obstruct the flow and change its dynamic pressure.
2. Acute total occlusion due to acute myocardial infarction because the total occlusion does not represent the level of most severe luminal stenosis. Acute myocardial infarction was proved to be caused by non-severe coronary lesion. (5)

3. Chronic total occlusion: In chronic total occlusion, the severity of the lesion prior to occlusion could not verified.

Coronary Hemodynamic Predisposing to Cavitation As a fluid is flowing in pipes, the dynamic pressure changes according to the geometry, the speed and the gradient between the pressure of the inlet and the outlet. In laminar flow, the liquid flows in symmetrical layers with the velocity faster at the central layers and slower in the peripheral layers. (Figure 5) (6)

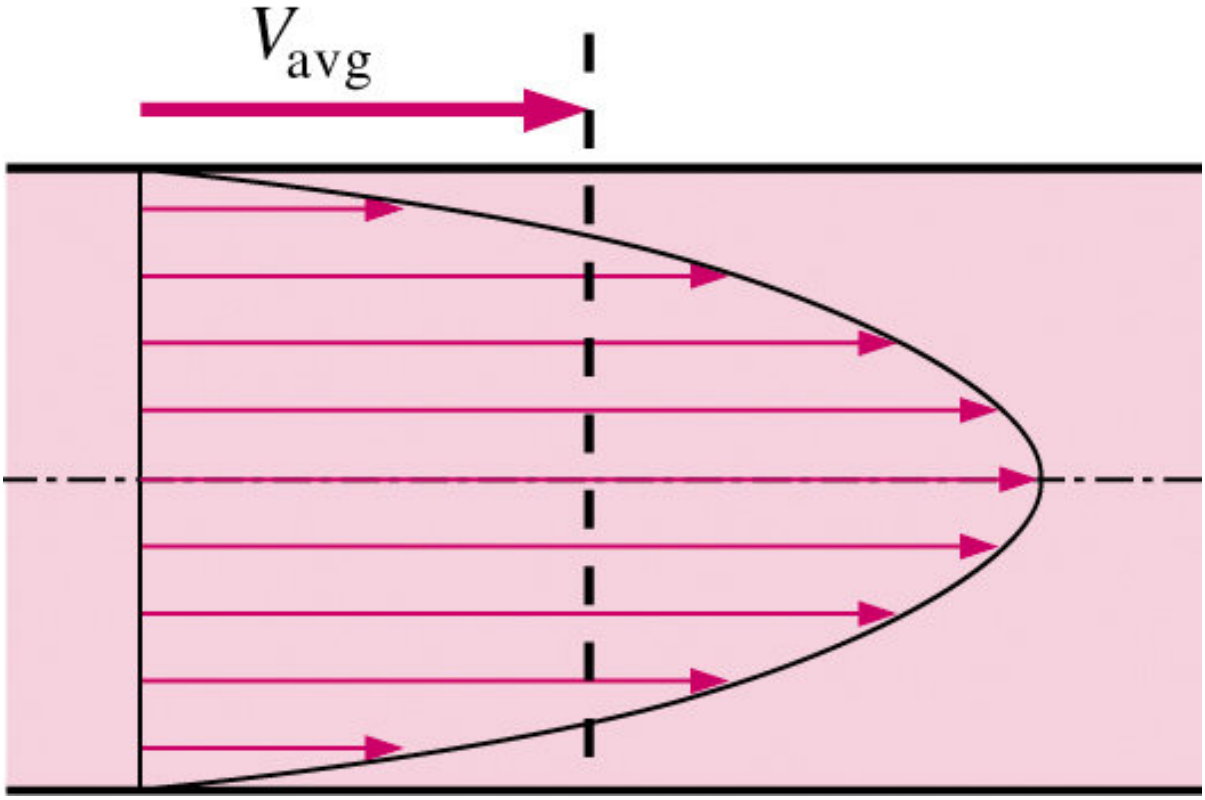

Figure 5. *In laminar flow, the speed of the layers is higher at the center and lower in the peripheries. (Adapted from reference 6)*

Furthermore, according to the rule of constancy of total energy (Bernoulli's principle), for any flowing liquid, upstream or downstream of a narrow area, when the velocity is lower, the local dynamic pressure is higher. In the narrow area itself, it is the reverse with lower dynamic pressure and higher speed. The presence of different areas with LOW and HIGH local dynamic

pressure along the length of the arterial wall is possibly the source and the mechanism causing bubble formation and collapse. (Figure 6) (7)

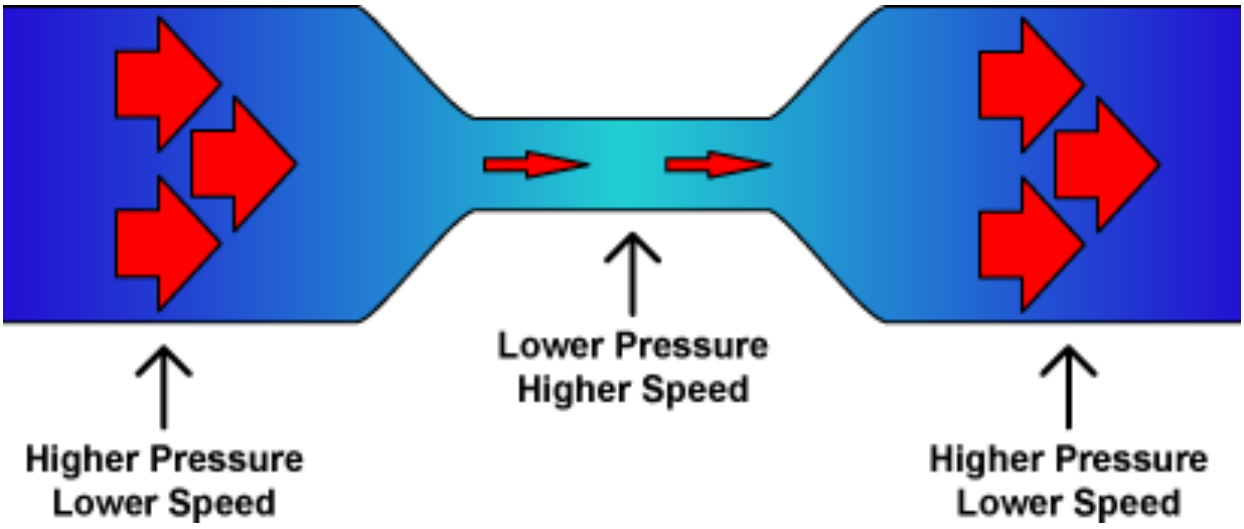

Figure 6. *Changes in the flow and pressure according to the rule of constancy of total energy (Bernoulli's principle).* In the narrow area, the velocity is higher and the pressure is lower. Once outside the narrow area, upstream or downstream, the velocity is lower and the pressure is higher. (Adapted from reference 7)

When the local dynamic pressure decreases below the vapor pressure of air in the fluid (water, oil or blood, etc.), the air molecules will congregate and form bubbles. In the case of domestic hydraulic with water running inside the pipes, approximately 36 percent of oxygen are dissolved in water (compared to 21% in air) and the remaining amount (64%) (of air dissolved in water) is nitrogen. (8) In the blood, the air molecules are most likely formed by the nitrogen molecules. At standard conditions, there are 0.000488 moles of nitrogen dissolved in every liter of blood. If converted to gas, the nitrogen would occupy 15 mL for every liter of blood. (8) These bubbles flow along the way and when they are pushed into the areas where the local dynamic pressure recovers above the vapor pressure, these bubbles will collapse or implode. These explosions create jet waves breaking the endothelial integrity allowing infiltration of cholesterol (in patients with hyperlipidemia) across the intima triggering atherosclerosis.

Hemodynamic Flow Pattern Predisposing to Cavitation in Coronary and Peripheral arteries In the coronary arteries, the two most important characteristics in flow dynamics are (1) that the antegrade flow happens during diastole and (2) is powered by negative pressure at the subendocardial arterial networks. This is in sharp contrast with the systemic flow (peripheral arteries) which moves forwards in systole and is powered by the positive pressure generated from the contraction of the left ventricle.

As the coronary flow is powered by negative suction pressure from the dilation of the ventricle in diastole, there is high probability to form bubbles when the two following pre-set conditions are met: (1) When the pressure in the subendocardial arterial networks drops too quickly, (2) and faster than the capability of the proximal coronary flow (at the LM artery level) to fill the void, then the flow (at the LM) would leave an area of low pressure (or multiple tiny areas) which is (are) a bubble(s) of gas. (Figure 7)

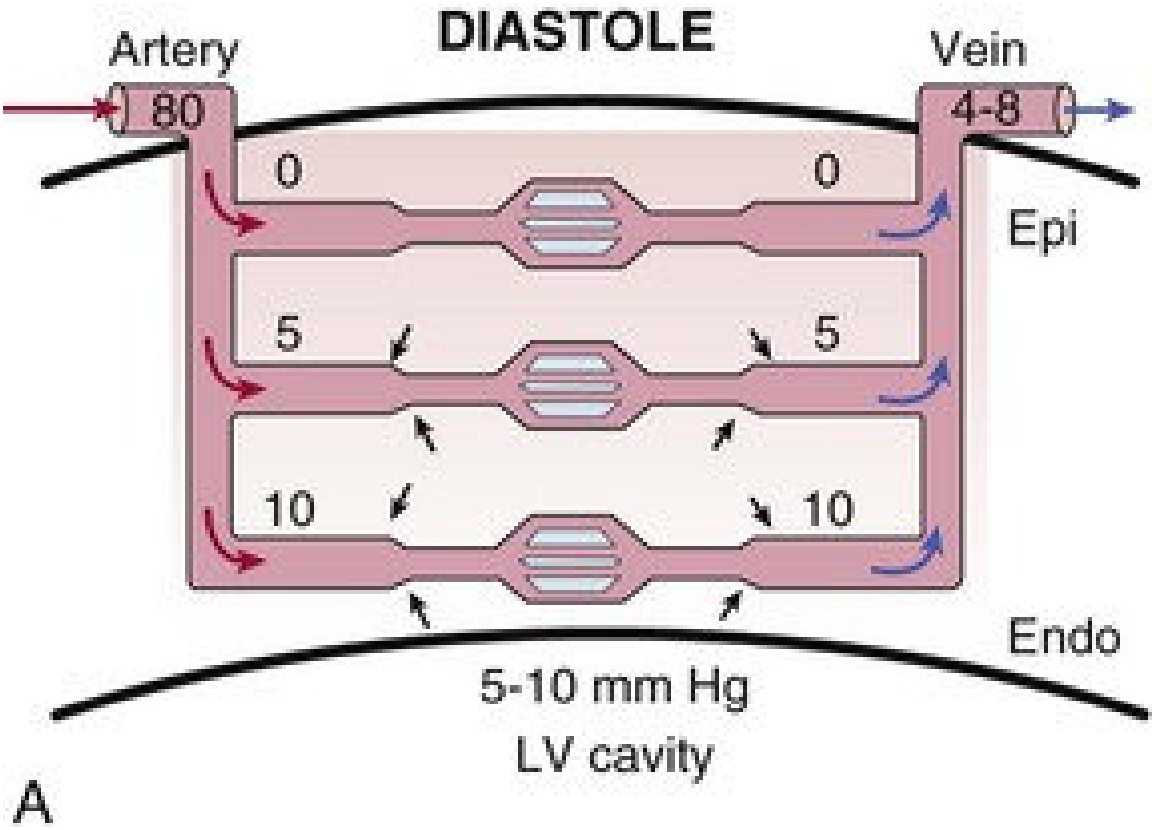

Figure 7. *Pressure changes in the endothelial vascular network. The negative pressure in the networks is the driving force of the coronary antegrade flow.*

The excessive decrease of the pressure in the subendocardial arterial networks can be evidenced as a strong and fast decrease of the left ventricular end diastolic pressure (LVEDP) (quick increase and decrease of the rate of rise dp/dt). This effect can be exaggerated if the gradient between the systolic and diastolic pressure is large. In that situation, the chance of bubble formation at the left main could happen. The needs of the coronary flow dynamic conditions in order to produce bubbles formation and burst (cavitation) are summarized in table 2.

Table 2. Structural Conditions Required for Cavitation

1. **An area of low pressure** so the bubbles can be formed. The possible area could be the central layers of the dominant flow from the left main (LM) to the left circumflex (LCX) or left anterior descending artery (LAD).
2. **An area of high pressure** After the LM divides into the LAD and LCX, at the exit shoulder, in the outer wall, the velocity is lower and the pressure is higher (re-circulating area). It is here where the bubbles could and would burst.
3. I**n an arterial segment with side branch, a high pressure area** is located proximal and at the same side of the sidebranch because the dominant flow moves towards the main branch. This high pressure area is where the bubbles could burst and the plaques are usually seen.

Identification of the Areas of High and Low Speed by the Coronary Angiogram As the bubbles are formed and grow in the area of low pressure and burst in the area of high pressure, how can the investigators identify and locate these areas in the coronary arteries? In a coronary angiogram, the flow of contrast does not show how high or low the pressure is however the angiogram can show how the speed of the flowing contrast is. The areas with normal speed can be recognized as the contrast moves in and disappears quickly. The areas with slow speed can be identified as the areas along the arterial wall where the contrast stays on for longer period of time (or long hangover or staining). In these areas of slow speed or hangover of contrast, the local dynamic pressure is expected to be high by the Bernoulli's principle. In this way, the coronary angiogram could show indirectly the areas with low and high local dynamic pressure by identifying the areas with normal or slow speed. The imaging requirements of a coronary

angiogram in order to highlight the areas of slow and normal speed or indirectly the areas of normal or high dynamic pressure are listed in table 3.

Table 3. *Angiographic Visualization Requirements for Coronary Arteries and their Rationales*

1. The left main (LM) needs to be delineated in full length from the ostium to the bifurcation in order to capture the laminar or turbulent flow or any area with contrast hangover in the upper or lower border of the LM. (Figure 8)

2. The transition from the LM to the left anterior descending artery (LAD) and left circumflex (LCX) has to be sharp and accurate so the dominant flow, the location and the duration of contrast hangover can be identified and measured (mostly at the entry and exit shoulder) (Figure 9A and 9B)

3. The proximal segment of the LAD and LCX need to be seen clearly, especially the outer wall because here the contrast hangover is longer and where the plaques are formed. (Figure 9A and 9B)

4. The bifurcations of the LAD and diagonal and the LCX and the obtuse marginal need to be delineated sharply so the time of contrast hangover can be measured because plaques used to form proximally to the origin and at the same side of the sidebranch (if the main flow is towards the distal main branch). The lesion will be seen on the outer wall of the main vessel proximal to the bifurcation if the contrast is seen to flow first to the side branch.

5. The mid and distal segment of the artery need to be seen well so the areas and the duration of contrast hangover could be identified and measured. Another important information is that the mid-segment shows the coronary bi-directional flow of which the meaning and clinical application are still unknown.

TECHNIQUE of Coronary Angiography in Order to Identify the Areas with Normal Velocity and Areas with Long Contrast Hangover

In order to see the dynamic flow during angiography, the coronary arteries should be filled completely with contrast. When some contrast is seen ejected back in the aorta from the coronary ostium, the manual injection of contrast could stop. During injection and afterwards, the camera should capture the whole artery, in full length with all the frames totally inside the screen. (**Figure 8**) The best angulation for capturing the left main coronary artery (LM), LAD and LCX bifurcation is the right anterior oblique (RAO) caudal view. The best angle for the RCA is the LAO Caudal view.

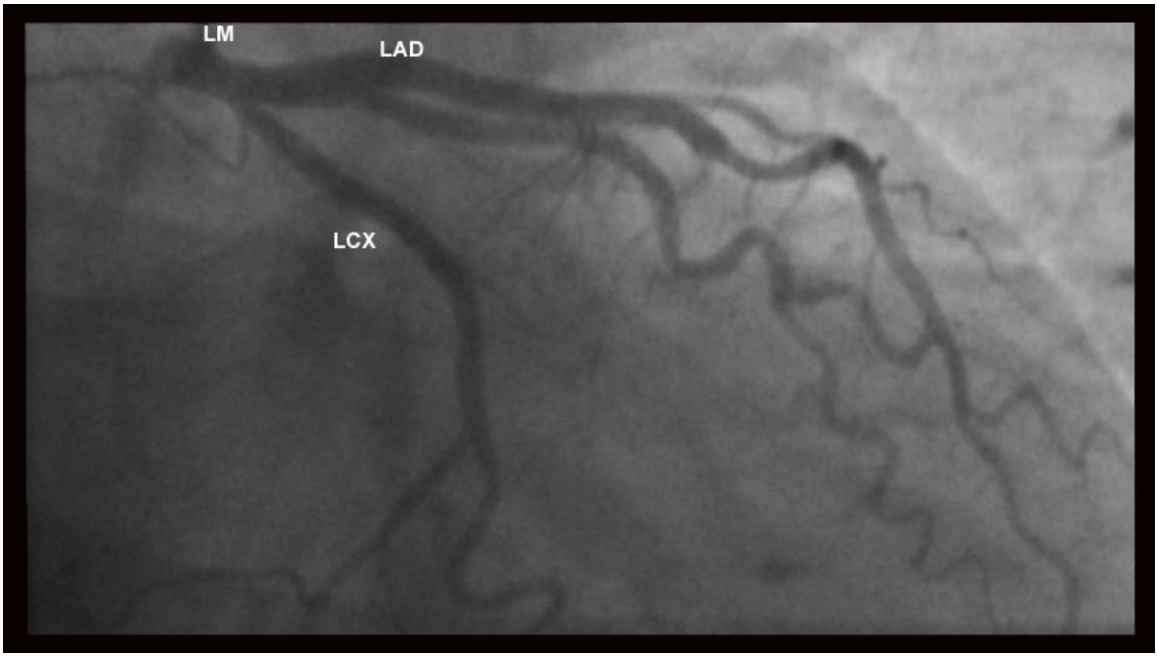

Figure 8. **Left Coronary Angiogram.** In this angiogram, the left coronary system is totally filled with contrast. At that time, the manual injection of contrast stops. The left main, left anterior descending or left circumflex arteries are in black because they are filled by contrast.

Once the injection stops, the blood (in white color) begins to move in and displaces the contrast (black color). In figure 9A, the blood goes in on a laminar fashion with a pointed tip, similar to the flow in figure 5. The flow at the center is faster and the flow at the sides is slower and seen as prolonged hangover of contrast. In figure 9A and 9B, the areas with delayed contrast

(the peripheral areas) are where the velocity is lower (and the pressure is higher) while the velocity is higher in the areas where the contrast clears quickly (and the pressure is lower here). The details of the coronary blood flow can be analyzed in a coronary angiogram running at slow speed, frame by frame (15 frames per second).

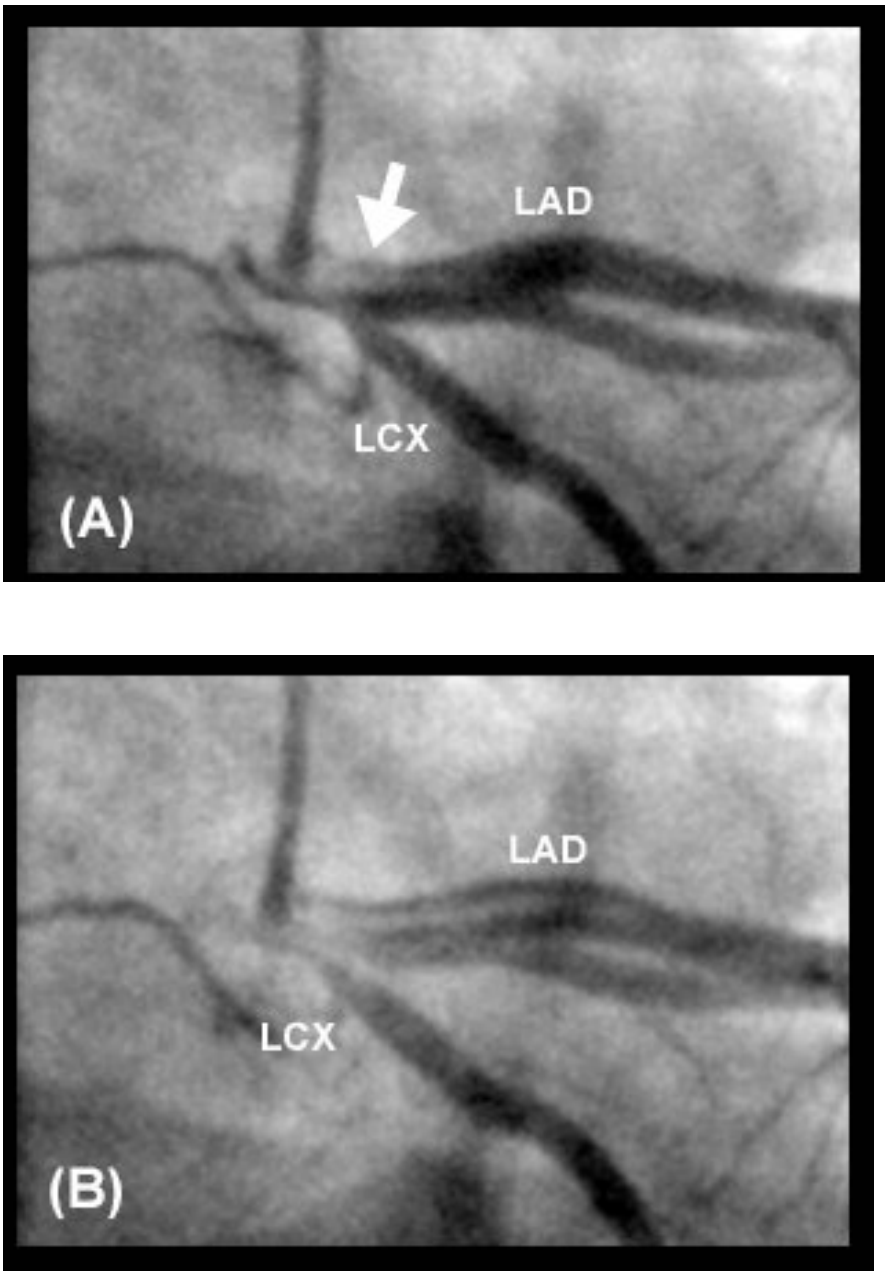

Figure 9 A-B. The blood without contrast is flowing into the left main and the ostium of the left anterior descending artery (LAD) and is seen in white at the white arrow). **9A**. The flow is laminar with the tip like an arrow. There is not much flow into the left circumflex because the blood is preferentially steered toward the LAD. **9 B.** The blood moves deeper in the LAD and

flows preferentially at the center while the contrast is seen delayed clearing on the lateral sides (boundary layers). The flow at the center is faster (and the pressure is lower) while in the areas with delayed (hangover) contrast, the velocity is lower (and the pressure is higher). The laminar flow is seen moving towards the mid segment of the left anterior descending artery. There is the beginning of flow into the left circumflex, mainly on the carina side.

TECHNIQUE: Review of a Coronary Angiogram Each coronary angiogram was reviewed for speed of the antegrade flow and duration of the contrast hangover at the curve, bifurcation and around the area of the lesions. The RAO caudal view was best when reviewing the LCX and the LM. The AP cranial view was best for the LAD and the LAO view for the RCA. Once an angiogram was selected, the reviewer made a right click and chose the Key Image option so each frame can be reviewed at a time. (Figure 10) The time was calculated in frame with 1 frame = 0.06 second based on a speed of recording of 15 frames per second.
This method was done on EPIC, an electronic health record program. The data to be calculated are listed in table 4.

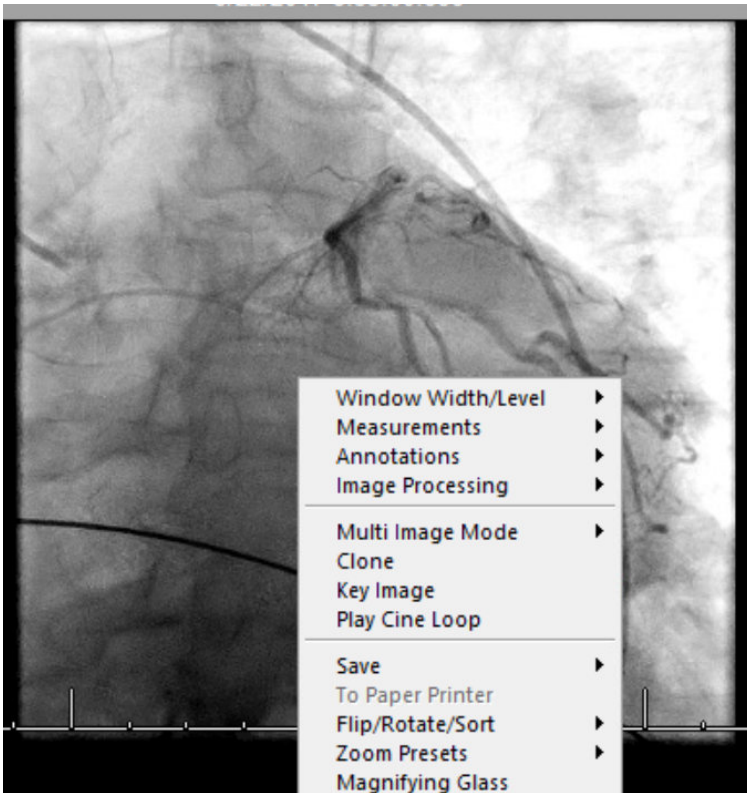

Figure 10. *To review the coronary angiogram frame by frame at 15 frames per second, first right click and then select Key Image option, then use the up and down arrows to move the picture, one at a time.*

Table 4. Data to be Calculated in a Coronary Angiogram

1. Time when the coronary artery is full with contrast (Figure 9)
2. Time when the blood begins to enter the LM or ostium of the RCA (Figure…)
3. Time when the blood begins to enter the LAD or RCA (Figure...)
4. Time when the blood begins to the LCX (Figure …)
5. Time and length of bi-directional flow
6. Length of time of contrast hangover
7. Time when the contrast is totally cleared from arteries

Areas of High and Low Pressure in the Coronary Angiogram In the areas of high speed and low pressure where the bubbles are formed and grow, the color of the segment is lighter because the contrast flows fast and clears quickly. (Figure 11)

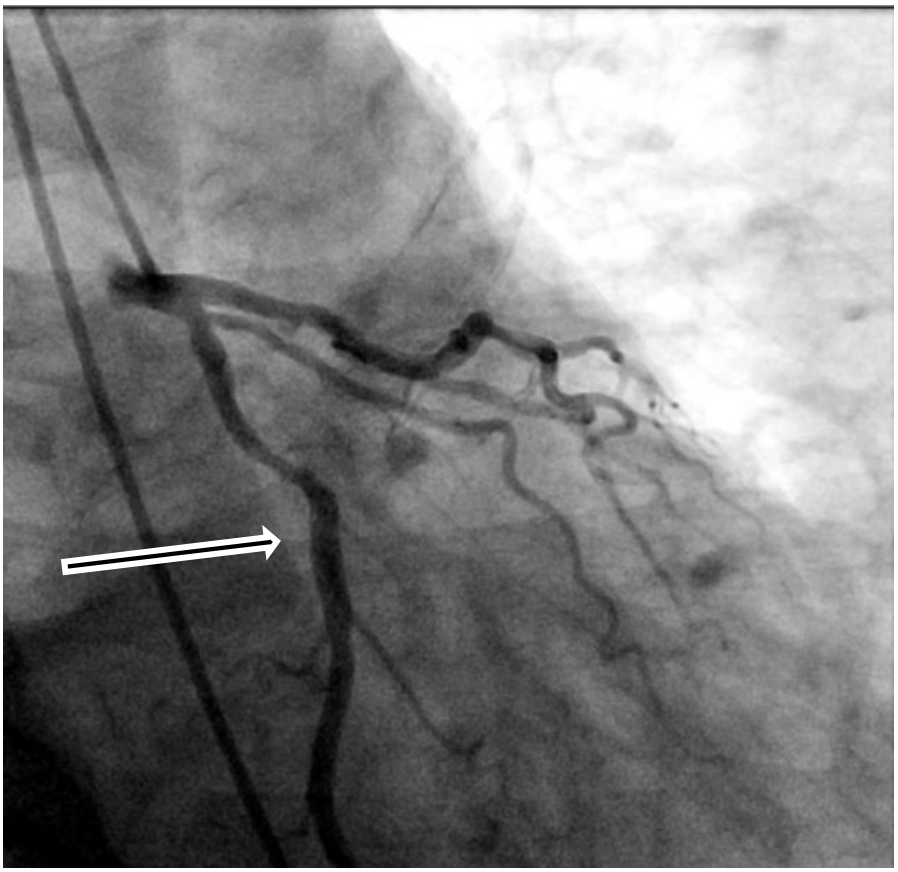

Figure 11. In this view, the mid-segment of the left circumflex artery (LCX) shows significant tubular lesion (white arrow). The color of contrast is darker in the proximal and distal LCX while it is much lighter in the narrow area. The reason is that in the narrow area, the speed if high and the dynamic pressure is low so the contrast clears more quickly.

Classification of Lesions The lesions are classified according to (1) the **locations** of the lesions, (2) the **severity** ranking among the 3 most severe lesions of the 3 arteries and (3) the **anatomical configurations (mechanism)** promoting the formation of plaques based on the cavitation mechanism.

1. Locations Based on the cavitation mechanism, the lesions should form before or after a curve of a coronary segment or near a sidebranch. There are cases where the lesions are seen specifically in the distal segments (mostly in the RCA). The coronary lesions are classified according to their locations at the ostium (o-), proximal (p-), mid (m-) and distal (d-) segments of the LAD, LCX and RCA. The lesions of the left main were not included in this study.

2. Severity Ranking In theory, all coronary arteries are exposed to the same risk factors and presence of air bubbles. However, some segments have predisposition for more cavitations or bubble explosions due to their location or anatomical configuration. Intuitively, these segments with more bombardments from the air bubbles explosions should present with earlier and more severe lesions. The severity of the lesion is selected based on the degree of stenosis in an average size artery (2 to 3mm). The reason is because the degree of stenosis depends on the size of the artery. A moderate lesion can be assessed as severe if the artery is small and mild if the artery is big. In this study, the severity of the lesion is used as a surrogate for the strength of the mechanism of plaque formation. As all the segments of the coronary arteries are subjected to the influence of multiple risk factors, the stronger the risk factors (or mechanism), the earlier the appearance of the lesion and the larger the volume of the lesion. The sequence of time of formation 1-3 with early as 1 and late as 3.

3. Mechanisms The main mechanism of plaque formation by cavitation is the presence and location of areas with high local dynamic pressure. These areas can be identified by the prolonged contrast hangover. Is the presence of only stained contrast strong enough to cause frequent bubble burst and break the endothelial barrier? Does the location of the arterial segment increase the intensity and frequency of cavitation resulting in earlier plaque formation? The anatomical architectures which promote and prolong the contrast hangover were tabulated and classified in table 5.

Table 5. Mechanisms Causing Injury to the Endothelium

1. **Long contrast hangover versus short or no** contrast hangover (low speed and high dynamic pressure)
2. **Large versus smaller branch** In the case of LAD and LCX, the larger arteries have less lesion than the smaller arteries (More air bubbles (or empty spaces) are formed in smaller arteries because a major part of the flow is preferentially steered to the large arteries)
3. **Curved segment versus straight segments** More bubble rupture happened around the curved segments of a bifurcation area
4. **Dominant versus secondary flow** More cavitation in secondary flow (mostly smaller arteries) than in dominant flow (mostly large arteries)
5. **At the apex of a curve with a sidebranch** in case of 2 risk factors
6. **In case of smooth proximal and mid segments, no large sidebranch:** Lesion happened in distal segment

Mechanism 1: **Long Contrast hangover** The lesion happens in the area with slow speed and high pressure (presence and length of contrast hangover). (Figure 12)

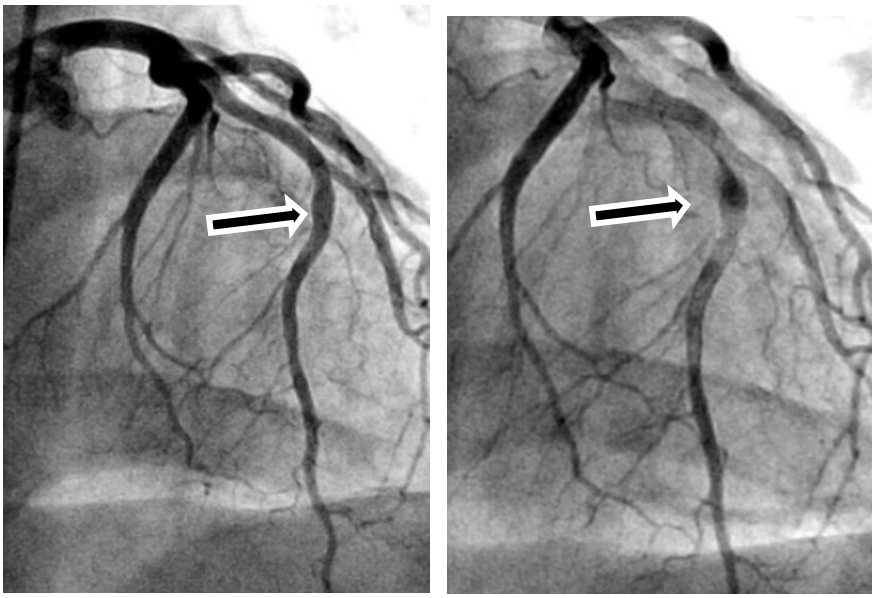

Figure 12. At the mid LAD, there is an area with aneurysmal changes. In this area, the contrast hangover was quite long. The plaques are supposed to form here.

Mechanism 2: **Larger versus Smaller Artery** Between the LAD and LCX, the smaller artery has earlier lesion. The reason is because the flow is preferentially steered toward the larger artery (e.g. the LAD), creating negative void(s) in smaller one (e.g. the LCX), thus facilitating bubbles formation. (Figure 13)

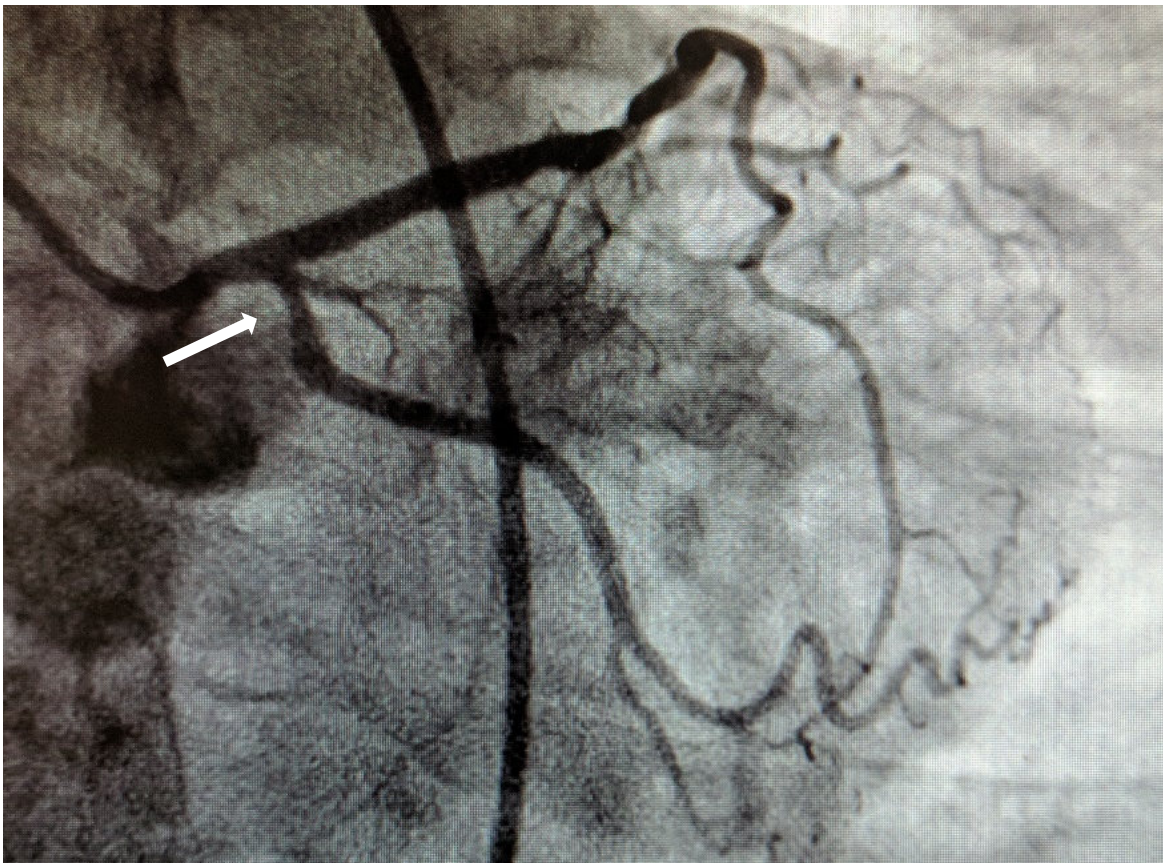

Figure 13. Between the LAD and LCX, there is an obvious lesion at the proximal LCX. Clearly the LAD is bigger. The lesion happened in the proximal LCX because the dominant flow is forwards the LAD, leaving empty spaces at the proximal LCX, at the outer curve. This is a common place where cholesterol plaques are formed.

Mechanism 3: **Curved segment and around the Bifurcation area** The lesions happen more around the bifurcation of the LM-LAD and LM- LCX or in the mid LAD at the bifurcation with a diagonal, in the mid-LCX at the bifurcation with an obtuse Marginal or the distal RCA at the bifurcation with a posterior descending artery (PDA). (Figure 14) In coronary

arteries, the more curved segments have earlier and more severe lesion than the straight ones because more slow flow and high pressure areas are formed at the entry or exit shoulders of these curved segments. (Figure 14 A to B)

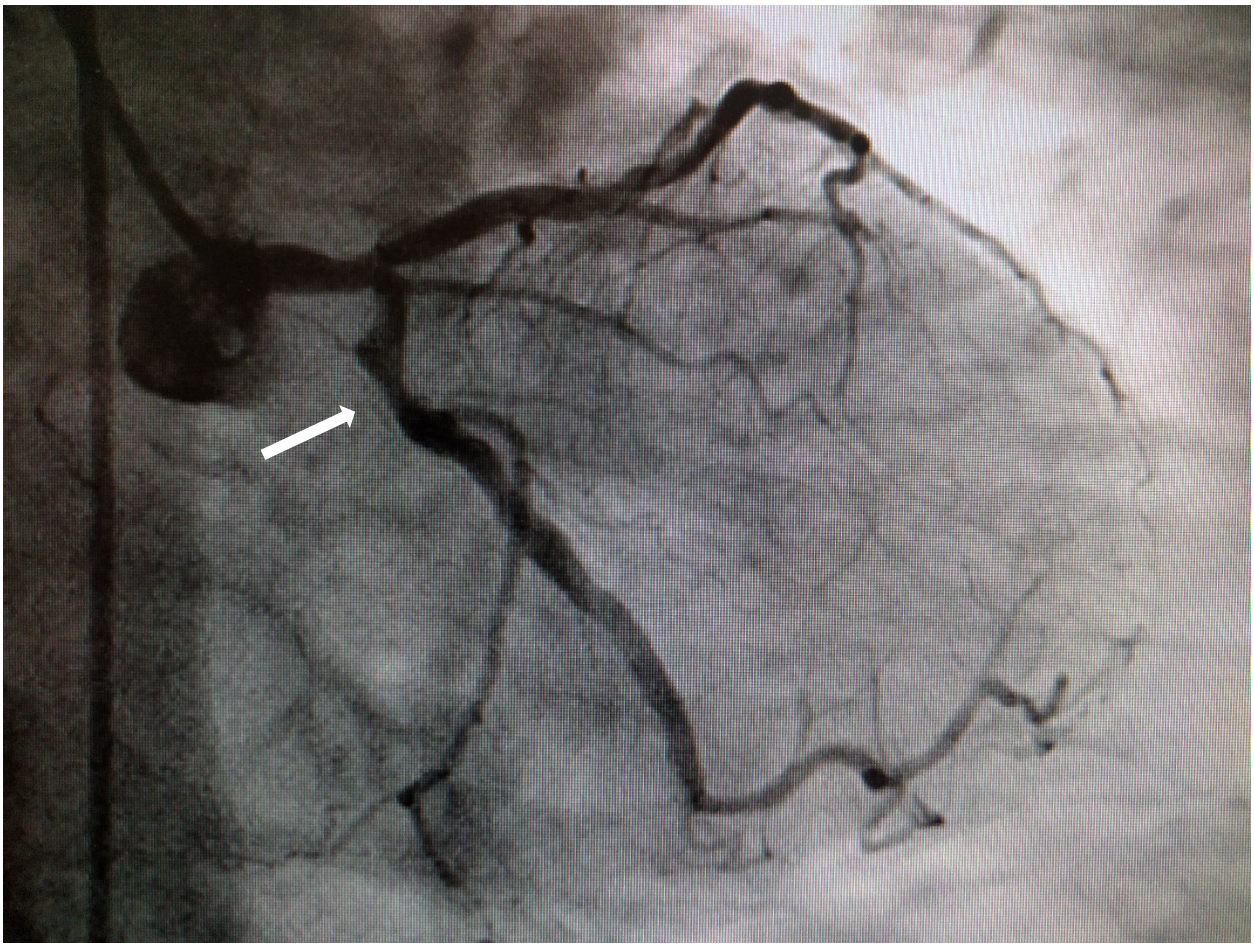

Figure 14 A. In this coronary angiogram, there were lesion in the distal left main, proximal left circumflex (LCX) and none in the proximal left anterior descending artery (LAD). Why did the plaques form more in the proximal LCX while all the segments were under the same influence of hypertension, hyperlipidemia, smoking, etc.

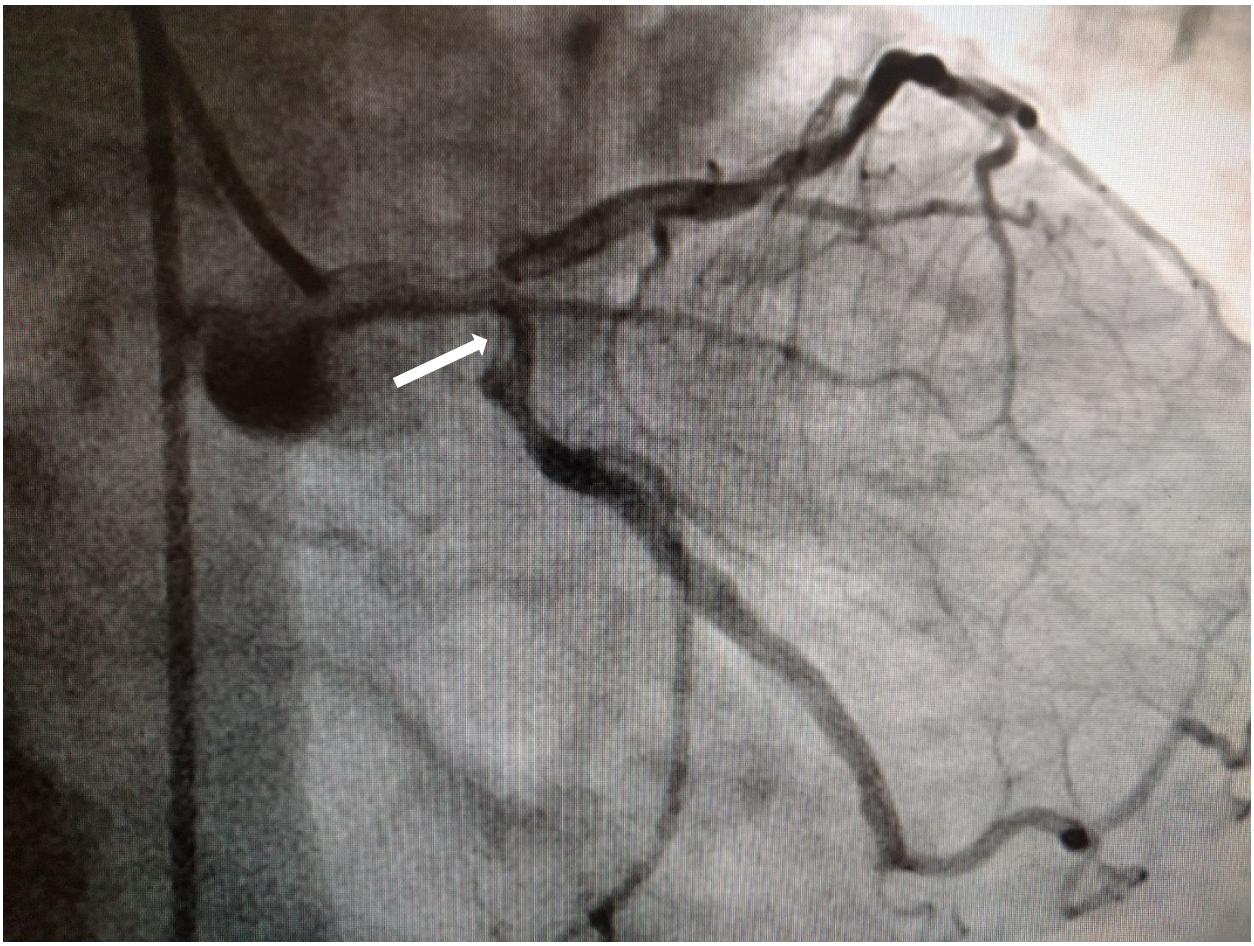

Figure 14B. In this picture taken around 3 frames after the 14A showed the flow to the LAD was laminar with the flow to the LCX was turbulent. The flow in the proximal LCX showed area with long contrast hangover which is a fertile ground for bubbles explosion or cavitation.

Mechanism 4: Dominant versus secondary flow More cavitation happens in secondary flow than in primary flow which occurs mostly in large arteries. The reason is because not all large arteries receive the primary flow. The fluid flow primarily towards the branch which form the straightest line with the main source. (Figure 15 A to C)

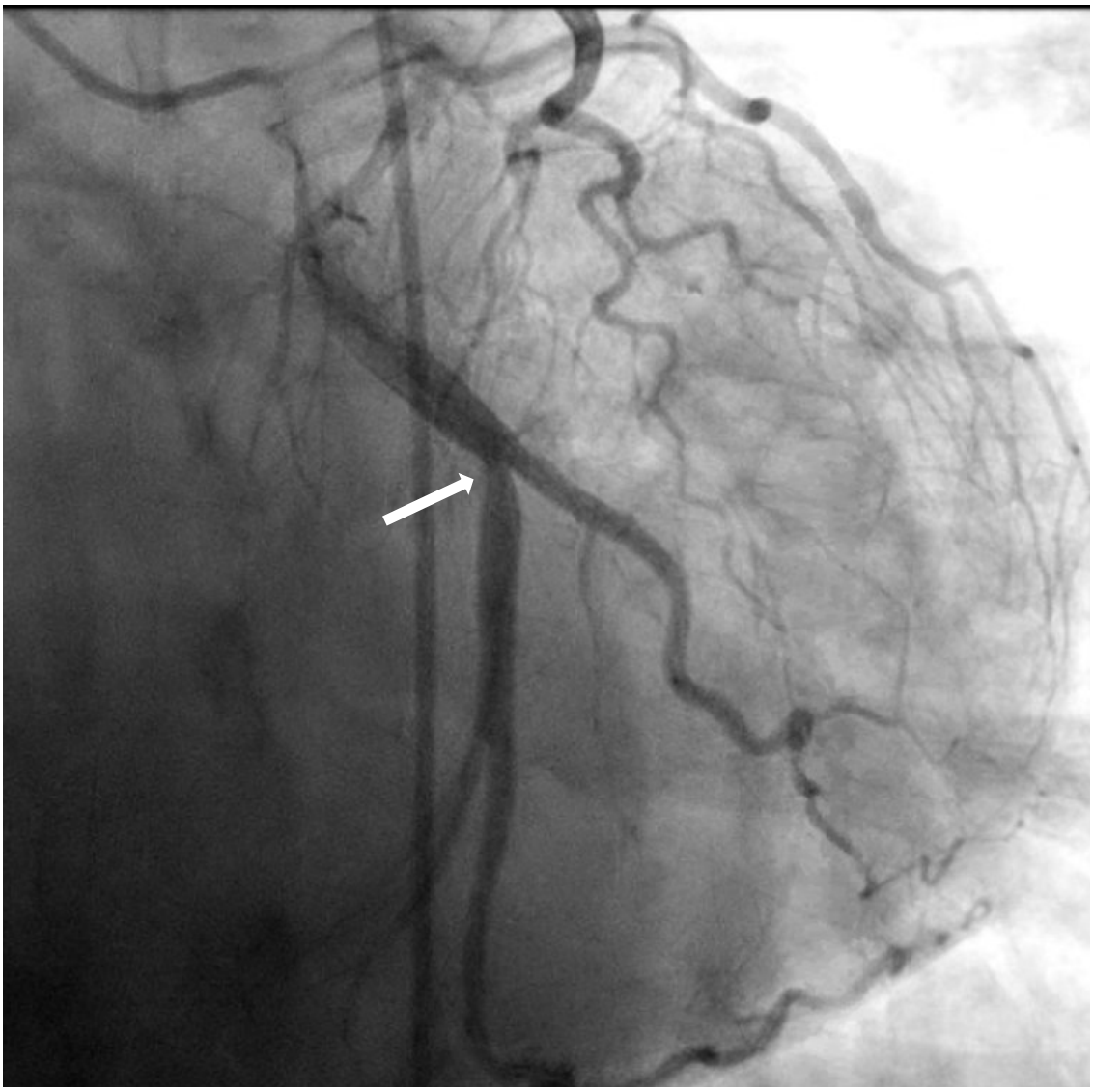

Figure 15A. In this angiogram, the lesion is seen at the main LCX, at the ostium of the mid segment, at the bifurcation with a large obtuse marginal. Why did the lesion happen at the mid-LCX, instead at the OM? The lesion was supposed to happen at the OM because the OM is smaller. However, when looking at the flow from the proximal to the mid LCX, the dominant flow was steered towards the OM, just because the OM formed a straight line with the proximal LCX.

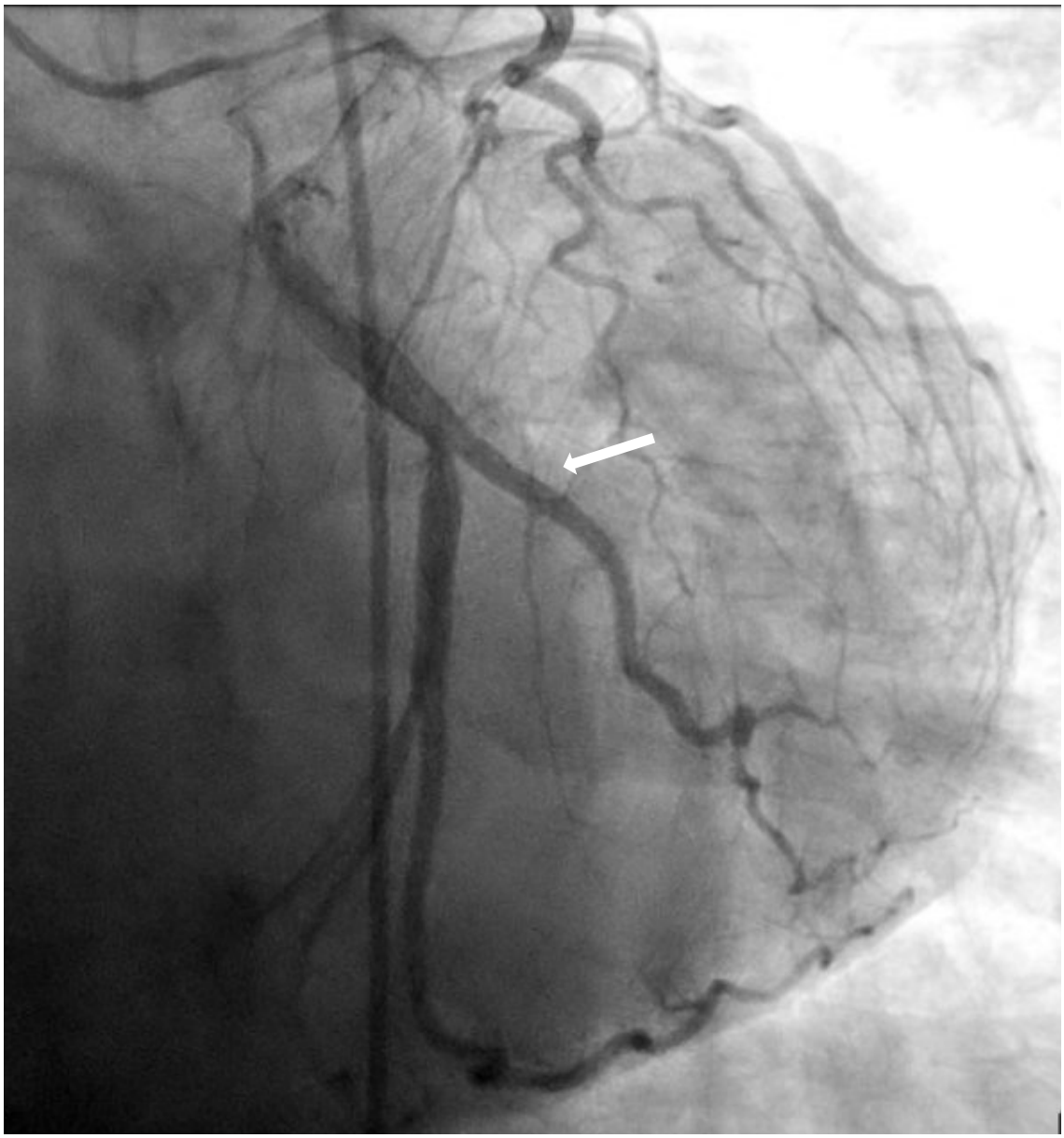

Figure 15 B. At frame 61, the flow (in white color) was seen entering the obtuse marginal while the flow has not entered the distal LCX.

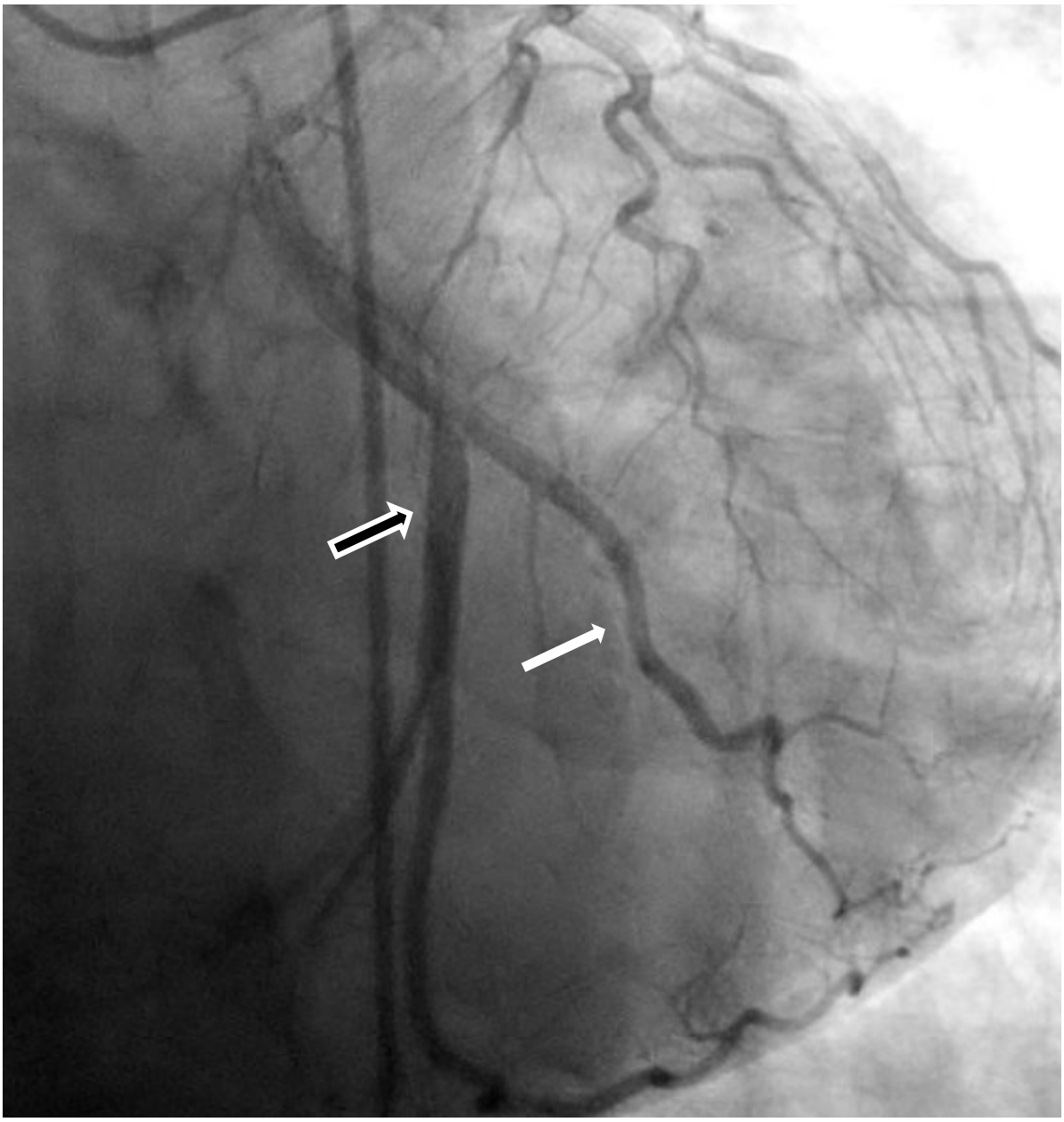

Figure 15C. At frame 63, the blood was at the mid segment of the obtuse marginal while the blood was only at the proximal segment of the mid LCX (black arrow). In this picture, the primary flow is towards the obtuse marginal (white arrow). This is why the plaques were formed at the proximal segment of the mid LCX

Mechanism 5: **The Presence of Sidebranch especially at the Apex of a Curved segment** The lesion happens in the area with slow speed and high pressure (longer contrast hangover) which is also located proximal to the origin of a large sidebranch (SB). The reason for this location is because here the air bubbles explode more frequently when the blood is steered preferentially away toward the main branch. (long contrast hangover plus sidebranch) (Figure 16)

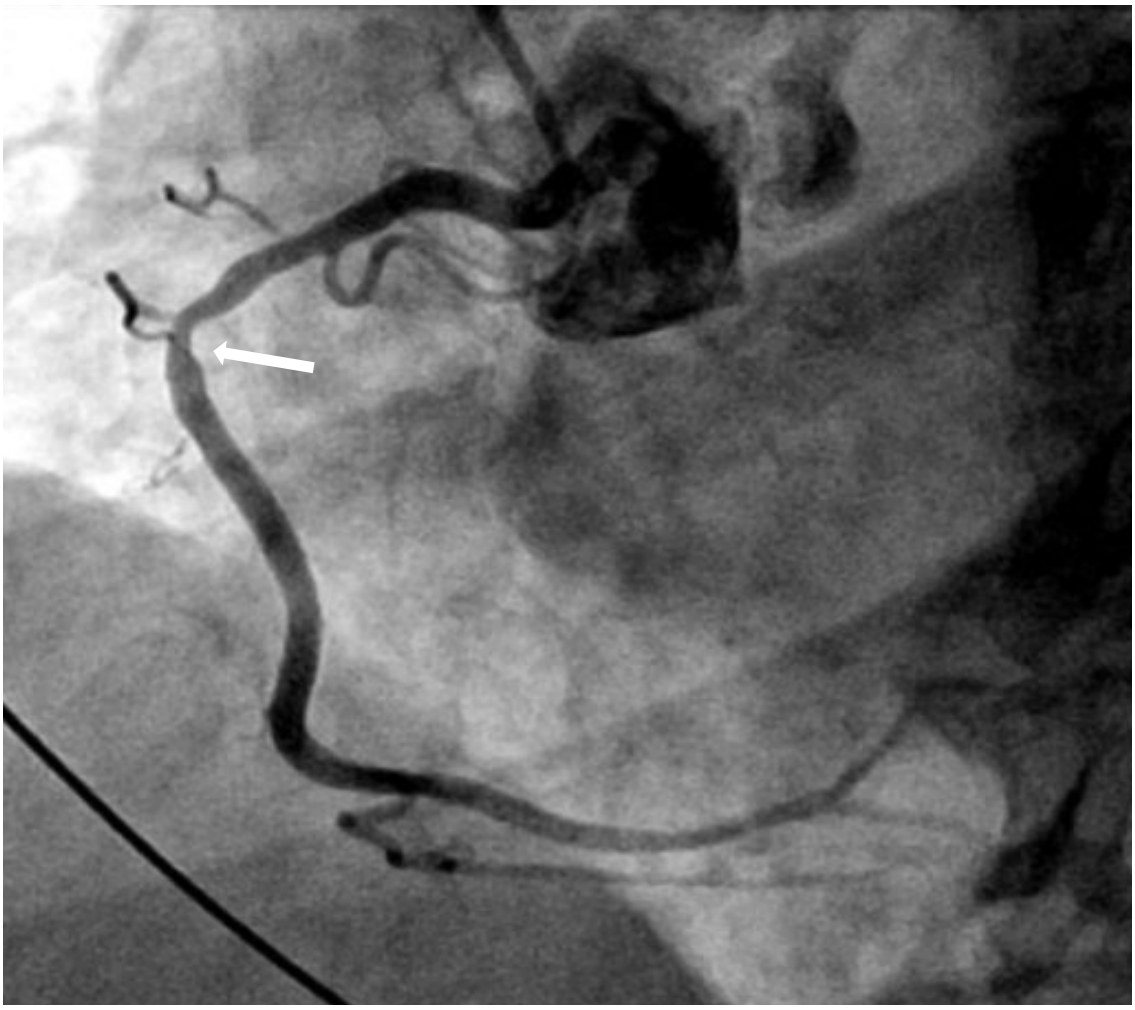

Figure 16. In this RCA, the proximal segment has no lesion, until at the beginning of the curve at the midsegment. The area with most severe lesion happens at the apex of the curve coupled with the presence of a small sidebranch. All proximal, mid and distal segments of the RCA were subjected to the same risk factors (hypertension, high cholesterol level, nicotine from cigarette, etc) and only the lesion at the curve at the mid-segment developed the lesion. The question is always "why at this location" The answer lies on the change of dynamic pressure in the area.

Mechanism 6 Smooth Proximal and Mid-Segment and no Sidebranch

In large artery with smooth transition with no SB, the lesions would form distally where the bubbles are trapped and burst (seen frequently at the RCA). (Figure 17)

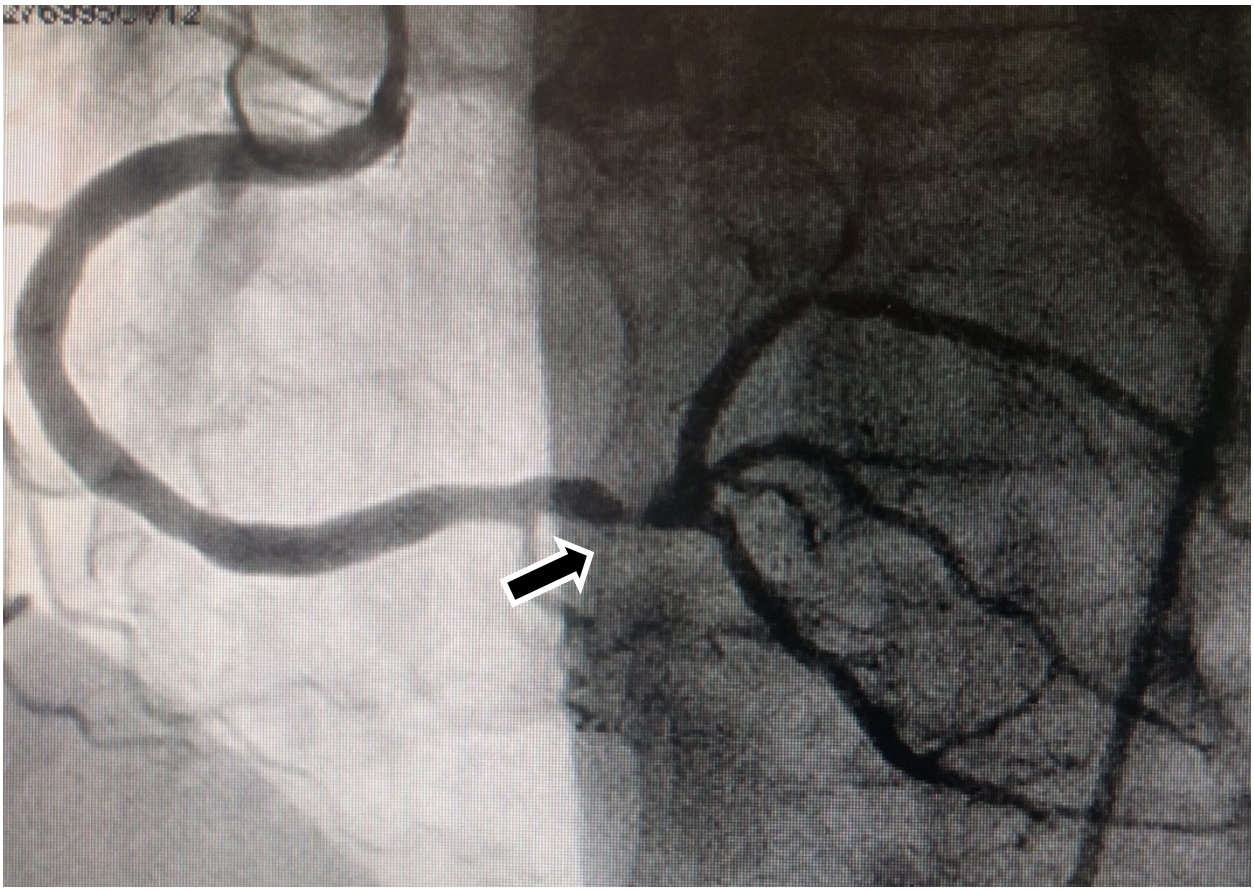

Figure 17. In large artery (such as the right coronary artery) with smooth transition with no side branch, the lesions would form distally where the bubbles are trapped and burst.

Statistical Analysis. Continuous variables are expressed as mean ± standard deviation (SD) for normal distributions or numbers (percentage) for categorical variables. A P value of < 0.05 was considered statistically significant.

CONCLUSION

The mechanism of formation of coronary lesions is most likely due constant injuries from explosion of air bubbles, breaking the endothelial integrity and allowing infiltration of cholesterol molecules and starting the atherosclerotic process. This protocol is the scientific basis of the study. The results will be calculated and presented accordingly.

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