Cavitation Phenomenon Creating Bubbles and their Explosion in the Coronary Artery Causes Damage to the Endothelium and Starts the Atheroslerotic Process

Thach N. Nguyen, Nhan MT Nguyen, Tri M. Pham, Quang NN Do, Vy Le, Vien T Truong, Viet M Vo, Gianluca Rigatelli, Methodist Hospital, Merrillville, IN, USA, Tan Tao University Medical School, E-city Tan Duc, Long An, Viet Nam

The American College of Cardiology 67\textsuperscript{th} Annual Scientific Meeting
March 12th, 2018, Orlando FL
• Disclosures

• Thach Nguyen  Nothing to disclose.
BACKGROUND
At the present time, there is no confirmed theory for the formation and growth of the atheroslerotic plaques. In each individual person, the entire arterial tree is exposed to atherogenic effects of systemic risk factors and yet only a few arteries develop plaques.
• In the coronary arteries, plaques are observed as to be clustered in the proximal segment of the left anterior descending artery or the left circumflex artery, whereas they can be seen in the proximal or distal segments of the right coronary artery.
PLUMBING
In hydraulic (plumbing) practice, when connecting pipes to pumps, the inlet should be larger than outlet and the speed should be slow. If not, air bubbles would form causing major damage to the inside surface of pipes and pumps.
Plumbing Practice 2

• The proximal pressure should be higher than the distal pressure. Also the length of the segment from the inlet to a bifurcation or side tube should be 10 times the diameter of the inlet.
Plumbing Practice 3

- Cavitation 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 can explode. Once these bubbles enter an area with high local DP, they will implode.
Plumbing Practice 3

Cavitation Phenomena

- Pressure
- Velocity

Formation of Vapor Bubbles
Flashpoint
Cavitation

Downstream Pressure Recovery Above Vapor Pressure
Local Fluid Pressure Drops Below Fluid Vapor Pressure

Credit: Basic Fluid Dynamic, Setpoint Integrated Solutions
These explosions or collapses are followed by a localized pressure pulse that can give rise to small but powerful micro jets or shock waves. When the shock waves impact against the surfaces of the pipes, or components of the valves inside the pump, the materials of construction for industrial valves or pipes can be work-hardened and fatigued.
Plumbing Practice 4

FLOW DIRECTION →

1. Initial spherical bubble
2. Perturbation of side away from surface
3. Upper fluid penetrating flattened side
4. Formation of jet

Credit: Basic Fluid Dynamic, Setpoint Integrated Solutions
Plumbing Practice 4

Credit: Basic Fluid Dynamic, Setpoint Integrated Solutions
There is high probability to form bubbles when:

1. When the pressure in the distal pumps drops too quickly,
2. and faster than the capability of the proximal inlet to fill the void, then the proximal flow would leave an area of low pressure (or multiple tiny areas) which is (are) a bubble(s) of gas.
HYPOTHESIS
Hypothesis 1

• In the field of domestic or industrial hydraulics, the damage on the inside surface of pipes is DEFINITELY proved to be caused by cavitation or collapse of air bubbles. Could the mechanism of cavitation be the cause of formation of cholesterol plaques?
Hypothesis 2

• In the coronary arteries, could the bubbles form in the left main area, grow as they move along, and explode when they are pushed in the area where the coronary pressure recovers above the vapor pressure of CO2. These explosions create jet waves breaking the endothelial integrity allowing infiltration of cholesterol (in patients with hypercholesterolemia) across the intima triggering atherosclerosis.
HEMODYNAMIC BASIS
Hemodynamic Background of Cavitation: Correlation between Pressure and Speed

- Laminar flow occurs when the fluid flows in parallel layers with no disruption between each layer. The flow is turbulent when the fluid undergoes irregular fluctuations, or mixing. The speed of the central layers is faster than the ones in the peripheries (boundary layers).
In laminar flow, according to the Bernoulli’s principle, the speed is higher at the center and lower in the peripheries.
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.
White Area = High Velocity and Low Pressure
Black Area = Low Velocity and High Pressure
Hemodynamic Basis of Cavitation

- As the coronary flow is powered by negative suction pressure from the distal end, there is high possibility to form bubbles when two conditions happen: (1) The pressure in the distal coronary flow drops too quickly, (2) faster than the capability of the proximal coronary flow (at the LM artery level or the proximal RCA) to fill the void. If so, the flow at the LM would leave an area of low pressure (or multiple tiny areas) which is (are) a bubble(s) of gas.
Hemodynamic Basis of Cavitation

• These bubbles expand as long as the vapor pressure is higher than the local dynamic pressure. When the local coronary dynamic pressure recovers above the vapor pressure inside the bubbles, they implode.
Hemodynamic Basis of Cavitation

- The bubble explosions create jet waves, breaking the endothelial integrity, allowing infiltration of cholesterol molecules across the intima and triggering the formation of the cholesterol plaques. Later, these same explosions create jet waves weakening and rupturing the cap of the plaques, triggering the clinical state of acute coronary syndrome. The same mechanism could cause critical limb ischemia transient ischemic attack or stroke.
Goals of the Study

- The goal of this study is to locate the cholesterol plaques and correlate them with the location of cavitation or air bubble collapse in the coronary arteries.
METHODS
Methods

• Coronary angiograms with 1 to 3 lesions were selected.
How To Image the Areas with Low and High Pressure in the Coronary Arteries

• 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 to the aorta from the coronary ostium, the injection of contrast can be stopped. During injection and afterwards, the camera should capture the whole artery, in full length with all the frames totally inside the screen.
Once the injection stops, the blood begins to move and displaces the contrast. 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). The best angle for the coronary angiogram highlighting the laminar flow at the LM and the proximal LAD is the RAO caudal view.
How To Image 2
Once an angiogram was selected, the reviewer used the Key Image option so each frame can be selected at a time.
How To Measure the Flow and the Time of Contrast Staining

After that, the parameters to be measured are the starting time of the flow, the time of the flow entering the index artery, slowing down, reversing direction and when all contrast disappearing totally. The location and the duration for the contrast hangover is calculated in frame (1 frame = 0.06 second) based on a speed of recording of 15 frames per second.
Where to Focus 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.

The transition from the LM to the left anterior descending artery and left circumflex artery has to be sharp and accurate so the dominant flow, the location and the time of contrast hangover can be identified and measured (mostly at the entry and exit shoulder).
Where to Focus 2

- 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.

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 proximal to the origin and at the same side with the sidebranch.
Where to Focus 3

• The mid and distal segment of the artery need to be seen well so the areas with contrast hangover could be identified and also because the mid-segment shows the visual evidence of the negative suction pressure which drives the coronary flow.
PRELIMINARY RESULTS
Locations Where the Bubbles Explode

The most common location where the bubbles explode and lesion is formed is the apex of a curved segment PLUS a side branch. In this RCA, the lesion started FIRST and more severe at a curve + a SB.
The second most common location where the bubbles explode and lesion is formed is the mid segment of a right coronary artery with an ostium in ANOMALOUS location. The reason is that an anomalous origin RCA causes turbulent flow.
The third most common location where the bubbles explode and lesion is formed is the location where the contrast staining persists for long period of time (1 to 2 minutes)
The fourth most common location where the bubbles explode and lesion is formed is the proximal segments of the LAD and LCX in patient with short LM. The reason is that in patient with short LM, the proximal flow is very turbulent.
If the artery is large, smooth transition and no large side branch, the bubbles will burst distally
QUESTION

Does the arterial architecture predispose the human race to CAD?
The coronary anatomy is predisposed to have plaques if the cholesterol is very high.

http://www.vasculardisease-management.com/content/radial-access-PCI-children-obstructive-coronary-artery-disease

Figure 1. Right anterior oblique caudal view of high-grade ostial circumflex artery and moderate left anterior descending artery stenoses.
QUESTION
If two hearts have the same coronary architectural design, can they have the same lesions?
CAD in Twins

Fig. 2  Schematic representation of coronary anatomy in the second twin pair. Left, case 3. Right, case 4.
QUESTION

Why does Betablocker Prevent Heart Attack?
Fig. 7. Aortic pressure curves under various conditions.
Curve (a), the administration of a vasodilator agent such as nitroprusside; curve (b), the baseline state; curve (c), β-blockade administration.
CONCLUSIONS
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. More studies are needed.

Contact: thachnguyen2000@yahoo.com
Thank You