A fractal physics explanation for acute thrombotic occlusion in an apparently healthy coronary artery

Nicolae Dan Tesloianu, Igor Nedelciuc[1], Vlad Ghizdovat[2], Maricel Agop[4,5,6], Corina Lupascu-Ursulescu[3]

Department of Cardiology, "St. Spiridon" University Hospital; Iasi-*Romania*, [1]Institute of Cardiovascular Disease "G.I.M. Georgescu"; Iasi-*Romania*
Department of [2]Biophysics and Medical Physics, [3]Radiology, "Grigore T. Popa" University of Medicine and Pharmacy,
Faculty of Medicine; Iasi-*Romania*, [4]Lasers, Atoms and Molecules Physics Laboratory, University of Science and Technology; Lille-*France*
[5]Physics Department, "Gheorghe Asachi" Technical University; Iasi-*Romania,*
[6]Academy of Romanian Scientists, 54 Splaiul Independentei, Sector 5; Bucuresti-*Romania*

The acute arterial occlusion of an artery that has no significant preexistent lesions leads to dramatic consequences due to the lack of collateral substitutive circulation, as this kind of circulation usually develops within years in the presence of hemodynamic significant stenosis (1).

Classical models which explain this phenomenon take into account the cracking of an intimal atheroma plaque, the activation of the prothrombogenic cascade through the denudation of the endothelium, and the formation of a completely occlusive thrombus in certain circumstances (2, 3). At least one counterargument should be considered: Why does an occlusive thrombus form so quickly in the absence of a stenosis when the sanguine flux is unaltered? Why the "wash-out'' phenomenon does not appear?

Without contradicting these usual models, through a fractal model (4, 5), we will prove that the blocking of the lumen of an absolutely healthy artery can happen as a result of the "stopping effect" (even in the absence of disputable cracked and nonprotrusive atheroma plaque), in the conditions of a normal sanguine circulation.

Therefore, if we consider blood a Bingham-type rheological fluid, then

$$\tau = \tau_0 + \eta \frac{dv}{dr} \quad (1)$$

where τ is the viscosity tangential unitary effort, τ_0 is the deformation tangential unitary effort, dv/dr is the velocity gradient with respect to the normal on the transversal section, and η is the viscosity coefficient.

Our fractal model (4, 5) was used for in vivo analyses of 10 clinical cases of patients with acute occlusive thrombus on an absolutely healthy artery. These cases were selected during a 2-year period (2013–2015). Patients with atrial fibrillation were excluded for preventing mismatch with thromboembolic acute coronary occlusion. Patients with patent foramen ovale (diagnosed by transesophageal echocardiography) were excluded to avoid a paradoxical coronary embolism. Intravascular ultrasound or coronary CT angiography were not performed in these patients; although some irregularities could be seen on angiography, it is clear that there are no significant ulcerated atheroma plaques or major signs of parietal atherosclerosis. Also, in patients >50 years, an absolutely normal coronary wall is more likely a utopia. We performed EKG Holter monitoring in all patients for exclusion of paroxysmal atrial fibrillation.

We present here the two most relevant cases (Fig. 1a–h) with thrombus dimensions of ≥60 mm (for the other eight cases, the thrombus dimensions were between 30 and 60 mm). For all the cases, our theoretical results were verified by coronarography images.

1) Patient 1 was a 52–year-old male patient who was diagnosed with acute inferolateral ischemia. Coronary angiography revealed an acute occlusive thrombus (4–4.5 mm diameter and 60–80 mm length) at the junction between segments I and II of the right coronary artery. After thrombus aspiration, a distal thrombotic embolism appeared with an apparently healthy artery (or possible minimal lesion with no sign of plaque dissection) at the initial thrombus level. Repeated thrombus aspira-

Address for correspondence: Maricel Agop, Lasers, Atoms and Molecules Physics Laboratory
University of Science and Technology, Villeneuve d'Ascq, 59655, Lille-*France*
E-mail: m.agop@yahoo.com
Accepted Date: 18.05.2017

DOI:10.14744/AnatolJCardiol.2017.7825

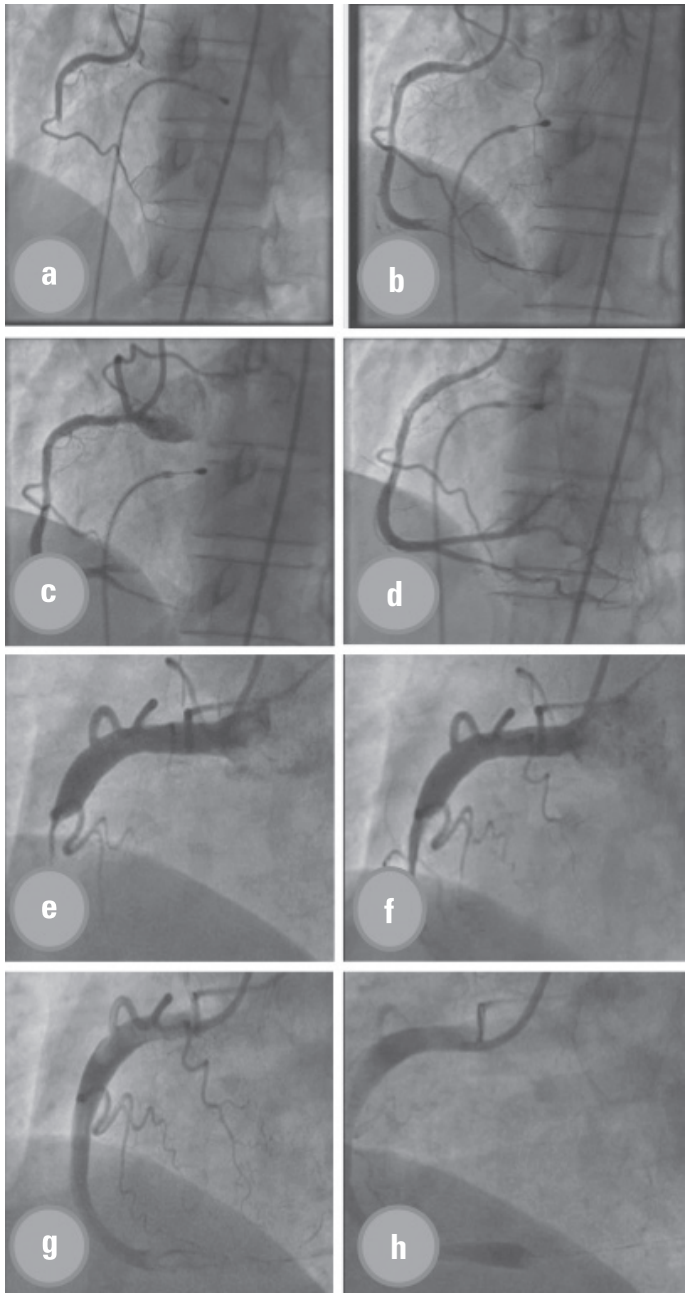

Figure 1. (a–h) Acute thrombus formation in apparently healthy artery with no evidence of plaque dissection like as a responsible lesion — different interventional approach stages: patient 1 (a–d), patient 2 (e–f)

tion at the level of secondary occlusion revealed the posterior descending branch and subsequently posterolateral branch. Also, there was no evident coronary lesion responsible for the above stated pathological phenomena.

2) Patient 2 was a 57–year-old male patient who was diagnosed with acute inferior and poster lateral ischemia. Coronary angiography revealed an acute occlusive thrombus that extended from the beginning of the right coronary artery segment II to crux (4.5–5 mm diameter and approximately 80–100 mm length), with a possible extension to the right posterior descending artery and poster lateral branches. Unsatisfying results in terms of distal TIMI flow were observed (0–1) but with no evidence of significant atherosclerotic disease at the level of culprit zone.

We present in Table 1 the average experimental parameters of blood flow through the right coronary artery used in our study and also the average theoretical parameters of blood flow through the right coronary artery obtained using our theoretical model (4, 5).

The mathematical procedure we used had the following steps:

1) Determining the values of Reynolds' number for blood flow through the right coronary artery, using the following relation:

$$R_e = \frac{v_S D}{\eta}$$

where v_S is the minimum value of the average experimental systolic velocity of blood, D is the average experimental diameter of the right coronary artery, and η is the average kinetic viscosity coefficient of blood;

2) Determining the values of the loss coefficient of blood flow through the same artery, using Darcy's formula (6):

$$\lambda = \frac{64}{\mathrm{R}_e} = \frac{64\eta}{v_S D}$$

3) Determining the values of the pressure loss for blood flow, using the following relation (6):

$$\Delta p = \lambda \frac{L}{D} \rho \frac{v_d^2}{2} = 32\eta\rho \frac{L}{D^2} \frac{v_d^2}{v_S}$$

where L is the average length of the experimental thrombus, ρ is the average experimental blood density, and v_d is the maximum value of average experimental systolic velocity of blood;

4) Determining the theoretical dimension of a right coronary artery thrombus, using the relation:

$$D_t = \frac{4\tau_0 L}{\Delta p} = \frac{1}{8} \frac{v_S \tau_0 D^2}{\eta \rho v_d^2}$$

where τ_0 is the average experimental deformation stress of blood (7, 8).

We can thus see a good conformity between the values from the theoretical model with the experimental/real estimated values (9, 10) in coronary angiography we found in the two cases presented above. Due to the fact that our model can be extrapolated to every cylindrical structure, in our opinion similar phenomena can occur, at least theoretically, in every artery of similar dimensions and hydrodynamic regimen (brain, kidney, and splanchnic system)

We must state that we do not propose a total rebutting of the classical models of thrombus formation, but we want to offer an alternative explanation for some unusual acute occlusion cases.

Conflict of interest: None declared.

Peer-review: Externally peer-reviewed.

Table 1. Average experimental parameters of blood flow through the right coronary artery for the two clinical cases

Patient's age (years)	D_e **(mm)**	L **(mm)**	τ_0 **(N/m²)**	v_d **(cm/s)**	v_S **(cm/s)**	ρ **(kg/m³)**	η **(m²/s)**
52	4	70	9/75 mm Hg	35±11	24±7	1060	3.04×10^{-6} at 36.5°C
57	5	90	7/83 mm Hg	35±11	24±7	1060	3.04×10^{-6} at 36.5°C
Observations			The method from [9] was used	The method from [9] was used	The method from [10] was used	The method from [10] was used	The method from [9] was used
R_e	λ	Δp **(N/m)**	D_t **(mm)**				
226	0.283	634	4.54				
283	0.226	457	5.52				

D - average experimental thrombus diameter; L - average experimental thrombus length; τ_0 - average experimental deformation stress as a function of diastolic pressure; v_d - average experimental diastolic velocity; v_S - average experimental systolic velocity; ρ - average experimental blood density; η - average experimental kinetic viscosity coefficient; R_e– Reynolds' number; λ - Darcy's loss coefficient; Δp - pressure loss; D_t - thrombus diameter determined using our model

Authorship contributions: Concept – N.D.T., M.A.; Design – N.D.T., M.A.; Supervision – I.N.; Fundings – I.N.; Materials – N.D.T., I.N.; Data collection &/or processing – V.G., M.A.; Analysis and/ or interpretation – V.G., M.A.; Literature search – N.D.T.; Writing – V.G., C.L.U.; Critical review – C.L.U.

References

1. Hiatt WR, Baumgartner I, Bluemke DA. Peripheral manifestations of atherothrombosis. In: Topol JE, editor. Atlas of Atherothrombosis. Beijing; China; 2004. p. 109-10.
2. Badimon L, Vilahur G. Thrombosis formation on atherosclerotic lesions and plaque rupture. J Intern Med 2014; 276: 618-32. [CrossRef]
3. Tomey MI, Narula J, Kovacic JC. Year in Review: Advances in Understanding of Plaque Composition and Treatment Options. J Am Coll Cardiol 2014; 63: 1604-16. [CrossRef]
4. Popa RF, Nedeff V, Lazăr G, Scurtu D, Eva L, Ochiuz L, et al. Bingham Type Behaviours in Complex Fluids. Stopper Type Effect. Journal of Computational and Theoretical Nanoscience 2015.p. 3178-82. [CrossRef]
5. Tesloianu ND, Ghizdovăţ V, Agop M. Flow Dynamics via Non-Differentiability and Cardiovascular Disease. A Proposal for an Interdisciplinary Approach between Non-Differentiable Physics and Cardiovascular Morphopatology. Saarbrucken: Scholars' Press; 2015.
6. Bar-Yam Y. Dynamics of Complex Systems. Reading: Addison-Wesley; 1997.
7. Axinte CI, Baciu C, Volovaţ S, Tesloianu D, Boros Z, Baciu A, et al. Flow dynamics regimes via nondifferentiability in complex fluids. UPB. Sci Bull 2014; Series VII: 233-42.
8. Tesloianu D, Vrajitoriu L, Costin A, Vasincu D, Timofte D. Dispersive behaviours in biological fluids. Applications II. The Bulletin of the Polytechnic Institute of Iasi – Mathematics, theoretical mechanics, physics section: Romania; 2014; LX 3.
9. Sharif D, Sharif-Rasslan A, Shahla C, Khalil A, Rosenschein U. Differences in coronary artery blood velocities in the setting of normal coronary angiography and normal stress echocardiograpgy. Heart Int 2016; 10: e6-e11.
10. Malek AM, Alper SL, Izumo S. Hemodynamic shear stress and its role in atherosclerosis. JAMA 1999; 282: 2035-42. [CrossRef]