

## Hemodynamic determination of risk turbulent flow on atherosclerotic and endothelial shear stress in coronary lumen stenosis regimes

### *Determinação hemodinâmica do risco de fluxo turbulento sobre o cisalhamento aterosclerótico e endotelial em regimes de estenose de lúmen coronariano*

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**ABSTRACT:** Introduction: Acute myocardial infarction is considered one of the main clinical conditions that cause death in the world. Its prevalence denotes its importance and several reasons can culminate in sudden obstruction of the coronary lumen. Objective: to determine the influence of shear stress for the early detection of atheromatous plaques at risk of rupture or erosion, making it possible to predict infarction in these situations. Methodology: articles were selected from the PubMed, Lilacs, Medline, Scielo and Google Scholar databases, using DeCS and MeSH descriptors to homogenize the results. As the discoveries in the field of study are recent, filters were not used for the research, linearly employing the articles mentioned above, to support this review. Results / discussion: The models brought from fluid mechanics associated with chemical/biological measurements of detection by laboratory and imaging tests have pointed to pathological shear stress as a stimulus for damage to atheromatous plaques and consequent exposure to the possibility of abrupt obstruction of coronary lumen. Conclusion: Many of the current essays have been pointing to this possible pillar of investigation, however, several variables involve the subject, still requiring a deepening in theoretical and practical studies to strengthen and map the details of this mechanical aspect, in relation to the consequent infarction.

**Keywords:** Shear; Turbulent; Flow; Hemodynamics; Acute myocardial infarction; Coronary.

**RESUMO:** Introdução: O infarto agudo do miocárdio é considerado como uma das principais condições clínicas causadoras de mortes no mundo. Sua prevalência denota sua importância e diversos motivos podem culminar na obstrução repentina do lúmen coronariano. Objetivo: determinar a influência da tensão de cisalhamento para a detecção precoce de placas de ateroma sujeitas a riscos de ruptura ou erosão, tornando-se possível prever o infarto nestas situações. Metodologia: artigos foram selecionados nos bancos de dados PubMed, Lilacs, Medline, SciELO e Google Scholar, utilizando descritores DeCS e MeSH para homogeneizar os resultados. Por serem recentes as descobertas neste campo de estudo, não foram utilizados filtros para a pesquisa, empregando linearmente os mencionados artigos acima, para embasamento desta revisão. Resultados / discussão: Os modelos trazidos da mecânica dos fluidos associados a medidas químicas/biológicas de detecção por exames laboratoriais e de imagem têm apontado a tensão de cisalhamento patológica como um estímulo para lesão de placas de ateroma e consequente exposição à possibilidade de obstrução abrupta de lúmen coronariano. Conclusão: Muitos dos ensaios atuais vêm apontando para esse possível pilar de investigação, entretanto, diversas variáveis envolvem o tema, ainda sendo necessário um aprofundamento nos estudos teóricos e práticos para fortalecimento e mapeamento dos detalhes deste aspecto mecânico, em relação consequente ao infarto.

**Palavra-chave:** Cisalhamento; Turbilhonamento; Fluxo; Hemodinâmica; Infarto agudo do miocárdio; Coronária.

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## INTRODUCTION

When observing the scenario of the last decades, the prevalence of cardiovascular events has been increasing gradually, even among the young adult population, since acute myocardial infarction (AMI) is the main cause of death in the world<sup>1</sup>. In patients with abrupt obstruction of the coronary artery by thrombus, erosion of the atheroma plaque generates 25 to 30%, while rupture leads to 65% of these events<sup>2</sup>. Updated studies consider that the volume of the atheroma plaque is not associated with the threat of rupture, as previously attributed, with occasional plaque lesions occurring in sites of mild/moderate lumen obstruction<sup>3,4</sup>.

The importance of this finding is on the fact that there may not be such a direct relationship between the presence of significant obstructions (usually coronary stenoses > 50%) and local thrombogenesis<sup>3,4</sup>. It is assumed that patients with an oligo or asymptomatic history of anginal events may also develop an acute occlusion event. Therefore, it is questionable whether the current stages of screening, investigation and conduct based mainly on plaque topography (location and percentage of obstruction), as well as post-obstructive nutritional intake (flow fraction reserve (FFR) and levels perfusion tests) are sufficient as a means of inquiring about the risk of coronary heart disease.

Recently, studies have recorded a possible key, which would be the missing piece in the puzzle for optimizing the investigation of risk in patients with stable chronic coronary artery disease (CAD): shear by turbulence and the composition of the atheroma plaque<sup>5</sup>.

## METHODOLOGY

This study is a narrative literature review on the recent evolution of the investigative methods for patients with asymptomatic plaques or stable angina, that manifest the presence of atheromatous plaques with a risk of progression to acute lumen obstruction.

The research was carried out in the PubMed, Lilacs, Medline, Scielo, Google Scholar databases, using terms registered in descriptors such as DeCS and MeSH: ischemia, infarction, shear stress, vortex, endothelial, atherosclerotic, in addition to their respective translations into Portuguese. The Boolean operator AND was added as a tool to cross information. Due to the recent discoveries of this branch of investigation in the literature, there was no filter for the date of publication of the articles or the type of work published.

The inclusion criterion was supported by a sequence of evaluations: title, abstract, result and conclusion. If, by chance, the weightings consistently contributed to the investigation of this review, in their entirety, they were included, then. Furthermore, papers in which certain topics

were not convergent or when they mentioned shear stress for other functions were excluded from the search. There was the incorporation of 56 works collaborating for the construction of this verification.

Because it is a narrative review, given the recent trend of these findings in the scientific field, exhausting the data sources published around this theme was not the focus, however, it was intended to create a line of investigation based on citations throughout of each topic addressed, in order to reforce the idea explored in this publication.

## RESULTS

### Current clinical protocols

The conducts for patients diagnosed with acute coronary syndromes (ACS), to date, are well established and the effectiveness of intervention in these cases has already been proven in a way that guarantees better survival<sup>6</sup>. However, for patients with chronic stable CAD, due to the large number of variables that act on the plaque (topography, percentage of obstruction, post-stenotic flow, patient's lifestyle, composition, medications in use, among others) it becomes more difficult to analyze which plaque is subject to interventional or conservative conduct for the prevention of an acute event<sup>7</sup>.

Some of these data have already been elucidated statistically, such as carrying out mass intervention procedure policies without prior functional evaluation, which did not show efficacy in medium to long-term survival, after 5 years, when compared to groups exposed to an interventionist or conservative protocol<sup>8</sup>.

Thus, the current guidelines first seek to screen patients at pre-test risk for CAD (chest pain, dyslipidemia, early family history, ankle-brachial index, coronary calcium score, among others). After that, non-invasive tests are performed, such as stress electrocardiogram (ECG), stress echocardiogram (ECO), stress myocardial scintigraphy or others, which are methods that will stratify the patient's cardiovascular risk<sup>9</sup>.

After the initial screening process, the guidelines have two main fomenters for assessing coronary artery disease: perfusion regions (inactive zones, FFR, among others) and anatomy of the lesion<sup>9</sup> (complexity of lesion morphology, site of obstruction, percentage of occluded lumen). The modalities of non-interventional exams are varied, and each one uses parameters in their findings, whose objective is to describe the two main pillars above. These tools usually try to differentiate CAD patients at high or low risk for ACS and thus stratify where and when to intervene<sup>9,10,11</sup>.

To optimize these conducts, there are, for example, applications of score tests, whose function is to assess the probability of CAD, before performing tests, such as the Diamond-Forrester, Hubbard or Morise, and the definition

of the severity of the post-test coronary artery disease, such as the Duke, Athens, or Syntax score. The latter assists in the choice of patients for revascularization surgery or percutaneous coronary intervention (PCI) in CAD, branch of left coronary artery (LCA) or three-vessel diseases. The analyzed variables are location, number of arteries, length, tortuosity, percentage of occlusion and degree of calcification<sup>12</sup>.

Consequently, when aligning the information, after using the data obtained from tests and scores, the guidelines merge these data to promote, when there is an indication of medication management, PCI angioplasty procedures or myocardial revascularization surgeries (CABG)<sup>9,13,14</sup>.

### Targeting by base guidelines

The key points that are generally adopted by the guidelines, considered weighty, to determine the conduct in the risk of atherosclerotic disease in chronic CAD, frequently include: 1- choice of patients who should be investigated for coronary disease (pre-test evaluation); 2 - methods that will diagnose and stage the CAD; 3 - intervention parameters in each situation. Enumerating some of the main guidelines that we take as a basis for actions, we have the Brazilian, European and American Guidelines, which, succinctly, designate the following conducts:

**Brazilian Stable CAD Guideline (2014)**<sup>9</sup> = applies the use of algorithms to identify CAD in asymptomatic patients during screening and symptomatic patients when performing a pre-test score (such as diamond/forrester). Classification is based on pain pattern, physical examination, medical history such as smoking, and family history. To consider significant CAD in this Guideline, criteria such as obstruction greater than 70% in a larger epicardial artery, stenosis greater than 50% in a proximal LCA, last vessels or ischemic area of the left ventricle greater than 10%. In patients with intermediate and high risk (pre-test) of having CAD, the investigation is guided by exams such as Ultrasound<sup>15</sup>, stress ECG, stress ECO, stress myocardial scintigraphy, computed tomography (CT) and magnetic resonance imaging (MRI) cardiovascular and catheter (coronary angiography), to stratify the risk of developing an acute cardiac event. Patients classified as high risk are those who met the criteria for functional issues (Duke score, myocardial contraction, ejection fraction) or tissue nutrition (perfusion and ischemia).

**Brazilian Guideline on Percutaneous Coronary Intervention (2008)**<sup>8</sup> = reports that patients with stable coronary disease are indicated for PCI when there is limiting angina in the routine or presence of ischemic definition. The Guideline shows that the Fame 2 study highlights that revascularization of plaques that do not generate ischemia has been shown to be harmful. Another analysis in the database of the state of New York demonstrated that in

4 years, there was a reduction in the number of AMI and mortality in patients under PCI, when compared to clinical treatment. However, the Guidelines indicate difficulties in assuring the results, published until that moment, due to the heterogeneity of variables, use of non-pharmacological or first-generation drug-eluting stents, low sample power in some studies, among other points.

**European Society of Cardiology (2021)**<sup>16</sup> = The European Society of Cardiology and the European Association of Cardiothoracic Surgery (ESC/EACTS) consider efforts to prevent the high number of deaths from coronary causes in asymptomatic adults. In general, it is advisable to use estimation systems for CAD and if the high risk is met, the investigation should continue with non-invasive and/or invasive tests, depending on the case. This Guideline points out that there are not enough data to describe the management of asymptomatic patients with only positive tests for obstruction. Non-invasive investigation tests, when selected, are described as functional (in order to verify sections with ischemia) and anatomical (lumen determination)<sup>16-18</sup>. The FFR is a tool to aid in the functional assessment of obstructions when the degree of stenosis is intermediate (40 to 90% of obstruction in sites without evidence of ischemia).

**American Guideline for Chest Pain (2021)**<sup>19</sup> = the American Guideline for chest pain demonstrates that the clinic directs investigation for CAD in order to assess the anatomy and severity of ischemia. The scores, in the pre-test assessment for chronic CAD, can predict whether there is a low obstructive risk, meaning that the other tests can be postponed. The Coronary Artery Calcification (CAC) score (obtained by CT primarily on the Agatston score) has been a good additional pre-test predictor for pathology. In those selected as intermediate/high risk diagnostic tests, the following are already indicated: exercise ECG, stress ECO, myocardial perfusion image by CT PET or SPECT and cardiovascular MRI. For those at low risk, the indication is in stress ECG or CAC definition. Those defined as significant obstruction are chosen for invasive coronary angiography, which is proposed precisely in 4 situations: moderate to severe ischemia, FFR <0.8, high risk for CAD in CCTA (>50%) that generate frequent angina and inconclusion in stress tests.

**Coronary Artery Revascularization Guideline (2021)**<sup>20</sup> = The most recent American Guideline on revascularization defines, as significant obstruction, a stenosis  $\geq 50\%$  for left-stem disease and a diameter  $\geq 70\%$ , visually estimated, for non-stem disease left. Lesion length has also been considered to outline the degree of risk. In multivessel CAD, the SYNTAX score can be useful to classify the lesion. This Guideline chooses as complicating factors of CAD: the anatomy of the lesion (such as length > 20 mm, trifurcations, tortuosities and complex bifurcations), functional parameters (diseased segments distal to the lesion), the degree of stenosis/obstruction

(total occlusion) and calcification irregular. In this regard, thrombotic injury is also considered a complex factor.

Therefore, in said Guidelines, the absence of citations for some variables that have been relevant in current studies for stable chronic CAD, such as shear stress, or even details on the composition of the atheromatous plaque. The European Guideline points out that in patients with CAD, situations of occurrence of acute ischemic events with fatal outcome are documented with some frequency, even in previously asymptomatic patients. Therefore, it is understood to be an abrupt interruption of coronary flow in a place with low previous obstruction<sup>16</sup>. Still pointing to the importance of CRM and PCI, both still need further studies to clarify their correct indication in these variables, as well as deepening the techniques of biomarkers and imaging tests for tracking asymptomatic patients, however, who already have CAD<sup>16</sup>.

### Proposed methods for coronary research

The importance of studying asymptomatic patients is evidenced by the possibility of the development of an acute ischemic event in a patient with stable chronic CAD without pain alarm<sup>21</sup>, something seen in clinical practice and medical literature<sup>11</sup>. For this, studies have aimed at which exam and variable to point out as high-risk identification in these patients.

A risk factor for CAD instability and conversion into an acute event are the pathological shear stresses, both due to the risk of rupture and erosion of the plaque, in addition to the endothelial shear stress itself<sup>22</sup>. This shear stress depends on flow turbulence factors, which in pulsatile regime are usually linked to variables known as Reynolds number and Womersley number<sup>23</sup>. In 2013, Campbell and colleagues were considered the first to correlate fluid mechanics with plaque erosion<sup>24,25</sup>.

However, in addition to the tangent/parallel force to the plate generating risks, the plate pattern exposed to this pressure can also contribute to facilitating its instability. An important point, of medical knowledge, is the characteristics of the atheromatous plaque that suggest an increased risk for thrombogenicity, such as low attenuation plaques (lipid characteristic < 30 Hounsfield units on CT), positive remodeling and calcification spots<sup>26</sup> or CAC<sup>19</sup>.

Some of the possible coronary mapping proposals for these two risk variables for CAD instability are:

**Biological and image biomarkers:** due to atherosclerotic disease being an association of an inflammatory process linked to the accumulation of cholesterol, methods of evaluating its cascade (E-selectin and P-selectin, interleukin-6 and tumor necrosis factor alpha, protein C (CRP), fibrinogen and serum amyloid A) may be a tool for cardiovascular risk markers. High sensitivity CRP, lipoprotein associated with phospholipase A2 and coronary artery calcium score are also among the current studies<sup>21</sup>. Endothelin 1 has been a studied marker to

assess endothelial dysfunction and inflammation and early stages of atherosclerosis development<sup>27</sup>.

**Magnetic Resonance:** the shear rate, through carotid considerations, was verified by the non-invasive MRI method. In this model, a sub-millimeter spatial definition, with high temporal resolution, was obtained, generating shear information throughout the entire arterial segment, added to the cardiac cycle variations<sup>28</sup>.

**Optical Coherence Tomography:** this tool has been able to detail the surface components of the plaque, with an average resolution of 10mm, including measurements of the thickness of the fibrous cap, the amount of constituent lipid and even the infiltration of macrophages<sup>29</sup>. All of these points can help determine a plaque pattern that is more prone to injury.

**Intravascular Ultrasound (IVUS):** it does not provide a functional assessment of the degree of stenosis, however, it may be useful for anatomical assessment of the lesion in relation to plaque composition and vessel size<sup>15</sup>.

**Endothelial Shear Stress Calculation:** this physical criterion, imported from fluid mechanics, has been applied to blood flow after hemodynamic engineering studies using materials stress-strain calculation tools and computational fluid dynamics<sup>14,30</sup>. Methods such as the Navier Stokes equation can help in the calculation of coronary shear stress<sup>31</sup>.

In this context, it would be possible to expand the investigation of patients, demonstrating the important variables (topographic and nutrition/post-stenosis flow) and extending it to an analysis arm, which according to new studies, has been shown to be strategic in view of the risk of AMI in Stable CAD: calculation of endothelial shear by turbulent flow and type of plaque subject to rupture risks.

### SHEAR STRESS BY FLOW TURBILLION

The application of hemodynamic engineering is progressively more present in the study of these patterns and demonstrates that the shear generated by a sudden change in flow produces a tangent force<sup>22</sup>, which is capable of producing three additional risks: rupture of the atheromatous plaque, erosion of the plaque and endothelial injury<sup>32</sup>.

Injuries to the plaque, as well as aggression to the endothelium, based on Virchow's triad<sup>33</sup>, lead to the exposure of prothrombotic factors, which potentiate a sudden occlusion of flow, in a place where there were not necessarily previous symptoms or significant obstruction, and may thus, to elucidate the dim situation where patients at low risk of AMI, with small plaques, even sometimes being negative in reliability markers such as FFR, develop an acute event<sup>34</sup>. This risk is apparently linked to two main points: the non-physiological shear stress and the pattern of atheroma plaque more susceptible to ruptures.

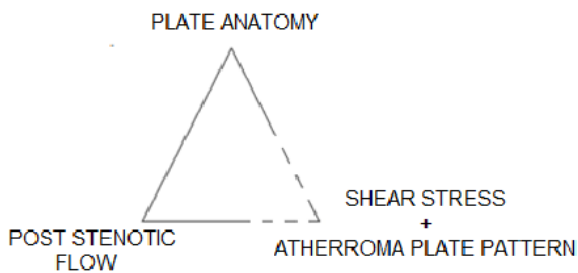
Shear stress is classified as physiological, high (>

2.5 Pa) and low (<1 Pa). This pressure difference generates different impacts on the endothelium. The physiological shear stress, in uniform movements (laminar regime), manifests protection against thrombotic events. In studies where there is more advanced atherosclerosis, sites with plaque rupture were associated with high shear stress (HSs)<sup>22,35</sup>.

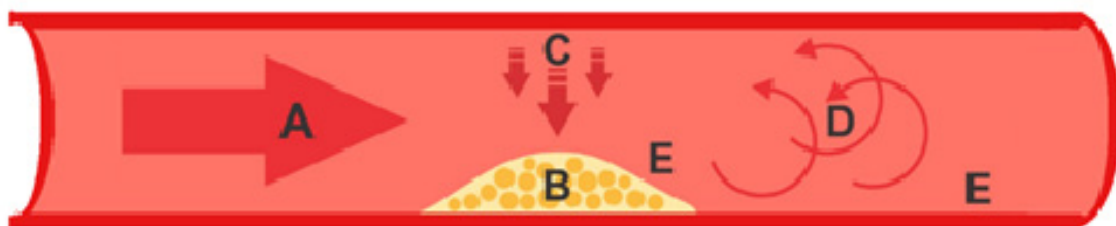
Detailed studies show that HSs generates increased plaque necrosis, expansive remodeling, increased tension, intraplatelet hemorrhage and necrotic core. In addition to these effects, HSs also increases the local thrombotic propensity for platelet dysfunction. Situations caused by super high HSs (~15 to 20 Pa) still need further studies in the literature<sup>22</sup>. Studies show that high levels of shear stress may be associated with the vulnerability of the atherosclerotic plaque. By adding the proximal plaque shear stress information to FFR values < 0.8, it has been possible to better predict the risk of developing myocardial infarctions<sup>35</sup>.

For low shear stresses (LSs), in sites with flow disorders, there is negative regulation for vasculoprotective pathways, in contrast to positive regulation for pro-inflammatory, pro-atherogenic and pro-thrombotic pathways<sup>22</sup>. Beyond this point, LSs promotes increased permeability of LDL to the subendothelial space. This provokes the attraction of inflammatory cells, weakening the arterial wall and leading to the thinning of the fibrous layer, which makes the plaque more prone to ruptures<sup>22</sup>.

These new studies have substantially pointed out that the coronary risk of infarction is not only related to the percentage of obstruction and the post-stenotic nutritional flow (mostly measured by the FFR), they suggest a possible triad of analysis, and the tripod also involves shear<sup>18,36</sup>, along with the plate pattern exposed to this pressure (Figure 1).



**Figure 1** - Possible triad of variables related to coronary obstruction risk.



**Figure 2** - theoretical demonstration of turbulent flow after atherosclerotic plate.

This theoretical risk of creating an obstruction due to thrombogenesis is then stimulated by an association between the chemical and physical aspects, coming both from the aforementioned pathophysiological basis and based on the laws of fluid mechanics. Thus, atherosclerosis decreases the cross-sectional free section for blood flow, which generates an increase in flow velocity, with consequent turbulence and shear. These assumptions create two main risks: increased shearing in arterial walls, as well as the formation of notches in atheromatous plaques that can produce clots in vessels that would cause infarction<sup>37</sup>.

When evaluating the current Guidelines on the subject, we noticed an apparent absence of reports that consider the physical principles, constructed by hemodynamic engineering in chaotic flow movements, as a potential thrombogenic risk due to shearing in plaques or endothelium. Creating a bridge between these sides, we have current studies that describe the importance of this item as a risk for patients with stable CAD.

## DISCUSSION

### Theoretical-experimental determination of turbillion shear

The physical principle underlying this concept encompasses a set of pulsation dynamics variables, endocrine/hormonal process issues, plaque and endothelium malleability, among others. However, the generic basis imported from fluid mechanics for this event can be adapted around the pressure drop located as a Venturi tube, nozzle or orifice tube, adapting the difference by the geometry of the obstructing singularities of the plate.

The history of flow in a coronary with plaque comprises the laminar flow (A) which, when touching the atheromatous plaque deposited on the endothelium (B), generates pressure loss (C) and change in flow conformation (D) projecting shear stresses to the endothelium or on the plate itself (E)<sup>37</sup> (Figure 2).

The localized head loss, noted by the difference in the Bernoulli equation<sup>38</sup> (Equation 1), is one of the critical points, at which the barrier will generate a change in the flow pattern (laminar-turbulent). One of the points that emphasizes this is the fact that the Reynolds number (Re) is inversely proportional to the flow diameter, therefore, during the plate, this can raise the Re, leading to the flow transition (Equation 2). Physically, the Bernoulli equation for real fluids demonstrates that the localized head loss dissipates this change directly proportional to the square of the velocity, as seen by the Darcy-Weisbach equation (Equation 3)<sup>38,39,40,41</sup>. Thus, by Newton's second law, this possible change in velocity (acceleration) can establish an increase in force, thus enhancing the shear stress.

**Equation 1:**

$$\frac{V_1^2}{2 \cdot g} + \frac{\rho_1}{\gamma} + Z_1 = \frac{V_2^2}{2 \cdot g} + \frac{\rho_2}{\gamma} + Z_2 + \Delta H$$

That said, when there is formation of the stenosis throat, changes are generated in the conformation of the laminar flow - whirlpool, head loss and shear stress. It is possible to verify by computer projections (Figure 3),

**Equation 2:**

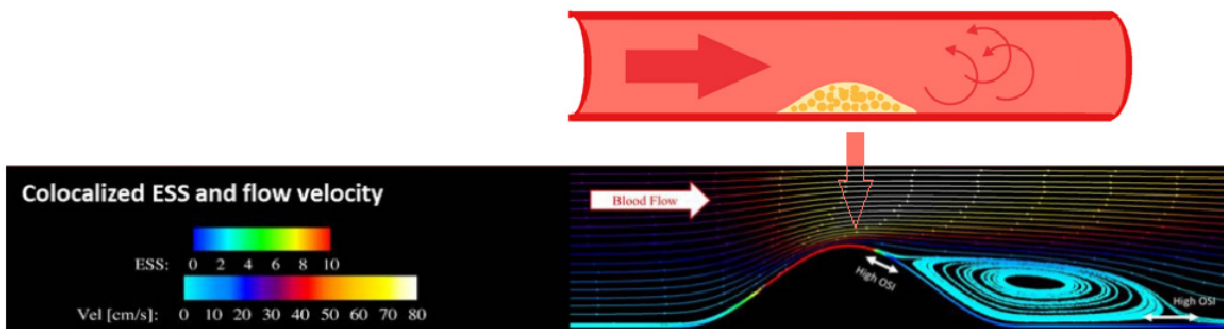
$$\left. \begin{aligned} R_e &= \frac{\rho \cdot V \cdot D}{\mu} \\ V &= \frac{Q}{A} = \frac{4 \cdot Q}{\pi \cdot D^2} \end{aligned} \right\} \rightarrow R_e = \frac{4 \cdot \rho \cdot Q}{\mu \cdot \pi \cdot D}$$

**Equation 3:**

$$\frac{V_1^2}{2 \cdot g} + \frac{\rho_1}{\gamma} + Z_1 - \left( \frac{V_2^2}{2 \cdot g} + \frac{\rho_2}{\gamma} + Z_2 \right) = \Delta H$$

$$\frac{V_1^2}{2 \cdot g} + \frac{\rho_1}{\gamma} + Z_1 - \left( \frac{V_2^2}{2 \cdot g} + \frac{\rho_2}{\gamma} + Z_2 \right) = K \cdot \frac{V_2^2}{2 \cdot g}$$

that hemodynamics creates zones of high shear pressure at the apex of the plate, as well as a decrease in tension downstream of the same, with reports in the literature that both types of tensions expose the plate to risks. erosion<sup>31</sup> and rupture trigger<sup>18,36</sup>.



**Figure 3** - Coronary layout with atheromatous plaque and its equivalent to a fluid dynamic computational projection (adapted original image, belonging to the text by Gijssen F. et al<sup>31</sup>).

### Shear stress as a prothrombotic variable

In recent years, attempts have been made to demonstrate which are the high-risk plaques in CAD that can lead to an acute event<sup>42</sup>. Until then, the modality described by the Guidelines focuses mainly on the morphology and location in which it is located. Chemically, it has been proposed that physiological shear stresses release atheroprotective signals, while LSs correlates with pro-atherogenic pathways and plaque progression, and HSs is related to the reduction of fibrous tissue, increased necrotic center and plaque calcium content<sup>43</sup>, may culminate in ACS<sup>42</sup>. Shear is capable of activating the PIEZO1 ion channel, initiating a signal that leads to the

opening of TRPV4, which is responsible for the sustained elevation of calcium, generating pathological events in endothelial cells<sup>44</sup>.

Another point is that studies show that HSs occurs at the apex of the stenosis, where the shear rate can help platelet adhesion and thrombotic formation, completely occluding this lumen<sup>45</sup>. For this to occur, it has been pointed out that high shear stresses may be related to platelet activation itself and the consequent prothrombotic effect<sup>46</sup>.

There is also the mechanical risk of plaque erosion, which is responsible for 20 to 40% sudden coronary deaths. This differs from rupture because a superficial injury occurs, being more linked to the plaque pattern with an abundant amount of smooth muscle cells and a small

lipid center, arising from turbulent flow disturbances from acute narrowings that generate superficial erosions with consequent formation of thrombus and vascular events<sup>47,48</sup>. It has been suggested that both high and low shear stress can lead to erosion<sup>49,50</sup>.

Plaque rupture with subsequent thrombogenesis is the most important mechanism for ACS formation, and studies have shown that a high localization of shear stress can correlate with coronary plaque rupture<sup>36</sup>. In this context, early identification of imminent rupture plaques is necessary to reduce cardiac morbidity and mortality<sup>51</sup>. Much of the advances in current discoveries are fostered in the technological evolution of studies, such as IVUS or optical coherence tomography<sup>52,53</sup>, which have been tools to aid in the *in-vivo* understanding of these findings.

Branched shear stress variables, such as high spatial gradient, indicate a value associated with atheromatous plaque rupture, while variables such as oscillatory shear index, spatial gradient and the shear stress itself are related to plaque erosion, and may also help more on understanding the pre-injury mechanism<sup>54,55</sup>.

Unraveling the pathogenesis of plaque aggression is a step towards understanding ACS<sup>55</sup>. Therefore, analyzes have shown that the risk is due to the association of a stress greater than the resistance of the plate<sup>8</sup>, with the shear stress capable of being the trigger of simultaneous risk in the chemical processes of atherogenesis and structural conformation changes, as well as risks mechanics that culminate in erosion and rupture<sup>47,56</sup>.

**Participation:** *Ferreira MHQ* - final review of the entire text, assistance in the construction of the text, assistance with text translation, evaluation of the modeling of formulas related to the case, determination of the title; *Fumagalli BC*: participation in the construction of the text, participation in the translation of the text; *Teixeira AB*: participation in the construction of the text, participation in the translation of the text; *Sampaio Neto S* - evaluation of physics and modeling of mathematical formulas related to the case of the mathematical and engineering part of fluid mechanics. *Barbosa LK*:

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## CONCLUSION

Shear stress is a physical principle that happens tangential to the impact region and its applicability in hemodynamics and flow rheology are complex fundamentals. Considering the evolution of coronary analysis methods, perspectives are expanded in the evaluative scope on the tension pattern and the risks that this force establishes.

So far, these studies have highlighted points of chemical activation that pathological tension can provoke, both in atherogenesis and in the change in the property of the atheromatous plaque, leading to a greater risk of ruptures. The mechanical action on the endothelium, capable of exposing the subendothelial content, is a pro-thrombogenic factor.

Considering that there is still a need for more studies that point out all the details of the risk of turbulent flow, in front of an atheromatous plaque, analyzing the critical Reynolds number, behavioral pattern of unstable plaques, shear pressure values, in addition to their own biological variables related to the patient, such as blood pressure, lipid levels, blood viscosity and others, it is concluded that this point may, in the future, be among one of the variables present in the Guidelines for considering high-risk plaques. Thus, turbulent flow risk analysis may be a new tool capable of predicting when to intervene in order to minimize cases of ACS resulting from stable CAD.

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