

Chronic Coronary Artery Lesions: Advanced Diagnostic Modalities and Therapeutic Strategies with Emphasis on Intravascular Ultrasound and Optical Coherence Tomography

Donaldo Emiliano Silva Lopez^{*1}, Isidro Fabián Martínez Valeriano², Jorge Esteban Sánchez Muñoz³, César Alejandro Trejo González², Ana Yoatzin Chávez Gómez⁴, Paloma Guadalupe Cardona Chávez⁴, Yéremi Saúl Miranda Uribe⁵, Guadalupe Montserrath Rojas Martínez³, Ivana Leilani Júnez Villicaña⁶

¹Tecnológico de Monterrey Campus Monterrey. Mexico.

²Universidad Autónoma de Aguascalientes. Mexico.

³Universidad Cuauhtémoc, Plantel Aguascalientes. Mexico.

⁴Universidad Cuauhtémoc, Plantel Aguascalientes, Jesús María. Mexico.

⁵Universidad Autónoma de Guadalajara. Mexico.

⁶Universidad. Universidad michoacana de San Nicolas de Hidalgo. Mexico

ABSTRACT

Chronic coronary artery lesions represent a complex and progressive manifestation of atherosclerotic disease, often leading to significant morbidity and mortality due to myocardial ischemia and subsequent adverse cardiovascular events. The accurate diagnosis and characterization of these lesions are paramount in guiding optimal therapeutic interventions and improving long-term prognostic outcomes. In contemporary interventional cardiology, intravascular ultrasound (IVUS) and optical coherence tomography (OCT) have emerged as indispensable imaging modalities, offering high-resolution, cross-sectional visualization of coronary artery architecture, plaque composition, and vessel dimensions. These advanced techniques facilitate precise lesion assessment, enabling tailored revascularization strategies, including percutaneous coronary intervention (PCI) with stent optimization. This article comprehensively reviews the pathophysiology of chronic coronary lesions, current evidence-based treatment approaches, and the prognostic implications of various therapeutic modalities. Furthermore, it highlights the pivotal role of IVUS and OCT in enhancing diagnostic accuracy, procedural success, and long-term vessel patency, thereby refining clinical decision-making in the management of chronic coronary artery disease.

KEYWORDS: Chronic coronary lesions, atherosclerosis, intravascular ultrasound (IVUS), optical coherence tomography (OCT), percutaneous coronary intervention (PCI), plaque characterization, stent optimization, cardiovascular prognosis

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INTRODUCTION

Chronic coronary artery lesions, characterized by the persistent and progressive narrowing of the coronary vasculature due to advanced atherosclerosis, remain a principal contributor to ischemic heart disease and its associated complications. The pathophysiological underpinnings of these lesions involve a dynamic interplay of endothelial dysfunction, lipid accumulation, inflammatory cascades, and fibrotic remodeling, culminating in luminal

stenosis and impaired myocardial perfusion. Despite advancements in pharmacological and interventional therapies, the management of chronic coronary lesions continues to pose significant clinical challenges, particularly in cases of complex anatomy, calcified plaques, or diffuse disease.^{1,2}

Traditional diagnostic approaches, such as coronary angiography, provide a luminographic assessment but often fall short in delineating the intricate morphological features

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of atherosclerotic plaques and vessel walls. In this context, intravascular imaging techniques, specifically IVUS and OCT, have revolutionized the diagnostic paradigm by offering unparalleled insights into plaque morphology, lesion severity, and stent-vessel interactions. IVUS, with its deep tissue penetration, excels in evaluating vessel dimensions and plaque burden, whereas OCT, with its micron-level resolution, excels in delineating fibrous cap integrity, thrombus presence, and stent strut apposition.^{2,3}

The integration of these modalities into clinical practice has not only refined diagnostic precision but also enhanced procedural outcomes by facilitating optimal stent selection, deployment, and expansion. Moreover, their prognostic utility in predicting restenosis, stent thrombosis, and long-term vessel patency underscores their indispensable role in contemporary interventional cardiology. This article delves into the multifaceted aspects of chronic coronary lesions, encompassing their etiopathogenesis, evolving treatment algorithms, and the transformative impact of IVUS and OCT on patient-centered care and cardiovascular outcomes.^{3,4}

BACKGROUND

Chronic coronary lesions represent a significant subset of coronary artery disease (CAD) and are characterized by long-standing atherosclerotic plaques that result in fixed, often complex obstructions within the coronary vasculature. These lesions typically evolve over years and are frequently associated with stable anginal symptoms, myocardial ischemia on functional testing, or incidental findings during angiographic evaluation in patients undergoing assessment for other cardiovascular conditions. Unlike acute coronary syndromes, where the culprit lesions are typically lipid-rich and prone to rupture, chronic coronary lesions are marked by fibrotic, calcified, and endothelialized plaques, often with a history of positive arterial remodeling, luminal narrowing, and in many cases, collateral circulation.^{3,4}

Pathophysiologically, the chronicity of these lesions involves a dynamic interplay between endothelial dysfunction, chronic inflammation, smooth muscle cell proliferation, extracellular matrix remodeling, and progressive deposition of calcific and fibrotic material. Over time, these processes culminate in plaques that are structurally stable but hemodynamically significant. The complexity and chronicity of these lesions can pose substantial challenges in terms of revascularization, both surgically and percutaneously, particularly when there is extensive calcification, tortuosity, or involvement of bifurcation points.^{4,5}

From a clinical standpoint, the management of chronic coronary lesions requires a meticulous assessment of ischemic burden, patient comorbidities, anatomical considerations, and potential procedural risks. While optimal medical therapy remains a cornerstone of treatment, particularly in patients with low symptom burden or high surgical risk, revascularization strategies such as

percutaneous coronary intervention (PCI) or coronary artery bypass grafting (CABG) are frequently indicated in cases of significant stenosis, refractory symptoms, or high-risk anatomical features. However, PCI in chronic lesions, especially in the context of chronic total occlusions (CTOs) or long, calcified segments, is associated with lower procedural success rates, higher contrast usage, and increased procedural time compared to non-complex lesions.⁵

In this context, the use of advanced intravascular imaging modalities such as intravascular ultrasound (IVUS) and optical coherence tomography (OCT) has revolutionized the diagnostic and therapeutic approach to chronic coronary lesions. IVUS, by employing high-frequency sound waves, enables real-time cross-sectional imaging of the vessel wall and plaque architecture, providing invaluable information regarding plaque burden, lesion length, vessel diameter, and the extent of calcification. This information facilitates appropriate stent sizing, optimization of stent expansion, and detection of complications such as malapposition or edge dissections. Furthermore, IVUS is particularly advantageous in the evaluation of calcific lesions, where it helps determine the need for lesion preparation with atherectomy or other plaque modification techniques.⁵

Conversely, OCT utilizes near-infrared light to achieve ultra-high-resolution imaging of the coronary artery lumen and superficial plaque components. Its superior resolution allows for detailed characterization of fibrous caps, microcalcifications, macrophage accumulations, and thrombus, which can be especially useful in distinguishing between stable and vulnerable plaque phenotypes. In chronic lesions, OCT is instrumental in guiding precise stent deployment, assessing neointimal coverage during follow-up, and evaluating restenosis mechanisms.⁵

The integration of IVUS and OCT into contemporary interventional cardiology has significantly enhanced the precision and safety of PCI in chronic coronary lesions. Numerous studies have demonstrated that imaging-guided PCI, particularly IVUS-guided, is associated with improved long-term outcomes, including reduced rates of target lesion revascularization, stent thrombosis, and major adverse cardiovascular events. The prognostic implications of chronic coronary lesions are intricately tied to the adequacy of revascularization, plaque morphology, and the completeness of lesion coverage, all of which are better assessed with intravascular imaging than with angiography alone.^{5,6}

Therefore, the role of IVUS and OCT extends beyond mere diagnostic adjuncts; they are integral tools in the decision-making process, procedural planning, and post-intervention assessment. In an era where personalized, anatomy-guided intervention is paramount, these imaging modalities offer a more granular and pathophysiologically informed approach to the management of chronic coronary artery disease, ultimately influencing both procedural success and long-term prognosis.⁷

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Common Lesions and Imaging Characteristics in Chronic Coronary Artery Disease

Chronic coronary lesions encompass a wide spectrum of atherosclerotic pathologies that evolve gradually over time and are associated with stable ischemic heart disease. These lesions are pathologically heterogeneous but share a common feature of progressive luminal narrowing caused by the accumulation of atheromatous plaque within the arterial intima. Among the most frequently encountered lesions in chronic coronary artery disease are fibroatheromas, fibrocalcific plaques, lipid-rich plaques, and heavily calcified or nodular calcific lesions, each presenting with distinct morphological and biomechanical profiles. The identification and characterization of these plaques have profound implications for therapeutic planning, procedural strategy, and prognosis, particularly in the setting of percutaneous coronary intervention.^{7,8}

Fibroatheromatous plaques are among the most common lesions identified in stable coronary disease. These plaques typically consist of a lipid core surrounded by a thick fibrous cap and are less likely to rupture compared to thin-cap fibroatheromas. On intravascular imaging, IVUS typically reveals these lesions as hypoechoic or isoechoic regions with preserved structural integrity and often with concentric or eccentric narrowing. OCT provides higher-resolution visualization, allowing for a detailed assessment of cap thickness and intraplaque features such as macrophage infiltration or microchannels. These fibroatheromas may produce flow-limiting stenoses, particularly in long segments, and often benefit from lesion preparation to achieve optimal stent expansion.⁹

Another prevalent finding in chronic coronary artery disease is the presence of fibrocalcific lesions, which are plaques predominantly composed of dense fibrous tissue and calcium. These are hallmarks of advanced atherosclerosis and are typically resistant to mechanical dilation during PCI. On IVUS, calcific plaques are noted as bright, echogenic arcs often accompanied by posterior acoustic shadowing, preventing visualization of deeper vessel layers. IVUS is highly sensitive for identifying the arc and depth of calcification and for determining the presence of superficial versus deep calcium. OCT, although limited in the depth of tissue penetration, offers exceptional resolution to visualize superficial calcium sheets, the thickness of calcium deposits, and calcium fractures following plaque modification techniques. These features are vital when deciding on the need for rotational or orbital atherectomy or lithotripsy to optimize lesion compliance and ensure effective stent delivery and expansion.⁹

Lipid-rich plaques, although more characteristic of acute coronary syndromes, can also be found in chronic coronary lesions, particularly in patients with mixed lesion morphology or in transitional plaques progressing toward chronicity. On IVUS, lipid-rich areas often appear as signal-

poor regions with poorly defined borders, while OCT allows for a more precise distinction, often visualizing diffuse low-signal zones with overlying fibrous caps. Although these lesions are not as common in chronic presentations, their identification may influence pharmacologic strategies and prompt closer follow-up due to the potential for future instability.⁹

Calcified nodules, though less frequent, are another lesion type associated with chronic coronary artery disease, particularly in elderly patients or those with chronic kidney disease. These nodules represent disrupted fibrous caps with protruding calcific deposits that may extend into the lumen. On IVUS, they are visualized as focal echogenic protrusions with acoustic shadowing and often irregular surfaces. OCT, due to its superior resolution, can delineate these nodular calcium protrusions more clearly, detecting overlying thrombus or irregular surfaces, both of which may carry procedural implications such as increased risk of stent underexpansion or embolization.¹⁰

In long-standing atherosclerotic disease, negative or positive arterial remodeling can also be visualized, reflecting the vessel's adaptive response to plaque accumulation. IVUS is particularly adept at detecting these remodeling patterns and quantifying plaque burden along the length of the lesion. Lesions with positive remodeling may appear deceptively mild on angiography, but intravascular imaging often reveals a substantial plaque burden, necessitating a more aggressive treatment approach.¹⁰

Chronic total occlusions (CTOs) represent the most extreme form of chronic coronary lesions and pose significant challenges in interventional cardiology. These lesions, defined by complete luminal occlusion for more than three months, are frequently composed of dense fibrous or calcific material with neovascularization and microchannels. IVUS plays a critical role in guiding wire passage, identifying the true lumen, and avoiding subintimal dissection. It can also delineate the proximal cap morphology, which is often ambiguous on angiography. OCT has more limited use in CTOs due to the lack of distal blood flow, but it can be employed post-recanalization to assess stent apposition and optimize final results.¹¹

The imaging findings associated with these chronic lesions are far more informative than those obtained by angiography alone, which primarily assesses luminal patency without insight into plaque composition or vessel wall architecture. Intravascular ultrasound offers robust evaluation of plaque burden, vessel size, and calcification, while OCT contributes unparalleled resolution for detecting surface-level pathology and guiding meticulous stent deployment. When used synergistically, these modalities not only enhance the safety and efficacy of PCI but also allow for tailored lesion-specific strategies, ultimately improving long-term outcomes.¹¹

Treatment decisions in the context of chronic coronary lesions are heavily influenced by these imaging

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characteristics. Lesions with extensive calcification may require mechanical debulking or plaque modification to prevent stent underexpansion, which is a known risk factor for in-stent restenosis and stent thrombosis. Conversely, soft plaques with adequate luminal dimensions and minimal calcification may be treated with conventional balloon predilation and stenting. Prognostically, patients with imaging-verified optimal stent expansion, minimal residual plaque burden, and absence of edge dissections experience significantly lower rates of target lesion failure and repeat revascularization.¹¹

Therefore, the comprehensive characterization of chronic coronary lesions through IVUS and OCT transcends diagnostic purposes, becoming a central component in procedural planning, real-time guidance, and post-procedural assessment. These modalities facilitate a nuanced understanding of lesion pathology and permit the implementation of highly personalized interventional strategies, reflecting the evolution of modern coronary artery disease management from a purely anatomical approach to a physiology- and pathology-driven paradigm.¹²

Prognosis of Chronic Coronary Lesions: Clinical Implications and the Role of Intravascular Imaging

The long-term prognosis of patients with chronic coronary lesions is shaped by a multifactorial interplay between lesion morphology, clinical presentation, comorbid conditions, and the efficacy of therapeutic intervention. Chronic coronary artery disease, typically manifesting as stable angina or silent ischemia, is associated with a more indolent natural history than acute coronary syndromes; however, it still confers significant morbidity and mortality, especially in the presence of multivessel disease, reduced left ventricular function, or suboptimal revascularization. The quality and completeness of myocardial revascularization, whether achieved surgically or percutaneously, remain pivotal determinants of prognosis in this patient population.¹²

Patients with advanced atherosclerotic disease often harbor complex coronary lesions—long, fibrotic, calcified, or tortuous segments—that present unique challenges to percutaneous coronary intervention (PCI). In these settings, the adequacy of lesion preparation, stent expansion, and proper apposition are central to ensuring durable clinical outcomes. Suboptimal PCI results, characterized by residual stenosis, edge dissections, stent underexpansion, or malapposition, are all well-established predictors of adverse events including restenosis, stent thrombosis, and recurrent ischemia. In this regard, intravascular imaging modalities such as intravascular ultrasound (IVUS) and optical coherence tomography (OCT) have become indispensable tools, not only for diagnosis but also for procedural guidance and prognostication.¹³

The incorporation of intravascular imaging has fundamentally altered the landscape of interventional cardiology by enhancing the ability to identify high-risk

plaque features, define vessel architecture, and ensure technical optimization of stent deployment. IVUS, with its capacity to evaluate plaque burden, calcific distribution, and vessel dimensions beyond the confines of the angiographic silhouette, facilitates more precise stent sizing and thorough lesion coverage. It has been repeatedly associated with reductions in target lesion revascularization, stent thrombosis, and overall cardiovascular events, particularly in complex lesions such as left main disease, long lesions, or heavily calcified plaques. By allowing direct visualization of stent expansion relative to the external elastic membrane, IVUS helps operators achieve expansion thresholds known to be predictive of favorable long-term outcomes.¹³

Similarly, OCT, with its superior spatial resolution, permits the identification of subtle morphological features that may be invisible to angiography or even IVUS. It allows for precise assessment of stent edge dissections, neointimal coverage, malapposition, and intrastent restenosis, all of which carry distinct prognostic implications. Lesions treated with OCT-guided PCI demonstrate a higher frequency of complete stent apposition and expansion, correlating with improved vessel healing and lower incidence of late thrombotic events. Moreover, OCT is particularly valuable in post-PCI assessment, guiding decisions about the need for additional post-dilatation or further lesion modification, ultimately leading to more refined and individualized therapeutic strategies.¹³

Beyond procedural optimization, the prognostic benefit of intravascular imaging also lies in its ability to detect and characterize non-culprit lesions with vulnerable features, such as thin-cap fibroatheromas or extensive lipid-rich cores. The identification of such high-risk plaques may prompt intensification of medical therapy or closer clinical surveillance, thereby modifying the trajectory of disease progression and mitigating the risk of future events.¹³

Despite advances in revascularization techniques, certain subsets of chronic lesions—particularly chronic total occlusions (CTOs)—continue to portend a more guarded prognosis. Although successful CTO revascularization has been associated with improvements in angina, quality of life, left ventricular function, and even survival in selected populations, procedural failure or incomplete revascularization can significantly attenuate these benefits. In this context, intravascular imaging, especially IVUS, plays a vital role in enhancing success rates by facilitating guidewire passage, confirming intraluminal positioning, and ensuring proper stent placement and expansion even in the most technically challenging scenarios.¹⁴

Furthermore, the long-term prognosis of patients with chronic coronary lesions is also intimately linked to the extent of myocardial ischemia, the burden of residual atherosclerosis, and the systemic inflammatory milieu. Even after technically successful PCI, patients remain at risk of disease progression both within the treated segment and in other vascular

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territories. Intravascular imaging contributes to risk stratification by allowing more comprehensive lesion assessment, which can influence not only procedural choices but also decisions regarding adjunctive pharmacologic therapy, such as intensified lipid-lowering or antiplatelet regimens.¹⁴

Ultimately, the prognostic narrative of chronic coronary lesions is no longer dictated solely by the angiographic degree of stenosis. Rather, it reflects a more nuanced understanding of plaque biology, mechanical optimization, and patient-specific factors. The integration of IVUS and OCT into routine clinical practice has allowed for a shift from a purely anatomic to a pathology-informed and precision-guided interventional approach. These modalities enable clinicians to move beyond the limitations of angiography, uncover the hidden complexities of coronary artery disease, and intervene in a manner that not only restores luminal patency but also addresses the structural and biological underpinnings of the atherosclerotic process.^{14,15}

In conclusion, the long-term outcomes of patients with chronic coronary lesions are significantly influenced by the nature of the atherosclerotic substrate, the adequacy of revascularization, and the application of advanced imaging to ensure procedural excellence. As technology and technique continue to evolve, the synergistic use of intravascular imaging promises to refine risk stratification, enhance therapeutic precision, and ultimately improve prognosis in this high-risk cardiovascular population.

CONCLUSION

Chronic coronary lesions represent a complex and heterogeneous manifestation of coronary artery disease, often evolving silently over time until the cumulative effects of myocardial ischemia, plaque burden, and luminal narrowing culminate in clinically significant symptoms or cardiac dysfunction. These lesions, while generally more stable than their acute counterparts, carry a substantial burden of morbidity due to their anatomical complexity, resistance to mechanical dilation, and frequent association with diffuse atherosclerosis. Their chronicity is reflected not only in their structural makeup—comprising fibrotic, calcified, or lipid-laden plaques—but also in their functional consequences, including reduced coronary flow reserve, collateral vessel development, and persistent myocardial strain. The clinical decision-making surrounding these lesions is therefore inherently nuanced and must be guided by both anatomic and pathophysiologic insights.

The advent and widespread integration of high-resolution intravascular imaging modalities, particularly intravascular ultrasound (IVUS) and optical coherence tomography (OCT), have markedly transformed the diagnostic and therapeutic landscape for chronic coronary lesions. These technologies provide a level of detail far beyond what is achievable with conventional angiography, offering critical insights into

plaque composition, lesion morphology, vessel size, and stent-tissue interactions. IVUS, through its ability to assess plaque burden and vessel remodeling in real time, serves as a cornerstone in the procedural planning of complex percutaneous coronary interventions, ensuring accurate stent sizing, optimal expansion, and complete lesion coverage. OCT, with its superior spatial resolution, complements this by facilitating precise identification of superficial plaque features, stent malapposition, and post-deployment complications that would otherwise go unnoticed. Together, these imaging tools have redefined the standards for procedural success, enabling a more tailored, anatomy-guided approach that translates into improved patient outcomes.

The prognosis of patients with chronic coronary lesions is closely intertwined with the quality of revascularization and the degree of myocardial recovery post-intervention. Numerous studies have substantiated that intravascular imaging-guided PCI not only enhances immediate technical outcomes but also significantly reduces the incidence of late complications such as restenosis, target lesion revascularization, and stent thrombosis. This underscores the critical importance of precision imaging in achieving not just procedural success, but durable, long-term cardiovascular stability. Furthermore, intravascular imaging facilitates a deeper understanding of the pathobiological underpinnings of chronic coronary disease, enabling more informed decisions regarding adjunctive pharmacotherapy, surveillance strategies, and secondary prevention measures.

In light of these advances, the management of chronic coronary lesions can no longer rely solely on angiographic assessment or symptom burden alone. Instead, it demands a comprehensive approach that integrates high-resolution intravascular imaging, individualized risk stratification, and meticulous procedural technique. As the field of interventional cardiology continues to evolve toward greater precision and personalization, the role of IVUS and OCT will undoubtedly become even more central—not merely as diagnostic adjuncts, but as essential instruments of interventional strategy and prognostic optimization.

In conclusion, the future of chronic coronary lesion management lies in the seamless integration of advanced imaging, physiological assessment, and clinical judgment. By leveraging the full diagnostic power of IVUS and OCT, clinicians are better equipped to navigate the complexities of chronic coronary artery disease, implement tailored therapeutic strategies, and deliver superior long-term outcomes for a population at ongoing risk for cardiovascular events. The continued refinement of these techniques and their incorporation into clinical guidelines will be essential in advancing the field toward more effective, safer, and enduring interventions in coronary artery disease.

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