Coronary Artery Tortuosity: Beyond an Incidental Angiographic Finding:Implications for Myocardial Mechanics Evaluated by Speckle-Tracking Echocardiography

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Abstract

Background: Coronary artery tortuosity (CAT) has traditionally been regarded as a benign angiographic finding with limited clinical significance. However, accumulating evidence suggests that CAT may be associated with altered coronary hemodynamics, reduced distal perfusion pressure, impaired coronary flow reserve, and myocardial ischemia even in the absence of obstructive coronary artery disease. Patients with CAT frequently present with angina-like symptoms, positive stress tests, or reversible perfusion abnormalities despite normal epicardial coronary arteries. In recent years, advances in myocardial deformation imaging have enabled the detection of subtle abnormalities in cardiac function that are not evident using conventional echocardiographic parameters such as left ventricular ejection fraction. Two-dimensional speckle-tracking echocardiography (2D-STE), particularly through the assessment of global longitudinal strain (GLS), has emerged as a sensitive and reproducible technique for identifying early myocardial dysfunction.

Aim: This review aims to summarize the current understanding of coronary artery tortuosity and its potential impact on myocardial mechanics as assessed by speckle-tracking echocardiography. Particular emphasis is placed on the pathophysiological mechanisms linking CAT to myocardial dysfunction, the evolving evidence supporting the presence of subclinical impairment in ventricular performance, and the potential clinical implications of incorporating deformation imaging into the evaluation of patients with tortuous coronary arteries.

Experimental and computational studies have demonstrated that tortuous coronary segments may produce significant alterations in blood flow patterns and pressure gradients, potentially leading to chronic low-grade myocardial ischemia. Clinical investigations have further identified associations between CAT and impaired left ventricular relaxation, reduced myocardial perfusion, and abnormalities in strain-derived indices of ventricular function. Emerging data obtained using 2D-STE indicate that patients with CAT may exhibit reductions in GLS and other deformation parameters despite preserved ejection fraction, suggesting the presence of early myocardial dysfunction that may otherwise remain undetected. These findings challenge the traditional perception of CAT as merely an incidental anatomical variant and support the hypothesis that coronary tortuosity may have important functional consequences.

Conclusion: Coronary artery tortuosity should no longer be viewed exclusively as an innocuous angiographic phenomenon. Growing evidence indicates that CAT may contribute to impaired myocardial performance through hemodynamic and ischemia-related mechanisms. Speckle-tracking echocardiography offers a valuable non-invasive approach for the identification of subclinical myocardial dysfunction in this population and may enhance risk stratification and clinical decision-making. Nevertheless, current evidence remains limited by small study populations and heterogeneous definitions of CAT. Larger prospective studies using standardized diagnostic criteria are warranted to clarify the prognostic significance of myocardial deformation abnormalities in patients with coronary artery tortuosity and to define the role of speckle-tracking echocardiography in routine clinical practice.

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Keywords: *Coronary Artery Tortuosity, Angiographic Finding, Speckle-Tracking Echocardiography*

Introduction

Coronary artery tortuosity (CAT) is a commonly encountered angiographic finding characterized by the presence of multiple bends, twists, or curvatures along the course of the epicardial coronary arteries. Although the precise definition varies among studies, CAT is generally identified by the presence of consecutive coronary angulations exceeding predefined thresholds during end-diastole. Historically, coronary tortuosity has been regarded as a benign anatomical variant without major clinical consequences and is often documented incidentally during invasive coronary angiography performed for the evaluation of chest pain or suspected coronary artery disease. However, increasing evidence suggests that CAT may represent more than a simple morphological abnormality and could have important pathophysiological and clinical implications. [1]

The prevalence of CAT varies considerably among different populations because of heterogeneous diagnostic criteria and differences in study design. Several investigations have demonstrated that coronary tortuosity is more frequently observed in elderly individuals, women, and patients with hypertension. Furthermore, associations between CAT and conditions such as spontaneous coronary artery dissection, fibromuscular dysplasia, connective tissue disorders, and Takotsubo syndrome have reinforced the hypothesis that tortuosity may reflect an underlying vasculopathy rather than an isolated angiographic curiosity. These observations have prompted renewed interest in understanding the mechanisms responsible for coronary tortuosity and its potential impact on cardiovascular function. [2]

The exact pathogenesis of CAT remains incompletely understood. Age-related degeneration of elastin fibers, alterations in the extracellular matrix, chronic exposure to elevated intraluminal pressures, and adaptive remodeling secondary to changes in myocardial geometry have all been proposed as contributing factors. Computational fluid dynamics studies have demonstrated that tortuous arterial segments may generate abnormal flow patterns, increased resistance, and pressure losses distal to the tortuous segment. These hemodynamic alterations may become more pronounced during periods of increased myocardial oxygen demand, potentially leading to impaired coronary perfusion and ischemia in the absence of obstructive epicardial coronary disease. [3]

Clinical studies have increasingly supported the concept that CAT may be associated with adverse functional consequences. Patients with severe tortuosity have been shown to exhibit a higher prevalence of chest pain, abnormal stress testing, and reversible myocardial perfusion defects despite angiographically normal coronary arteries. Moreover, previous investigations have identified associations between coronary tortuosity and impaired left ventricular diastolic function, suggesting that chronic subtle ischemia or altered ventricular–vascular interactions may contribute to myocardial dysfunction. Collectively, these findings challenge the traditional perception of CAT as a benign phenomenon and highlight the need for more sensitive tools capable of detecting early myocardial impairment. [4]

Conventional echocardiographic parameters, particularly left ventricular ejection fraction, may remain within normal limits until relatively advanced stages of myocardial injury. Consequently, subtle abnormalities in myocardial performance can remain undetected using standard imaging techniques. Speckle-tracking echocardiography (STE) has emerged as a robust, angle-independent modality for the quantitative assessment of myocardial deformation. By tracking natural acoustic markers within the myocardium throughout the cardiac cycle, STE enables the evaluation of global and regional myocardial mechanics through measurements of strain and strain rate. Among these parameters, global longitudinal strain (GLS) has gained widespread clinical acceptance as a sensitive marker of subclinical left ventricular systolic dysfunction. [5]

The clinical utility of STE has been demonstrated across a broad spectrum of cardiovascular diseases, including ischemic heart disease, cardiomyopathies, valvular disorders, heart failure, and cardio-oncology. In the setting of coronary artery disease, deformation imaging can identify myocardial dysfunction before detectable reductions in ejection fraction occur and has shown incremental value in diagnosis, risk stratification, and prognostic assessment. The ability of STE to detect subtle alterations in myocardial performance has generated interest in its application to patients with coronary abnormalities that may not produce significant epicardial stenosis but nevertheless impair myocardial perfusion. [6]

Emerging evidence indicates that patients with coronary artery tortuosity may exhibit abnormalities in myocardial deformation despite preserved conventional measures of ventricular function. Studies employing speckle-tracking echocardiography have reported reductions in left ventricular global longitudinal strain and alterations in other indices of myocardial mechanics among individuals with CAT. These findings support the hypothesis that tortuous coronary anatomy may contribute to subclinical myocardial dysfunction through chronic hemodynamic disturbances and intermittent ischemia. However, available studies remain limited by relatively small sample sizes, variations in the definitions used to characterize CAT, and heterogeneity in echocardiographic methodologies. [7]

Despite growing interest in this field, there remains a lack of comprehensive reviews integrating the existing evidence regarding the relationship between coronary artery tortuosity and myocardial mechanics assessed by STE. Most published reviews have focused either on the anatomical and interventional aspects of CAT or on the technical applications of deformation imaging, without adequately addressing the intersection between these two evolving areas of cardiovascular research. Consequently, clinicians may underestimate the potential significance of CAT in symptomatic patients with non-obstructive coronary arteries and preserved ejection fraction. [1]

The present review aims to provide a comprehensive overview of coronary artery tortuosity and its implications for myocardial performance evaluated by speckle-tracking echocardiography. Specifically, this review will discuss the epidemiology and pathophysiological mechanisms of CAT, summarize current approaches for its diagnosis and classification, review the principles and clinical applications of STE, and critically appraise the available evidence linking coronary tortuosity to abnormalities in myocardial deformation. By synthesizing contemporary data, we seek to clarify whether CAT should continue to be regarded as an incidental angiographic finding or recognized as a potential marker of subclinical myocardial dysfunction with important diagnostic and prognostic implications.

Coronary Artery Tortuosity: Definitions, Epidemiology, and Classification

Coronary artery tortuosity (CAT) refers to the presence of multiple bends, twists, or curvatures along the course of the epicardial coronary arteries and is frequently encountered during invasive coronary angiography. Despite its common occurrence in daily clinical practice, a universally accepted definition of CAT remains lacking. The absence of standardized diagnostic criteria has contributed substantially to variations in the reported prevalence and has complicated comparisons among studies investigating its clinical significance. Traditionally, CAT has been considered a benign anatomical variant; however, accumulating evidence suggests that this phenomenon may have important pathophysiological and prognostic implications that extend beyond its angiographic appearance. [8]

Several definitions of CAT have been proposed in the literature, with the most widely adopted classification introduced by Eleid and colleagues. In this system, tortuosity is defined as the presence of at least three consecutive curvatures ranging from 45° to 90° measured during end-diastole in a major epicardial coronary artery with a diameter of at least 2 mm. This approach provides a practical framework for identifying tortuous vessels and has been extensively utilized in studies evaluating the association between CAT and spontaneous coronary artery dissection, fibromuscular dysplasia, and myocardial dysfunction. Nevertheless, differences in angiographic projections and observer interpretation continue to influence the reproducibility of these measurements. [9]

According to the angiographic classification proposed by Eleid et al., coronary tortuosity can be categorized into mild, moderate, and severe forms based on the degree and number of vessel angulations. Mild tortuosity is characterized by at least three consecutive curvatures between 45° and 90°, whereas moderate tortuosity involves three or more consecutive bends measuring 90°–180° in a major epicardial vessel. Severe tortuosity is defined by the presence of at least two consecutive curvatures of 180° or greater. This classification has enhanced the uniformity of CAT assessment and facilitated the investigation of potential relationships between the severity of tortuosity and clinical outcomes. [9]

The prevalence of CAT reported in the literature varies considerably, reflecting differences in patient populations, angiographic techniques, and diagnostic definitions. Studies involving patients undergoing coronary angiography for evaluation of chest pain have demonstrated that CAT is not an uncommon finding. In particular, severe coronary tortuosity appears to be more frequently observed among individuals without significant obstructive coronary artery disease, raising the possibility that CAT itself may contribute to ischemic symptoms in a subset of patients. These observations have challenged the conventional view that tortuous coronary arteries merely represent incidental anatomical findings devoid of functional significance. [10]

Demographic characteristics have consistently emerged as important determinants of CAT. Female sex has been repeatedly identified as an independent predictor of coronary tortuosity, with women exhibiting a higher prevalence of tortuous coronary anatomy compared with men. Advanced age has also been strongly associated with CAT, likely reflecting age-related alterations in the structural composition of the arterial wall, including fragmentation of elastin fibers and increased vascular stiffness. In addition, hypertension has been implicated as a major contributing factor, possibly through chronic exposure of the arterial wall to elevated hemodynamic stress that promotes vascular remodeling and elongation. [8]

The relationship between CAT and traditional cardiovascular risk factors remains controversial. While some investigations have suggested an association between coronary tortuosity and atherosclerotic disease, others have reported a lower prevalence of obstructive coronary artery disease among patients with severe tortuosity. These conflicting findings may be explained by differences in study design, definitions of tortuosity, and patient selection criteria. Consequently, whether CAT represents an independent marker of early atherosclerosis or a distinct vascular phenotype unrelated to plaque burden remains an area of ongoing investigation. [11]

Beyond its association with conventional cardiovascular risk factors, CAT has been increasingly recognized in patients with non-atherosclerotic vascular disorders. Among these conditions, spontaneous coronary artery dissection (SCAD) has demonstrated one of the strongest relationships with tortuous coronary anatomy. The presence of CAT in patients with SCAD has been proposed as a marker of an underlying arteriopathy and has been linked to an increased risk of recurrent events. Moreover, similar angiographic features have been described in individuals with fibromuscular dysplasia, further supporting the concept that CAT may reflect a manifestation of systemic vascular abnormalities rather than an isolated coronary phenomenon. [12]

From an interventional perspective, the recognition and classification of CAT are of considerable practical importance. Severe tortuosity may complicate percutaneous coronary intervention by increasing the technical difficulty of guidewire advancement, balloon delivery, and stent deployment. Tortuous anatomy has also been associated with longer procedural times, increased contrast utilization, and a higher risk of complications, including vessel dissection and equipment failure. Consequently, coronary tortuosity has been incorporated into lesion complexity scoring systems such as the SYNTAX score, emphasizing its relevance in therapeutic decision-making and procedural planning. [8]

Despite advances in the characterization of CAT, important knowledge gaps remain. The lack of universally accepted diagnostic criteria continues to limit comparisons across studies, while the clinical implications of varying degrees of tortuosity are incompletely understood. Future investigations employing standardized definitions and multimodality imaging approaches are needed to clarify the epidemiology, pathophysiological significance, and prognostic impact of coronary tortuosity. Improved understanding of this frequently encountered angiographic finding may ultimately facilitate more accurate identification of patients at risk of myocardial dysfunction and adverse cardiovascular outcomes.

Pathophysiological Mechanisms Linking Coronary Artery Tortuosity to Myocardial Dysfunction

The mechanisms through which coronary artery tortuosity (CAT) influences myocardial performance remain incompletely understood. For decades, CAT was considered a benign angiographic variant because it rarely produces fixed epicardial coronary obstruction. However, growing evidence suggests that the geometric alterations characteristic of tortuous coronary arteries may substantially affect coronary hemodynamics and myocardial perfusion. These functional consequences have emerged as a plausible explanation for the occurrence of ischemic symptoms and subclinical myocardial dysfunction in patients with CAT despite the absence of significant atherosclerotic stenosis. [13]

One of the principal mechanisms proposed to explain myocardial impairment in CAT is the reduction in distal coronary perfusion pressure. Tortuous arterial segments increase the effective length of the vessel and introduce multiple directional changes that can increase resistance to blood flow. Computational simulations have demonstrated progressive pressure loss distal to tortuous segments, particularly as the degree of angulation becomes more severe. Such reductions in perfusion pressure may compromise myocardial blood supply, especially during periods of increased oxygen demand when coronary flow reserve is required. [14]

Altered coronary flow dynamics constitute another important pathophysiological pathway. The normal coronary circulation depends on relatively streamlined blood flow patterns that optimize endothelial function and myocardial perfusion. In tortuous vessels, however, repeated curvatures disturb laminar flow and generate complex hemodynamic environments characterized by flow separation and energy dissipation. These disturbances may reduce flow efficiency and predispose susceptible myocardial territories to transient ischemia, even in the absence of anatomically significant stenosis. [15]

The hemodynamic consequences of CAT may become particularly evident during physical exertion or emotional stress. Under resting conditions, basal myocardial perfusion may remain adequate despite the presence of tortuous anatomy. During exercise, however, increased myocardial oxygen demand requires augmentation of coronary blood flow. The inability of tortuous vessels to provide sufficient increases in distal perfusion pressure and flow reserve may result in demand-induced ischemia. This hypothesis is supported by reports of reversible perfusion defects and positive stress tests in patients with severe CAT and angiographically normal coronary arteries. [16]

Endothelial dysfunction has also been proposed as a contributing mechanism linking CAT to myocardial abnormalities. Variations in shear stress generated by altered flow patterns can influence endothelial cell behavior and vascular homeostasis. Oscillatory shear stress has been associated with impaired nitric oxide bioavailability, increased oxidative stress, and enhanced expression of pro-inflammatory mediators. Although direct evidence remains limited, these endothelial alterations may further compromise coronary vasodilatory capacity and contribute to the development of myocardial ischemia in patients with tortuous coronary anatomy. [17]

Subclinical myocardial ischemia resulting from chronic hemodynamic disturbances may eventually affect ventricular relaxation and myocardial mechanics. The subendocardial longitudinal fibers are particularly vulnerable to reductions in perfusion because of their high metabolic demand and greater exposure to intramyocardial pressure. Consequently, impairment of longitudinal myocardial function may occur before abnormalities in radial function or left ventricular ejection fraction become evident. This pathophysiological sequence provides a strong rationale for employing deformation imaging techniques capable of detecting early changes in myocardial performance. [18]

Previous echocardiographic studies have demonstrated an association between CAT and abnormalities of left ventricular diastolic function. Impaired relaxation indices observed in patients with tortuous coronary arteries suggest that chronic low-grade ischemia may adversely influence ventricular compliance and filling dynamics. Because diastolic dysfunction often precedes overt systolic impairment, these findings support the concept that CAT may have clinically relevant effects on myocardial function even when conventional echocardiographic parameters remain within normal ranges. [19]

Recent advances in myocardial deformation imaging have further expanded understanding of the functional consequences of CAT. Investigations utilizing speckle-tracking echocardiography have identified reductions in strain-derived indices of myocardial performance among patients with coronary tortuosity. These abnormalities likely reflect the cumulative effects of chronic perfusion disturbances on myocardial fiber function, particularly within the longitudinally oriented subendocardial layers. Such observations challenge the traditional perception of CAT as a harmless anatomical variant and suggest that it may instead represent a marker of subclinical myocardial injury. [20]

Although the currently available evidence supports a biologically plausible relationship between CAT and myocardial dysfunction, several uncertainties remain. Most existing studies are observational in nature and have involved relatively small populations. Furthermore, variability in the definitions of tortuosity and differences in imaging methodologies have limited direct comparisons among investigations. Future prospective studies integrating coronary physiology, advanced cardiac imaging, and clinical outcomes are necessary to elucidate the precise mechanisms by which CAT influences myocardial performance and to determine the prognostic significance of these alterations.

Principles and Clinical Applications of Two-Dimensional Speckle-Tracking Echocardiography

Two-dimensional speckle-tracking echocardiography (2D-STE) is an advanced imaging modality that enables quantitative assessment of myocardial deformation through the analysis of naturally occurring acoustic markers, known as speckles, within the myocardium. Unlike tissue Doppler imaging, speckle-tracking is relatively angle independent and provides objective evaluation of both global and regional myocardial function. Since its introduction, 2D-STE has evolved into a valuable tool for the detection of subtle myocardial abnormalities that may not be apparent using conventional echocardiographic parameters such as left ventricular ejection fraction (LVEF). [21]

The fundamental principle underlying STE is the tracking of unique speckle patterns generated by the interaction between ultrasound beams and myocardial tissue. Dedicated software identifies these speckles frame by frame throughout the cardiac cycle, allowing calculation of myocardial displacement, velocity, strain, and strain rate. Because the technique evaluates actual myocardial deformation rather than simple motion, it provides more accurate information regarding intrinsic myocardial contractility and minimizes the influence of translational motion and tethering effects. [22]

Strain represents the percentage change in myocardial fiber length relative to its original dimension, whereas strain rate reflects the speed at which deformation occurs. Longitudinal strain describes shortening along the base-to-apex axis, circumferential strain reflects contraction around the ventricular circumference, and radial strain represents myocardial thickening. Among these parameters, longitudinal strain has emerged as the most reproducible and clinically relevant marker because the subendocardial longitudinal fibers are particularly sensitive to ischemic injury and increased wall stress. [23]

Global longitudinal strain (GLS), derived from averaging segmental longitudinal strain values obtained from standard apical views, has become the most widely used parameter in contemporary clinical practice. GLS can identify early myocardial dysfunction before reductions in LVEF occur and has demonstrated diagnostic and prognostic value across various cardiovascular conditions. Because conventional measures of systolic function may remain preserved despite significant impairment of myocardial mechanics, GLS has gained increasing acceptance as a complementary measure of ventricular performance. [24]

In patients with coronary artery disease, STE has proven useful for detecting regional and global myocardial dysfunction associated with ischemia. Reductions in strain values have been observed in myocardial segments supplied by stenotic coronary arteries, and GLS has shown potential in identifying significant coronary artery disease even among patients with preserved ejection fraction. Furthermore, strain abnormalities may persist after episodes of transient ischemia, allowing STE to detect subtle functional impairment that may otherwise escape conventional echocardiographic evaluation. [25]

The clinical applicability of STE extends beyond obstructive coronary artery disease. The technique has been increasingly utilized to evaluate patients with conditions characterized by microvascular dysfunction, diffuse myocardial involvement, or subclinical ischemia. Given that coronary artery tortuosity may alter coronary hemodynamics without producing fixed luminal obstruction, deformation imaging offers a promising non-invasive approach for assessing the potential impact of CAT on myocardial performance. By detecting early alterations in myocardial mechanics, STE may contribute to improved characterization of patients with tortuous coronary anatomy who present with unexplained chest pain or evidence of ischemia. [26]

Despite its advantages, several technical considerations should be acknowledged when interpreting STE findings. Accurate strain analysis depends on optimal image quality, appropriate frame rates, and careful delineation of the endocardial border. Inter-vendor variability and differences in post-processing algorithms may also influence strain measurements, although recent efforts toward standardization have improved reproducibility. Consequently, adherence to established recommendations and consistent use of vendor-specific reference values are essential to ensure reliable assessment of myocardial deformation. [27]

The ability of STE to detect subtle abnormalities in myocardial mechanics before the development of overt ventricular dysfunction makes it particularly relevant in the context of coronary artery tortuosity. Because the hemodynamic consequences of CAT are thought to predominantly affect subendocardial myocardial fibers, longitudinal deformation parameters may serve as sensitive markers of early ischemic injury. Accordingly, growing interest has focused on the use of GLS and other strain-derived indices to explore whether CAT is associated with clinically meaningful alterations in myocardial performance. The current evidence addressing this relationship is reviewed in the following section. [28]

Myocardial Mechanics in Coronary Artery Tortuosity: Current Evidence from Speckle-Tracking Echocardiography

The concept that coronary artery tortuosity (CAT) may influence myocardial function has gained increasing attention in recent years. Traditionally, patients with CAT and angiographically non-obstructive coronary arteries were considered to have a favorable prognosis, and their symptoms were frequently attributed to non-cardiac causes. However, the emergence of myocardial deformation imaging has challenged this assumption by demonstrating subtle abnormalities in ventricular performance despite preserved left ventricular ejection fraction (LVEF). Speckle-tracking echocardiography (STE) has therefore become a promising tool for evaluating the functional consequences of CAT beyond conventional echocardiographic assessment. [29]

Among the various deformation parameters derived from STE, global longitudinal strain (GLS) has emerged as the most sensitive indicator of early myocardial dysfunction. Since longitudinal myocardial fibers are predominantly located within the subendocardial layer, they are particularly vulnerable to ischemia and disturbances in coronary perfusion. Consequently, reductions in GLS may precede changes in radial function and LVEF, making this parameter especially relevant in conditions characterized by subtle impairments in myocardial blood supply, including CAT. [30]

One of the earliest observations linking CAT to altered cardiac performance involved abnormalities in left ventricular diastolic function. Although conventional Doppler parameters suggested impaired relaxation in patients with coronary tortuosity, these findings did not fully explain the mechanisms underlying symptoms experienced by many individuals with non-obstructive coronary arteries. The introduction of strain imaging provided an opportunity to investigate whether myocardial deformation abnormalities coexist with these diastolic changes, thereby offering a more comprehensive understanding of ventricular mechanics in CAT. [31]

Dogdus and colleagues performed one of the most important studies exploring myocardial function in patients with coronary tortuosity using three-dimensional speckle-tracking echocardiography. The investigators demonstrated that patients with CAT exhibited significantly impaired left ventricular deformation parameters despite preserved LVEF. Reductions in longitudinal strain and abnormalities in rotational mechanics suggested the presence of subclinical systolic dysfunction that could not be detected by conventional echocardiographic measurements alone. These findings provided compelling evidence that CAT may have clinically meaningful effects on myocardial performance. [28]

More recently, Tweet and colleagues evaluated the relationship between coronary tortuosity and echocardiographic characteristics in patients with spontaneous coronary artery dissection (SCAD). Their study identified an association between CAT and impaired GLS, supporting the hypothesis that tortuous coronary anatomy may reflect an underlying vascular phenotype associated with myocardial dysfunction. Importantly, the study highlighted the potential utility of strain imaging in detecting subtle abnormalities in ventricular function among patients with tortuous coronary arteries, even when traditional echocardiographic indices appear normal. [32]

Several mechanisms may explain the observed relationship between CAT and impaired myocardial deformation. Computational studies have demonstrated that tortuous coronary arteries are associated with pressure drops distal to the affected segments and reduced flow efficiency. These hemodynamic disturbances may result in repetitive episodes of subclinical ischemia, particularly during conditions of increased myocardial oxygen demand. Chronic exposure to such perfusion abnormalities may selectively affect subendocardial fibers, ultimately manifesting as reductions in longitudinal strain before overt ventricular dysfunction becomes apparent. [33]

The predominance of longitudinal strain abnormalities in CAT is biologically plausible considering the vulnerability of subendocardial myocardial fibers. These fibers contribute substantially to GLS and are exposed to greater wall stress and lower perfusion reserve than mid-wall and epicardial layers. Consequently, even modest reductions in coronary flow reserve resulting from tortuous coronary anatomy may preferentially impair longitudinal mechanics. This phenomenon may explain why patients with CAT often exhibit preserved ejection fraction despite measurable reductions in strain-derived indices of myocardial performance. [34]

The current body of evidence evaluating myocardial mechanics in CAT remains limited. Most studies have involved relatively small sample sizes and have employed heterogeneous definitions of coronary tortuosity. Variations in strain analysis software, differences in imaging protocols, and the inclusion of patients with diverse cardiovascular risk profiles further complicate interpretation of available findings. Consequently, caution should be exercised when extrapolating these results to broader patient populations. [35]

Despite these limitations, existing studies consistently suggest that CAT should not be regarded merely as an incidental angiographic finding. The demonstration of impaired myocardial deformation in patients with tortuous coronary arteries raises important clinical questions regarding risk stratification, symptom evaluation, and long-term prognosis. STE may therefore serve as a valuable adjunctive tool in the assessment of symptomatic patients with CAT, particularly when conventional echocardiographic findings are inconclusive and obstructive coronary artery disease has been excluded. [36]

Future research should focus on prospective multicenter investigations employing standardized definitions of CAT and uniform strain imaging protocols. Studies integrating coronary physiological assessment, stress imaging, and longitudinal follow-up are needed to determine whether strain abnormalities in CAT predict adverse cardiovascular outcomes or identify patients who may benefit from closer surveillance and targeted therapeutic strategies. Such efforts may ultimately redefine the clinical significance of coronary tortuosity and establish myocardial deformation imaging as an integral component of its evaluation. [37]

Clinical Implications and Future Perspectives

The emerging evidence linking coronary artery tortuosity (CAT) with abnormalities in myocardial deformation challenges the longstanding perception that tortuous coronary anatomy is merely an incidental angiographic finding. Traditionally, patients with CAT and non-obstructive coronary arteries have been reassured regarding the benign nature of their condition. However, the demonstration of impaired myocardial mechanics in this population suggests that CAT may represent a clinically relevant entity deserving greater attention during cardiovascular evaluation. Recognition of these potential functional consequences may improve the understanding of persistent symptoms in patients without significant epicardial coronary stenosis. [38]

One of the most important clinical implications of these findings relates to symptomatic patients presenting with angina despite angiographically normal coronary arteries. In such individuals, the presence of CAT may provide an explanation for myocardial ischemia resulting from altered coronary hemodynamics rather than fixed obstructive disease. The incorporation of speckle-tracking echocardiography (STE) into the diagnostic work-up of these patients may facilitate the detection of subtle myocardial dysfunction and improve diagnostic confidence when conventional echocardiographic indices remain within normal limits. [39]

Global longitudinal strain (GLS) assessment may offer incremental value in the risk stratification of patients with CAT. Since reductions in GLS frequently precede declines in left ventricular ejection fraction, identification of impaired deformation parameters could help identify individuals with early myocardial involvement who might otherwise be overlooked using traditional imaging approaches. Although evidence remains limited, strain imaging has the potential to distinguish patients with functionally significant CAT from those with incidental anatomical tortuosity without measurable myocardial consequences. [40]

The relationship between CAT and conditions such as spontaneous coronary artery dissection (SCAD) and fibromuscular dysplasia further emphasizes the need for comprehensive cardiovascular assessment in selected patients. Recognition of tortuous coronary anatomy should prompt clinicians to consider the possibility of underlying systemic arteriopathies, particularly in younger women presenting with acute coronary syndromes or recurrent ischemic symptoms. In these settings, deformation imaging may provide additional information regarding myocardial involvement and contribute to individualized patient management. [41]

Despite these promising observations, the routine use of STE in all patients with CAT cannot currently be recommended. Existing studies have generally involved small cohorts and have employed heterogeneous definitions of tortuosity and varying imaging methodologies. Consequently, there is insufficient evidence to establish definitive strain thresholds for clinical decision-making or to determine whether abnormalities in myocardial deformation independently predict adverse cardiovascular outcomes in this population. [42]

Future investigations should prioritize the development of standardized angiographic criteria for the diagnosis and grading of CAT. Uniform definitions would improve comparability across studies and facilitate the generation of high-quality evidence regarding the epidemiology and clinical significance of this condition. In parallel, consensus recommendations addressing the optimal use of STE in patients with tortuous coronary anatomy would enhance the reproducibility and applicability of deformation imaging findings. [43]

Prospective multicenter studies incorporating coronary physiological assessment, myocardial deformation imaging, and long-term clinical follow-up are essential to clarify the prognostic implications of CAT. Such investigations should evaluate whether strain abnormalities correlate with symptom burden, exercise capacity, recurrent ischemic events, or progression to overt ventricular dysfunction. Furthermore, integration of stress imaging modalities may help determine whether myocardial deformation abnormalities worsen under conditions of increased oxygen demand, thereby strengthening the proposed ischemic mechanism underlying CAT-related myocardial dysfunction. [44]

Advances in echocardiographic technology and artificial intelligence may further enhance the evaluation of patients with CAT. Automated strain analysis has the potential to improve reproducibility, reduce operator dependence, and facilitate broader implementation of deformation imaging in routine clinical practice. As these technologies continue to evolve, future studies should explore whether artificial intelligence–assisted interpretation can improve the identification of patients with clinically significant myocardial impairment related to tortuous coronary anatomy. [45]

In conclusion, coronary artery tortuosity should no longer be viewed exclusively as a benign angiographic curiosity. Emerging evidence suggests that CAT may influence myocardial performance through complex hemodynamic mechanisms that preferentially affect subendocardial function. Speckle-tracking echocardiography represents a promising non-invasive tool capable of detecting these subtle abnormalities before conventional measures of systolic function become impaired. Although further research is required before widespread clinical implementation can be advocated, the integration of coronary anatomy and myocardial deformation assessment may ultimately improve the evaluation and management of patients with coronary artery tortuosity. [46]

Study	Design	Population	Imaging modality	Main findings
Turgut et al., 2007	Cross-sectional	CAT vs controls	Conventional echo	CAT associated with impaired LV relaxation
Dogdus et al., 2020	Case-control	Patients with CAT	3D-STE	Reduced LV deformation despite preserved EF
Tweet et al., 2024	Observational	SCAD patients	2D-STE	CAT associated with lower GLS values
Aslan et al., 2022	Cross-sectional	CAT patients	Conventional echo	Association between CAT and LV diastolic dysfunction

Conclusion

Coronary artery tortuosity should no longer be regarded solely as an incidental angiographic finding. Emerging evidence suggests that CAT may contribute to altered coronary hemodynamics, impaired myocardial perfusion, and subtle abnormalities in myocardial mechanics despite preserved left ventricular ejection fraction. Speckle-tracking echocardiography, particularly through the assessment of global longitudinal strain, has demonstrated promise in detecting subclinical myocardial dysfunction in this population and may provide incremental value beyond conventional echocardiographic parameters. Nevertheless, the current evidence remains limited by heterogeneous definitions of CAT and relatively small study populations. Future well-designed prospective studies using standardized diagnostic criteria and advanced deformation imaging are warranted to clarify the prognostic significance of these findings and to establish the role of speckle-tracking echocardiography in the routine evaluation of patients with coronary artery tortuosity. [47]

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