

## Coronary spasm: It's common, but it's still unsolved

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### Abstract

Coronary spasm is caused by a transient coronary nar-

rowing due to the constriction of epicardial coronary artery, which leads to myocardial ischemia. More than 50 years have passed since the first recognition of coronary spasm, and many findings on coronary spasm have been reported. Coronary spasm has been considered as having pivotal roles in the cause of not only rest angina but also exertional angina, acute coronary syndrome, and heart failure. In addition, several new findings of the mechanism of coronary spasm have emerged recently. The diagnosis based mainly on coronary angiography and spasm provocation test and the mainstream treatment with a focus on a calcium-channel blocker have been established. At a glance, coronary spasm or vasospastic angina (VSA) has become a common disease. On the contrary, there are several uncertain or unsolved problems regarding coronary spasm, including the presence of medically refractory coronary spasm (intractable VSA), or an appropriate use of implantable cardioverter defibrillator in patients with cardiac arrest who have been confirmed as having coronary spasm. This editorial focused on coronary spasm, including recent topics and unsolved problems.

**Key words:** Vasospastic angina; Medically refractory coronary spasm; Variant angina; Coronary vasospasm

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**Core tip:** Coronary spasm is the transient vasoconstriction of epicardial coronary artery, leading to myocardial ischemia. Recently, coronary spasm has become widely accepted as one of the important pathophysiologies of coronary artery disease. However, even at present, there are several unsolved problems regarding coronary spasm.

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## INTRODUCTION

More than several decades have passed since the first recognition of coronary spasm<sup>[1-3]</sup>. Since then, numerous studies have been conducted, and many findings regarding coronary spasm have been clarified. Coronary spasm is caused by transient narrowing due to the vasoconstriction of the epicardial coronary arteries, leading to myocardial ischemia, and it plays pivotal roles in the cause of not only rest angina but also exertional angina, acute coronary syndrome, including unstable angina, acute myocardial infarction, and ischemic sudden death<sup>[4-9]</sup>. Recently, coronary spasm has been considered one of the causes of heart failure with reduced ejection fraction<sup>[10-12]</sup>. Mechanisms responsible for coronary spasm were reported to be the abnormal response of the autonomic nervous system<sup>[13]</sup>, endothelial dysfunction<sup>[14-17]</sup>, abnormal or hyper-reaction of vascular smooth muscles<sup>[18-20]</sup>, and other factors, such as magnesium deficiency<sup>[21,22]</sup>, inheritance<sup>[23]</sup>, or specific anatomy of the coronary artery<sup>[24-27]</sup>. In addition, the diagnosis and treatment of coronary spasm were based on the guidelines of coronary spasm<sup>[28,29]</sup>. Its diagnosis has been based on several examinations on the presence of coronary spasm; however, coronary angiography and spasm provocation test (SPT) have been recognized as the standard and final tests<sup>[28,30]</sup>. It is mainly treated with coronary vasodilators particularly with calcium-channel blocker (CCB)<sup>[28,31]</sup>. According to the accumulations of experiences, numerous studies, and recent guidelines<sup>[6,7,28,29]</sup>, recently, many physicians roughly know "coronary spasm" or "vasospastic angina" (VSA). However, even at present, there have been undoubtedly several uncertain or unsolved problems on coronary spasm, such as management of medically refractory coronary spasm (intractable VSA) and coronary microvascular angina or appropriate use of implantable cardioverter defibrillator (ICD) for patients with cardiac arrest, who were confirmed as having coronary spasm<sup>[28,32,33]</sup>. Therefore, this paper focuses on the mechanisms, diagnosis, and treatment of coronary spasm, including recent topics and uncertain or unsolved problems.

## MECHANISM OF CORONARY SPASM

Several mechanisms have reported the causes of coronary spasm, such as the abnormal response of the autonomic nervous system<sup>[13]</sup>, endothelial dysfunction of the coronary artery or systemic peripheral vasculature<sup>[14-17]</sup>, abnormal or hyper-reaction of vascular smooth muscles<sup>[18-20]</sup>, and other factors such as a magnesium deficiency<sup>[21,22]</sup>, inheritance<sup>[23]</sup>, or specific anatomy of the coronary artery<sup>[24-27]</sup>. Naturally, the mechanism of coronary spasm may not be always simple, but may be also multi-factorial. We have come to strongly recognize the multi-factorial mechanisms responsible for coronary spasm when we consider sex differences in the clinical characteristics of VSA patients. Smoking, presence of atherosclerosis of the coronary

artery, and morphology of coronary spasm during the SPT differ in male and female VSA patients<sup>[8,34,35]</sup>, indicating the presence of multi-factorial mechanisms of coronary spasm. Findings that the presence of family history of coronary artery disease is higher in women than in men or that younger female VSA patients had higher incidence of smoking than older female VSA patients did, despite the lower incidence of smoking among the whole of female VSA patients<sup>[8]</sup>, are of great interest, taking into consideration the mechanisms of coronary spasm in female patients (Table 1).

Among the mechanisms of coronary spasm shown above, Ohyama *et al.*<sup>[20,36]</sup> have recently reported the relationship between coronary spasm and perivascular components, such as perivascular adipose tissue and adventitial vasa vasorum (Table 1). They showed that such perivascular components play an important role as a source of various inflammatory mediators and showed that inflammatory changes of such perivascular components caused increased the formation of adventitial vasa vasorum and increased the activity of Rho-kinase, leading to the occurrence of coronary spasm<sup>[20,36]</sup>. These findings appeared to be novel and noteworthy. These findings may account for the presence of focal spasm, because it appears quite difficult to consider the presence of focal spasm based solely on endothelial dysfunction of the coronary artery. On the contrary, the studied VSA patients had coronary spasm of the left anterior descending coronary artery (LAD)<sup>[20,36]</sup>. Moreover, coronary spasm occurs more frequently in the LAD and right coronary artery (RCA) than in the left circumflex coronary artery (LCX)<sup>[37]</sup>, and it remains unclear whether the findings reported by Ohyama *et al.*<sup>[20,36]</sup> may also account for coronary spasm in the RCA or differences in the frequency of coronary spasm according to the territory of coronary arteries.

Recently, some interest has also focused on the specific coronary anatomy in VSA patients (Table 1): The presence of myocardial bridge (MB), which is characterized by the systolic narrowing of the epicardial coronary artery because of myocardial compression during systole<sup>[24-27]</sup>. Furthermore, coronary spasm occurs more frequently at the MB, which is in part mediated by coronary vascular dysfunction, including endothelium-dependent and endothelium-independent dysfunctions, at the MB segments. Further observation regarding the occurrence of coronary spasm at MB segments is needed in the international registry of VSA.

Previously, the prevalence of coronary spasm had been considered higher in Asians than in Caucasians<sup>[38,39]</sup>, showing the presence of racial difference in the occurrence of VSA. However, recently, the presence of VSA is more frequent in Caucasians when SPT is aggressively performed<sup>[40,41]</sup>. In addition, coronary spasm is considered as playing some roles in the cause of acute coronary syndrome with plaque rupture<sup>[42]</sup> or myocardial infarction with non-obstructive coronary artery<sup>[43]</sup>. The aggressive effort of making a diagnosis of VSA may clarify the real presence of VSA worldwide (Table 1).

**Table 1** Recent topics and unsolved problems regarding coronary spasm

	Previously reported or established	Recent topics	Unsolved problems
Mechanism	Abnormal autonomic nervous system		
	Endothelial dysfunction		
Others	Hyperreactivity of the coronary smooth muscle	Inflammation of perivascular components	
	Inheritance	Specific anatomy of the coronary artery (myocardial bridge)	Different mechanisms in men and women
	Magnesium deficiency		Is there a racial difference in coronary spasm?
Diagnosis	Non-invasive: Holter ECG	Malondialdehyde-modified low-density lipoprotein	Is a biochemical marker for coronary spasm present?
	Invasive: SPT	Exercise ECG	
		Higher doses of ACh infusions	Detailed SPT protocol using EM
		Sequential SPT	Are higher doses of ACh for SPT being used?
Treatment	Life style		
	Stop smoking		
	Pharmacological		
	Calcium-channel blockers	Cilostazol	Treatment of intractable VSA
	Sublingual nitroglycerin during attacks	Statin	Which combinations of coronary vasodilator are the most effective?
Combination of coronary vasodilators	Aspirin	Which is effective in preventing adverse events in VSA patients with cardiac arrest?	
Non-pharmacological	Use of ICD in VSA patients with cardiac arrest	Does SPT positivity continue for decades?	
	Cardiac rehabilitation	Treatment of accompanying microvascular angina	

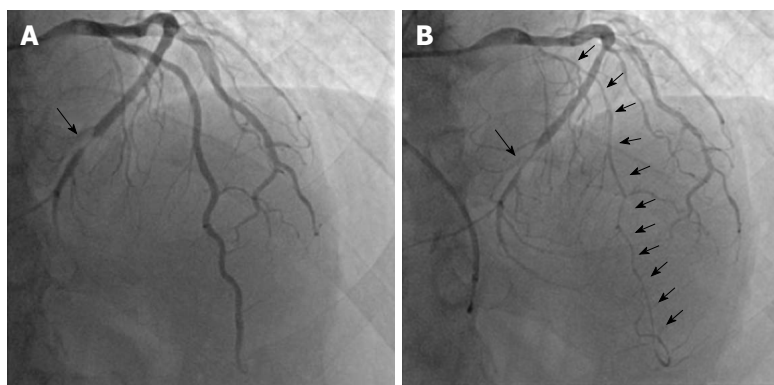
ACh: Acetylcholine; ECG: Electrocardiogram; EM: Ergonovine maleate; ICD: Implantable cardioverter defibrillator; SPT: Spasm provocation test; VSA: Vasospastic angina; SPT: Spasm provocation test.

## DIAGNOSIS OF CORONARY SPASM

According to the guideline on coronary spasm<sup>[28,29]</sup>, the recognition of transient changes in ST-T segments on electrocardiogram (ECG) during chest symptoms, as well as the presence of chest symptoms derived from coronary spasm, including the good responses to sublingual nitroglycerin and timing of occurrence of coronary spasm at rest, during sleep, or early in the morning, is very important in the diagnosis of VSA. Thus, needless to say, Holter ECG monitoring is important in the diagnosis of VSA<sup>[28]</sup>; however, Sueda *et al.*<sup>[44]</sup> reported that approximately half of VSA patients had pathologic exercise tests, showing the importance of exercise ECG testing in the clinical setting. Exercise ECG testing may be also useful in patients suspected of coronary spasm (Table 1). As a biochemical index, which has been eagerly longed for but has not been detected until now (Table 1), the level of malondialdehyde-modified low-density lipoprotein (MDA-LDL) was increased in VSA patients<sup>[45]</sup>. However, this biochemical marker is reported elevated in patients with other unstable coronary diseases<sup>[46,47]</sup>. An elevated MDA-LDL level may be carefully interpreted in the diagnosis of VSA. In general, using coronary computed tomography (CT) angiography alone, the diagnosis of VSA itself cannot be obtained, and we doubt the presence of VSA when no significant coronary stenosis is detected on coronary CT angiography. We have sometimes experienced patients with coexistence of coronary spasm and organic coronary stenosis (Figure

1), and the assessment of or exclusion for organic coronary stenosis using a coronary CT angiography may be also needed even in patients, whose diagnosis of VSA was made based on the typical chest symptoms and transient ST-T changes in ECG. Furthermore, as shown above, coronary spasm sometimes occurs at the MB segments<sup>[24-27]</sup>, and the presence of MB on a coronary CT angiography<sup>[48]</sup> may be a useful clue of the possibility of VSA in patients with chest pain when atherosclerosis was absent on a coronary CT angiography. According to Ohyama *et al.*<sup>[20]</sup>, positron-emission tomography, which has been adopted in the assessment of inflammatory perivascular components, cannot be performed widely in the clinical setting.

Thus, SPT is considered the gold standard examination and actually has been performed frequently because transient ST-T changes on ECG during chest symptoms cannot always be obtained in the clinical setting. Furthermore, SPT may be useful not only in the diagnosis of VSA but also in providing some information in the activity of coronary spasm and prognosis; presence of organic stenosis, multi-vessel spasm, focal spasm, coronary spasm induced by a low dose of acetylcholine (ACh), and total occlusion due to coronary spasm<sup>[49-51]</sup>. The provocative drugs in SPT are ACh and ergonovine maleate (EM). The methodology of SPT using ACh infusions has been almost established<sup>[28-30,52,53]</sup>, except for the use of transient pacing catheter or the maximal doses of ACh. In general, during SPT using ACh infusions, an insertion of transient pacing catheter *via* an internal



**Figure 1** A representative case with coronary spasm and coronary stenosis. The patient, who had chest symptoms for 20 min at rest, accompanied with cold sweating, was admitted to our institution for the evaluation of his chest symptoms. A: Coronary angiography showed coronary stenosis at the distal segment of the left circumflex coronary artery, which cannot be considered as the cause of his chest symptoms; B: The spasm provocation test using 100  $\mu$ g of acetylcholine showed diffuse coronary spasm throughout the left anterior descending coronary artery, accompanied with usual chest pain, which had been restored after nitroglycerin injection. Coronary stenosis and spastic segments were indicated by bold arrow and plain arrows, respectively.

jugular vein or a medial cubital vein may be safer to avoid ACh-induced bradycardia despite the duration of ACh infusion into the coronary artery<sup>[54]</sup>. The recommended maximal doses of ACh is 100  $\mu$ g for the left coronary artery (LCA) and 50  $\mu$ g for the RCA<sup>[28]</sup>; however, such maximal doses of ACh were determined based on the doses of ACh adopted for the provocation of coronary spasm in patients with variant angina<sup>[55]</sup>, which involved increased coronary spasm activity<sup>[49,56]</sup>. Thus, the higher maximal doses of ACh in patients with stable VSA are reasonable. Recently, some adopt the maximal doses of ACh as 200  $\mu$ g for the LCA and 80  $\mu$ g for the RCA, showing the higher induction of coronary spasm without a significant increase in complications<sup>[40,57]</sup>. However, it remains unclear whether the higher doses of ACh than the above-mentioned doses are useful or harmful in the SPT (Table 1). On the contrary, the methodology of SPT using EM infusion has not been established sufficiently, compared with that of using ACh (Table 1). The total doses of EM, which are described as the doses of EM with 20-60  $\mu$ g for 2-5 min for each coronary artery in the guideline<sup>[28]</sup>, vary. In addition, the method of EM infusion, which was infused continuously or with a stepwise incremental dose, has still not been determined. In general, the insertion of transient pacing catheter is unnecessary, and this appears to be advantageous.

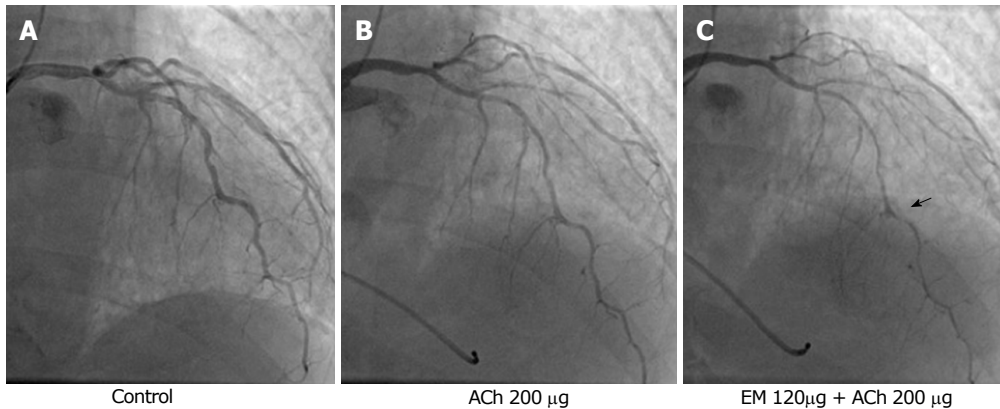
Moreover, the experienced method of SPT using ACh or EM at each institution may be performed safely; however, several tips regarding SPT using these provocative drugs have been known. Female VSA patients have more sensitivity to ACh provocation<sup>[8,34,35]</sup>, and the SPT using ACh infusion may be recommended in female patients who undergo SPT. In addition, some patients have positive SPT using EM infusions despite the negative results in SPT using ACh infusions<sup>[30]</sup>. Furthermore, Sueda *et al.*<sup>[58]</sup> have reported the sequential SPT, which was induced by infusions of first ACh, then EM, and finally ACh, showing the high provocative rate without a significant increase in complications<sup>[53]</sup>. Naturally, the ACh or EM working receptors are dif-

ferent<sup>[59]</sup>, and the use of different provocative drugs for a short duration is reasonable. The sequential SPT may stimulate both receptors simultaneously, leading to a higher provocation of coronary spasm. To our knowledge, the sequential SPT may be the strongest until now. Sueda *et al.*<sup>[53,58]</sup> showed no difference in complications including major ones or atrial fibrillation between the sequential and standard SPTs. On the contrary, further verification on the presence of false-positive cases will be needed using the sequential SPT. Furthermore, younger patients have a tendency of negative induction of coronary spasm in response to standard provocation<sup>[60]</sup> due to the not-severe coronary vascular dysfunction, and the sequential SPT may be useful in such patients. In addition, we have experienced some patients who showed no significant coronary stenosis on coronary angiography despite the fact that significant coronary stenosis was suspicious based on the results of examinations and patients' symptoms. In such cases, the diagnosis of VSA was possible; however, performing an SPT was difficult because an intracoronary nitroglycerin infusion had been administered or taking vasodilators before coronary angiography were continued. Under such circumstances, the sequential SPT may also be useful (Figure 2).

According to the length of coronary spasm induced by the SPT, there have been a subclassification with "focal spasm", which is defined as vasoconstriction within the confines of one isolated coronary segment, and "diffuse spasm", which is defined as the vasoconstriction of  $\geq 2$  adjacent coronary segments<sup>[29,50]</sup>. Sato *et al.*<sup>[50]</sup> have shown poorer prognosis in focal spasm than in diffuse spasm. On the contrary, Sueda *et al.*<sup>[61]</sup> have shown the importance of diffuse spasm as one of causes of medically refractory VSA. Thus, it may be an unsolved problem which "focal spasm" or "diffuse spasm" is worse in the clinical setting<sup>[50,61]</sup> (Table 1).

The positive criteria of SPT is defined as "transient, total, or sub-total occlusion ( $> 90\%$  stenosis) of a coronary artery with signs/symptoms of myocardial





**Figure 2** A case of coronary spasm, which was documented by sequential spasm provocation test, which was performed after the routine coronary angiography, vasodilator administration, and preprocedural infusion of nitroglycerin. A: The patient had chest symptoms at exercise early in the morning. Coronary computed tomography angiography showed stenosis of the left anterior descending coronary artery. However, the coronary angiography showed no significant coronary stenosis; B: Because the presence of vasospastic angina was suspicious, the spasm provocation test was performed despite the intracoronary infusion of nitroglycerin and calcium channel blocker intake. The standard doses of acetylcholine (ACh, up to maximal 200 µg) did not cause coronary spasm; C: Consequently, we performed the sequential spasm provocation test: 120 µg of ergonovine maleate was infused first followed by 200 µg of ACh, showing the presence of coronary spasm (right panel) and obtained the diagnosis of vasospastic angina. The spastic site was indicated by an arrow. Ach: Acetylcholine; EM: Ergonovine maleate.

ischemia (anginal pain and ischemic ST changes)<sup>[28]</sup>. However, some patients have significant narrowing induced by provocative drugs despite the chest symptoms and ST-T changes on ECG. Sueda *et al*<sup>[37]</sup> showed that such patients were detected in 6.8% of studied patients who underwent an SPT. In addition, we have also experienced some patients with moderate vasoconstriction diffused with chest symptoms and/or ECG changes. Under such circumstances, the diagnosis of VSA may be difficult. At that time, other supportive index for the diagnosis of VSA may be needed. We have shown that the use of pressure wire may help in the diagnosis of VSA<sup>[62-64]</sup>, showing the sudden drop of intracoronary pressure in response to ACh infusions in SPT-positive vessels and less frequency of major complications related to SPT. The validity of SPT using a pressure wire should be verified (Table 1); however, this method may be useful in the following situations: (1) when hemodynamic instability may be precipitated by coronary spasm, such as when patients have hypertrophic cardiomyopathy or left ventricular dysfunction; (2) when patients have chronic kidney disease; and (3) when cardiologists seek to clarify the disease status through a second SPT. SPT has been considered the final examination; however, the results of SPT is not absolute, and we have to make a diagnosis of VSA comprehensively, taking other conditions as well as the results of SPT into consideration. The second session of SPT may be needed in patients who had repeated chest symptoms despite the negative results of the first SPT<sup>[64]</sup>.

## TREATMENT OF CORONAY SPASM

Needless to say, smoking cessation is an important treatment of VSA<sup>[28]</sup>. As a pharmacological treatment for VSA, CCB as prevention and sublingual nitroglycerin during anginal attacks are the first-line therapies for VSA<sup>[28,29,31,65]</sup>. The monotherapy of  $\beta$ -blockers is class III

in VSA patients with organic stenosis<sup>[28]</sup>. However, VSA is accompanied with many cardiovascular diseases, in which  $\beta$  blockers are effective, such as left ventricular dysfunction<sup>[10-12]</sup>, hypertrophic cardiomyopathy<sup>[66]</sup>, and myocardial bridging<sup>[24,26,27,62,67]</sup>. Under such conditions, coronary vasodilators should be administered first, and then  $\beta$  blockers should be administered from small doses, observing carefully for the worsening of chest symptoms and hemodynamics.

In addition, the sudden cessation of coronary vasodilators while chest symptoms disappeared under long-term intake of coronary vasodilators may cause severe conditions due to coronary spasm<sup>[68]</sup>. Avoidance of sudden cessation of coronary vasodilators should be repeated to VSA patients, although the duration of continued coronary spasm activity has not been clarified (Table 1).

Some patients have angina attacks even while under CCB medications. In such conditions, several countermeasures should be followed. First, we must consider the type of CCB, because CCBs may differ in their ability to prevent angina attacks<sup>[31,65]</sup>. Second, the dosing regimen should be considered, such as whether a submaximal or maximal dose or medication once or twice a day would be appropriate. There are patients on a once-a-day CCB regimen who have had angina attacks just before the dosage time. Third, dosage-timing should be considered. In general, angina attacks often occur between midnight and early morning<sup>[5-7,28]</sup>. Thus, taking CCB at bedtime is usually recommended. However, for some VSA patients, taking CCB at the time of rising may be effective. Fourth, we must check whether the vasodilators prescribed are branded vasodilators. In VSA patients with high coronary spasm activities, switching from branded vasodilators to generic ones may worsen their chest symptoms<sup>[69]</sup>. Finally, another vasodilator must be added such as long-acting nitrates, nicorandil, and other type of CCBs (dihydropyridine CCB vs non-dihydropyridine CCB).

The combination of more than one and two kinds of coronary vasodilators varies and dependent mainly on each primary doctors' experience. However, which combination of coronary vasodilators was more useful in preventing coronary spasm is still unclear<sup>[70]</sup> (Table 1).

Recently, in a randomized, multicenter, double-blind, placebo-controlled study, Shin *et al*<sup>[71]</sup> have shown that an addition of cilostazol, which was a selective inhibitor of phosphodiesterase 3, to a CCB decreased the frequency and severity of chest symptoms in VSA patients. Moreover, they showed that an additional of cilostazol may be promising, although the finding that the CCB adopted in the present study was amlodipine, which was not the standard CCB for the prevention of coronary spasm in VSA patients, was a slightly controversial. The usefulness of other drugs such as statins<sup>[72,73]</sup> and a low-dose aspirin<sup>[74,75]</sup> on clinical outcomes has been accumulated, and these drugs may be considered to improve the clinical outcomes in VSA patients (Table 1).

## UNCERTAIN OR UNSOLVED PROBLEMS REGARDING CORONARY SPASM

First, one of the unsolved problems related to coronary spasm is the presence of intractable VSA, which was defined as angina that cannot be controlled even with the administration of two types of coronary vasodilators. A study revealed that 13.7% of VSA patients had intractable VSA with a younger age at the time of onset and included higher proportions of tobacco smokers and normotensive patients<sup>[28]</sup>. Our previous report has shown that the presence of SPT-related angiographic findings, such as provocation induced by a low-dose ACh, total occlusion due to coronary spasm, and multi-vessel coronary spasm, were predictors for the presence of intractable VSA<sup>[51]</sup>, showing the importance of performing SPT. When we have controlled the condition of taking several kinds of coronary vasodilators, as shown above, there have been many patients who were refractory to the administrations of several kinds of coronary vasodilators. Among the VSA patients, there have been some VSA patients with microvascular dysfunction<sup>[76,77]</sup>. Standard coronary vasodilators are less effective in patients with microvascular dysfunction or microvascular angina<sup>[33]</sup>. Therefore, the comorbid of VSA and microvascular dysfunction may contribute to the presence of intractable VSA. Thus, additional novel drugs may be anticipated. Cardiac rehabilitation has been reportedly effective in preventing coronary spasm in VSA patients<sup>[78]</sup>, and non-pharmacological treatment may be also anticipated.

Second, the need for ICD in VSA patients with cardiac arrest has been one of the unsolved problems of coronary spasm<sup>[28,32,56,79,80]</sup>. Recently, Sueda *et al*<sup>[32]</sup> have summarized the results that appropriate ICD shocks were observed in 24.1% of VSA patients with aborted ICD. Rodríguez-Mañero *et al*<sup>[80]</sup> have shown that ICD was effective when insufficient medications were

administered in VSA patients. In the clinical setting, whether sufficient medications without ICD can prevent such malignant arrhythmia due to coronary spasm is still undetermined. The physicians-in-chief of the heart team should carefully determine the ICD by taking patient background such as taking coronary vasodilators sufficiently and the results of SPT under sufficient medications<sup>[81]</sup> into consideration (Table 1).

## CONCLUSION

Given the accumulation of studies on coronary spasm for more than half a century, coronary spasm is the key player and main cause in the pathophysiology of heart diseases. At present, its mechanisms, diagnosis, and treatments have been understood. Nonetheless, some unsolved problems on coronary spasm are still present, and we have to make efforts in obtaining clues to these unsolved problems.

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