Ventricular fibrillation storm after revascularization of chronic total occlusion of the left anterior descending artery: is this reperfusion arrhythmia?

Xingji Liu ⓘ**, Binay Kumar Adhikari** ⓘ**, Tianlong Chen, Yonggang Wang** ⓘ**, Quan Liu and Shudong Wang**[1]

Abstract

Electrical storm is a life-threatening emergency condition defined as three or more episodes of ventricular tachycardia or ventricular fibrillation (VF) within 24 hours requiring anti-tachycardia therapy, electrical cardioversion, or defibrillation. However, studies of the incidence of electrical storm after chronic total occlusion-percutaneous coronary intervention (CTO-PCI) are limited,[7] and post-procedural VF after revascularization of CTO has not been described. The purpose of this article was to present a case of post-operative VF electrical storm after revascularization of CTO of the left anterior descending (LAD) artery to determine whether the electrical storm was caused by reperfusion arrhythmia or compromise of either branch vessels or the collateral circulation during intervention.

[1]Department of Cardiology, the First Hospital of Jilin University, Changchun, Jilin Province, China
[2]Department of Medicine, Nepal APF Hospital, Kathmandu, Nepal

Corresponding author:
Shudong Wang, Department of Cardiology, the First Hospital of Jilin University, Changchun, Jilin Province 130000, China.
Email: shudong_wang@jlu.edu.cn

Background

Electrical storm is a state of extremely unstable ventricular electrical activity that is characterized by multiple episodes of ventricular arrhythmia in a short period of time.[1] Electrical storm is a life-threatening emergency condition defined as three or more episodes of ventricular tachycardia or ventricular fibrillation (VF) within 24 hours requiring anti-tachycardia therapy, electrical cardioversion, or defibrillation.[2] Patients with chronic total occlusion (CTO) are at high risk of developing ventricular arrhythmias, and sudden cardiac death. After reviewing the literature, we identified one case of ventricular tachycardia electrical storm after CTO revascularization,[3] but no cases of VF electrical storm after percutaneous coronary intervention (PCI) for CTO have been reported. The purpose of this article was to present a case of post-operative VF electrical storm after revascularization of CTO of the left anterior descending (LAD) artery and to investigate the mechanisms underlying the electrical storm to determine whether this was caused by reperfusion arrhythmia or compromise of either branch vessels or collateral circulation during intervention.

Case presentation

A 37-year-old man suffered post-prandial sudden and continuous chest pain radiating to his left arm for 2 hours before presenting to our emergency department. He had no history of hypertension or diabetes, but smoked 10 cigarettes/day for 20 years, and occasionally consumed alcohol. He had no history of surgery for cerebral hemorrhage and no significant family history of cardiac disease. Physical examination findings were not significant. Electrocardiography revealed mild ST segment depression in leads II, III, aVF, V4 to V6, and a qs pattern in leads V1 and V2 (Figure 1).

The patient's baseline laboratory test results with their respective reference ranges are shown in Table 1. The patient was diagnosed with acute non-ST-elevation myocardial infarction (NSTEMI) and underwent coronary angiography (CAG). CAG revealed triple vessel disease (TVD) with total occlusion of the proximal LAD; small left circumflex (LCX) artery with diffuse proximal lesions and a maximum diameter of 70%; diffuse proximal plaques in the right coronary artery (RCA) with a maximum diameter of 80%; and collateral circulation from the RCA to the LAD, and from the LCX to the LAD (Figure 2). The SYNTAX score was >22. We recommended coronary artery bypass grafting (CABG), but the patient declined surgical management, and we then attempted interventional treatment for the LAD. First, the Runthrough (Terumo, Aichi, Japan) guidewire failed to pass the occluded segment. Considering that CTO was present in the LAD, we used the antegrade wire escalation technique and placed a microcatheter and exchanged the Runthrough for a Fielder XT Gaia 2 guidewire (Asahi Intecc, Nagoya, Japan), but this also failed to pass the LAD occlusion segment, repeatedly. Finally, we successfully passed the Conquest Pro (Asahi Intecc) guidewire and exchanged the Runthrough guidewire. We implanted three stents in the LAD and two stents in the RCA. On post-operative day 2 after PCI, the patient suddenly lost consciousness and experienced the first episode of VF (Figure 3). We immediately began cardiopulmonary resuscitation (CPR) and administered a 200-J biphasic shock, which converted the rhythm to sinus rhythm. The patient then developed repeated episodes of VF. Serum electrolytes were then measured, which revealed a serum potassium concentration of 2.86 mmol/L (range: 3.5–5.3 mmol/L), and potassium supplementation was administered both orally and intravenously to
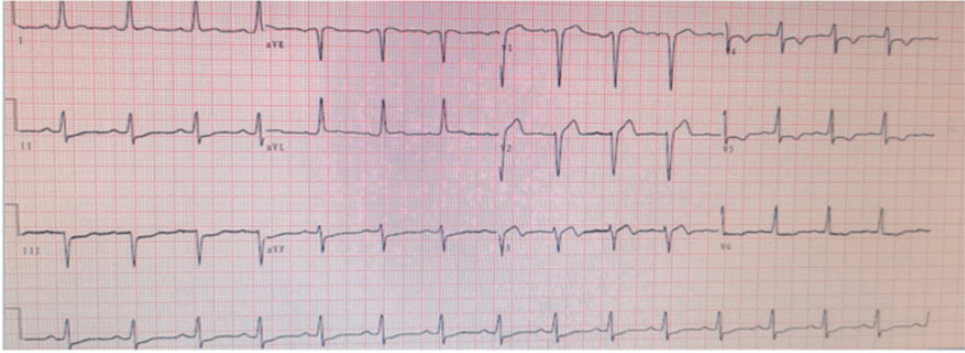
Figure 1. ST depression in leads II, III, AVF, and V4 to V6, and qs pattern in leads III, V1, and V2.

Table 1. Baseline laboratory data and the respective reference ranges.

Parameter	Result	Units	Reference range
Creatine kinase-MB fraction	<0.5	μkat/L	0.4–3.3
D-dimer	<361	nmol/L	361–2166
Troponin I, baseline	$<5 \times 10^4$	μg/L	$0–5 \times 10^4$
Troponin I, 2 hours after baseline measurement	1.33×10^6	μg/L	$0–5 \times 10^4$
Myoglobin	159.92	nmol/L	0–386.27
B-type natriuretic peptide	7.71×10^{-5}	ng/L	$0–10^{-4}$
Aspartate aminotransferase	20.5	U/L	15.0–40.0
Alanine aminotransferase	40.2	U/L	9.0–50.0
γ-glutamyl transpeptidase	31.8	U/L	10.0–60.0
Alkaline phosphatase	71.7	U/L	45.0–125.0
Total protein	69.2	g/L	65.0–85.0
Albumin	40.8	g/L	40.0–55.0
Globulin	28.4	g/L	20.0–40.0
Uric acid	0.365	mmol/L	0.21–0.43
Total cholesterol	3.65	mmol/L	2.6–6.0
Triglycerides	3.71	mmol/L	0.28–1.80
HDL	0.94	mmol/L	0.76–2.1
LDL	1.71	mmol/L	2.06–3.10
Fasting Glucose	4.62	mmol/L	3.9–6.1
TSH	2.480	μIU/mL	0.27–4.2
FT3	4.41	pmol/L	3.1–6.8
FT4	14.58	pmol/L	12.0–22.0
WBC	9.36	$\times 10^9$/L	3.50–9.50
RBC	4.57	$\times 10^{12}$/L	4.30–5.80
PLT	250	$\times 10^{12}$/L	125–350

correct the potassium level. No further hypokalemia was noted during subsequent episodes of VF storm. The other electrolyte concentrations were within normal limits, and 24-hour urinary electrolyte concentrations were also within the normal ranges. Ten episodes of VF occurred during a 24-hour period. The patient was managed
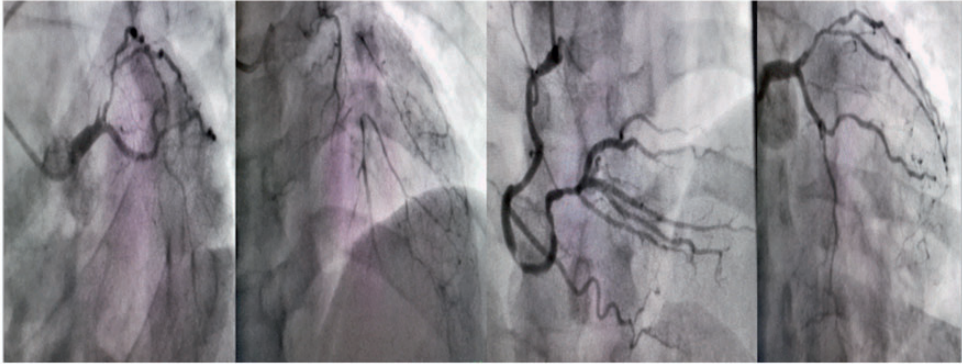
Figure 2. (a) Normal left main coronary artery; (b) total occlusion of the proximal left anterior descending artery (LAD); (c) small left circumflex artery (LCX) with diffuse proximal lesions and a maximum diameter of 70%; and (d) diffuse proximal plaques in the right coronary artery (RCA) with a maximum diameter of 80%.
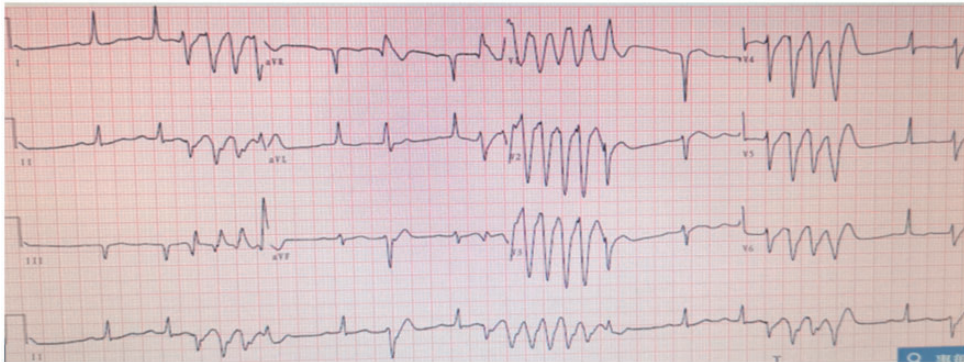

Figure 3. ECG monitoring showed frequent premature ventricular contractions, paroxysmal ventricular tachycardia, and ventricular fibrillation.
ECG, electrocardiogram.

with CPR, asynchronous defibrillation with a biphasic 200-J DC shock, and antiarrhythmic drugs, namely amiodarone, lidocaine, and magnesium sulphate. After achieving hemodynamic stability, CAG was repeated, which revealed well-positioned stents with no thrombi (Figure 4); however, compromised collateral circulation between the LCX and LAD, and inadequate flow in the diagonal artery were seen (Figure 5). Because further intervention in the diagonal branch could have

damaged the stent in the LAD, and because the patient was stable, no active intervention was performed. The patient had occasional premature ventricular contractions and remained stable during the following days. Cardiac color Doppler ultrasonography showed that the left ventricular ejection fraction increased from the initial 43% to 56%, the left ventricular end-diastolic diameter decreased from 54 mm to 48 mm, and the initial decrease in left ventricular diastolic function had disappeared.
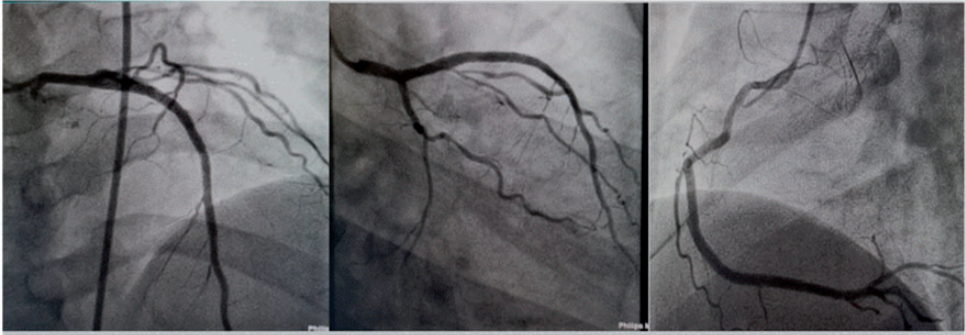
Figure 4. Repeat coronary angiography showing well-positioned stents, with no thrombi.
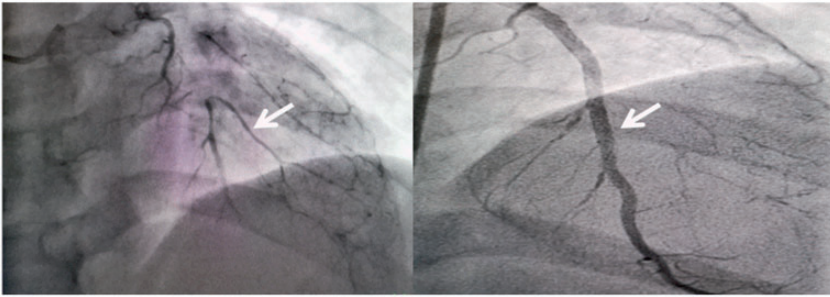

Figure 5. Comparison of the LAD before (left) and after (right) PCI showing compromised collateral circulation between the LCX and LAD, and inadequate flow in the diagonal artery; arrows indicate stenosis in the diagonal artery in both views.
LAD, left anterior descending artery; PCI, percutaneous coronary intervention; LCX, left circumflex artery.

Discussion

With technological improvements and clinical evidence of increased long-term survival after PCI for CTO, the number of patients undergoing PCI is increasing steadily.[4] Coronary CTO is encountered in 15% to 30% of patients undergoing CAG.[5] Coronary artery CTO is more frequent in men compared with women, and men with CTO are more likely to undergo invasive strategies (PCI or surgery).[6] Current research shows that coronary revascularization of CTO (CTO-PCI or CABG) was associated with lower all-cause and cardiac mortality rates compared with optimal medical therapy in a long-term follow-up.[7] However, it is unclear why CTO revascularization is associated with improved survival. The quantity of viable myocardium subtended by a CTO artery may play an important role.[7] CTO revascularization, especially complete anatomical revascularization, is associated with favorable clinical outcomes.[7] Another study showed that regardless of age, both cardiac and all-cause mortality were significantly higher in the medical therapy group compared with those who underwent revascularization (PCI or CABG); however, the survival benefit with revascularization was especially notable in older patients.[8] Revascularization of viable/ischemic myocardium in the CTO territory may improve survival by preventing the development of

post-myocardial infarction scarring.[7] Therefore, it is necessary to attempt CTO revascularization when appropriate, although a meta-analysis showed that approximately 3% to 4% of CTO-PCI patients experienced major adverse cardiac events.[9] However, studies evaluating the incidence of electrical storm after CTO-PCI are limited,[10] and post-procedural VF after revascularization of CTO has not been described.

Regarding the occurrence of VF electrical storm shortly after CTO-PCI in an electrically stable patient, we believe that reperfusion injury may play a role in the pathogenesis of VF in CTO. In patients with old myocardial infarction, the occurrence of VF electrical storm usually depends on the scar-related re-entry circuit. The border zone of the infarction, where areas of surviving cardiomyocytes are interposed among fibrotic tissue, often host the slow conduction channels that are an essential part of the re-entry circuit.[11] CTO in an infarct-related artery is associated with greater scarring and, above all, with a greater border zone, which is central to the development of arrhythmias, and sudden cardiac death.[12] Relevant reports indicate that the increased vulnerability of hibernating myocardium may play a role in VF initiation.[12] Additionally, a larger penumbra zone (0.5–1.5 mV) can be observed on the electroanatomic voltage maps of patients with chronic total occlusion, and VF, indicating that these patients have widespread myocardial heterogeneity.[3] We hypothesized that restoring coronary blood flow in the CTO caused the mechanical and electrical "silent" areas suddenly to resume electrical activity, thereby altering the electrophysiological characteristics of chronic hibernating myocardium. Delayed depolarization (DAD) may be the most common electrophysiological cause of reperfusion arrhythmias. DADs are oscillations of membrane potential that occur after complete repolarization of the preceding action potential.[13] DADs after reperfusion are caused by intracellular calcium overload. When calcium flows into the cell, the calcium released by the sarcoplasmic reticulum is further amplified,[14–16] and when the threshold of the depolarization current is reached, a spontaneous action potential is generated. This action potential can re-evoke an after-potential, thereby generating a self-sustaining rhythmic activity. In addition, intracellular calcium overload can lead to reperfusion arrhythmias through uncoupling of oxidative phosphorylation,[5,17] which leads to decreased adenosine triphosphate (ATP) concentrations and induces shortening of the action potential by closing potassium-ATP channels.[18,19] Additionally, in early-stage VF electrical storm, the serum potassium concentration is low, and arrhythmias caused by hypokalemia can be attributed to prolonged ventricular repolarization, slow conduction, and abnormal pacemaker activity.[20] However, even after potassium supplementation, patients may still have frequent VF when potassium ions return to normal physiological levels. Moreover, electrolyte concentrations are essentially at normal physiological levels during electrical storm, indicating that an electrolyte disorder is unlikely to cause VF electrical storm.

VF electrical storm suddenly stopped in our patient, and the electrocardiogram during 24-hour cardiac monitoring was essentially normal, suggesting a different mechanism for the VF electrical storm. CAG was performed again after achieving hemodynamic stability, and the implanted stents were well-seated, without thrombi. When we compared angiograms before and after the operation, the diagonal branch, as the collateral circulation between the LAD and LCX, was significantly thinner and more compressed than before. The most commonly observed collaterals in cases of CTO of the LAD are from the

septal branch of the posterior descending artery, right atrial and right ventricular branches of the RCA, and the obtuse marginal branches of the LCX;[21] the diagonal branch is rare as collateral circulation. Relevant research shows that the diagonal branch is significantly important to the coronary collateral blood flow, especially when the anterior descending branch has insufficient blood flow.[22] In this condition, diagonal branch occlusion can cause arrhythmia, although the incidence is relatively low compared with main branch disease.[22] Therefore, we speculate that the diagonal branch, as collateral circulation, is not protected during the treatment of LAD-CTO, which leads to poor blood flow and may also lead to transient VF electrical storm.

The diameter, length and range of the diagonal branch differ in different populations; therefore, the influence of diagonal branch occlusion on cardiac function also differs. Generally, the number of diagonal branches varies from two to nine, and diagonal branches >2 mm in diameter are considered the main supply branch to the LAD.[23] Currently, the treatment of isolated diagonal occlusion is a matter of debate.[24] Regarding acute myocardial infarction, the incidence of mechanical complications is greater when the culprit of the acute myocardial infarction (AMI) is the side branch. Therefore, LAD-AMI with poor diagonal blood flow should be reconstructed as soon as possible, including the diagonal branch. If sufficient diagonal flow is not necessary in LAD-AMI, we can limit the primary PCI to the LAD.[25] This allows avoiding complex procedures, such as the kissing balloon technique or two-stent strategy, and permits concentrating only on revascularizing the LAD to achieve thrombolysis in myocardial infarction (TIMI)-3 flow. As these complex procedures are associated with stent thrombosis or adverse events in primary PCI, simplified procedures are safer than complex procedures in primary PCI.[26] However, for patients with complete coronary artery occlusion, especially those with anterior descending coronary artery occlusion, the prognosis is poor owing to the large infarct size and significant decline in left ventricular function. Studies have shown that in LAD-CTO with collateral circulation, the presence of collateral circulation can effectively reduce myocardial ischemia and the scope of the myocardial infarction, enable myocardial survival, and reduce ventricular remodeling; therefore, the prognosis is better than that of patients without collateral circulation.[27] Studies have shown that when the dichotomous collateral flow index (CFI) threshold of 0.25 is used to distinguish good from bad collateral supply, patients with insufficient collateral protection have a four to eight times higher incidence of major adverse cardiac events (MACE) after PCI than patients with sufficient collaterals.[28] Currently, with global collaboration and shared knowledge, there are seven widely accepted common principles considered best practices for CTO-PCI;[29] however, there is no consensus regarding intraoperative management for the collateral circulation. Therefore, we speculate that in LAD-CTO, a diagonal branch, as collateral circulation, with a diameter >2 mm, should be protected, and a stent should be implanted if necessary. If the patient's condition is stable, and the results of 24-hour electrocardiogram (ECG) monitoring are essentially normal, performing intervention for the diagonal branch may damage the implanted stent and affect forward blood flow.

VF electrical storm is a clinical emergency and requires appropriate early management. The first choice of treatment in early-stage VF electrical storm is administering antiarrhythmic drugs, such as beta blockers and amiodarone, which are commonly used. Beta blockers play an

important role in suppressing sympathetic discharge after arrhythmia and defibrillation. In addition, some drugs can be used as adjuvants to amiodarone and beta blockers, such as procainamide, lidocaine, sotalol, and mexiletine.[30–32] If medical treatment fails, radiofrequency ablation surgery is an effective treatment for VF electrical storm.[23] Regarding electrophysiological treatment, overdrive treatment has been recommended as a class IIa indication in the recent guidelines of the European Society of Cardiology for the management of ventricular arrhythmias.[33]

Conclusion

There are several mechanisms underlying VF electrical storm after CTO PCI, and reperfusion arrhythmia after coronary revascularization as a cause of electrical storm cannot be excluded. In addition, during PCI for CTO, larger branches providing collateral circulation should be protected. Compromise of either branch vessels or collateral circulation during intervention leads to limited and insufficient flow, resulting in VF electrical storm.

Author contributions

Xingji Liu was responsible for organizing and writing the manuscript. Tianlong Chen and Yonggang Wang were responsible for collecting the materials. Binay Kumar Adhikari was responsible for language editing. Quan Liu and Shudong Wang were responsible for reviewing relevant articles. All authors read and approved the manuscript

Ethics statement

Ethical approval was obtained from the Ethics Committee of The First Hospital of Jilin University, China. Written informed consent was obtained from the patient for publication of this case report and any accompanying images. A copy of the written consent is available for review by the Editor of this journal.

ORCID iDs

Xingji Liu 🔟 https://orcid.org/0000-0001-9147-4831
Binay Kumar Adhikari 🔟 https://orcid.org/0000-0002-1301-5899
Yonggang Wang 🔟 https://orcid.org/0000-0003-0370-4591

References

1. Chen M. Ventricular tachycardia ablation and substrate modification in ICD patients with electrical storm. *J Biomed Res* 2015; 29: 52–55.
2. Pedersen CT, Kay GN, Kalman J, et al. EHRA/HRS/APHRS expert consensus on ventricular arrhythmias. *Europace* 2014; 16: 1257–1283.
3. Koenig S, Arya A, Hindricks G, et al. Catheter ablation of ventricular tachycardia in the setting of electrical storm after revascularization of a chronic total occlusion of the right coronary artery: an uncommon presentation of reperfusion arrhythmia. *HeartRhythm Case Rep* 2016; 2: 462–464.
4. Nombela-Franco L, Mitroi CD, Fernandez-Lozano I, et al. Ventricular arrhythmias among implantable cardioverter-defibrillator recipients for primary prevention: impact of chronic total coronary occlusion (VACTO Primary Study). *Circ Arrhythm Electrophysiol* 2012; 5: 147–154.
5. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *Ann Intern Med* 2009; 151: W65–W94.
6. Flores-Umanzor EJ, Cepas-Guillen PL, Caldentey G, et al. Sex-based differences in chronic total occlusion management and

long-term clinical outcomes. *Int J Cardiol* 2020; 319: 46–51.

7. Flores-Umanzor EJ, Cepas-Guillen PL, Vázquez S, et al. Survival benefit of revascularization versus optimal medical therapy alone for chronic total occlusion management in patients with diabetes. *Catheter Cardiovasc Interv* 2020.

8. Flores-Umanzor EJ, Vázquez S, Cepas-Guillen P, et al. Impact of revascularization versus medical therapy alone for chronic total occlusion management in older patients. *Catheter Cardiovasc Interv* 2019; 94: 527–535.

9. Patel VG, Brayton KM, Tamayo A, et al. Angiographic success and procedural complications in patients undergoing percutaneous coronary chronic total occlusion interventions: a weighted meta-analysis of 18,061 patients from 65 studies. *JACC Cardiovasc Interv* 2013; 6: 128–136.

10. Sesselberg HW, Moss AJ, Mcnitt S, et al. Ventricular arrhythmia storms in postinfarction patients with implantable defibrillators for primary prevention indications: a MADIT-II substudy. *Heart Rhythm* 2007; 4: 1395–1402.

11. Horowitz L, Josephson M and Harken A. Epicardial and endocardial activation during sustained ventricular tachycardia in man. *Circulation* 1980; 61: 1227–1238.

12. Di Marco A, Paglino G, Oloriz T, et al. Impact of a chronic total occlusion in an infarct-related artery on the long-term outcome of ventricular tachycardia ablation. *J Cardiovasc Electrophysiol* 2015; 26: 532–539.

13. Weg K, Prinzen FW and Gorgels AP. Editor's Choice- Reperfusion cardiac arrhythmias and their relation to reperfusion-induced cell death. *Eur Heart J Acute Cardiovasc Care* 2019; 8: 142–152.

14. Jeroudi MO, Hartley CJ and Bolli R. Myocardial reperfusion injury: role of oxygen radicals and potential therapy with antioxidants. *Am J Cardiol* 1994; 73: 2B–7B.

15. Del Monte F, Lebeche D, Guerrero JL, et al. Abrogation of ventricular arrhythmias in a model of ischemia and reperfusion by targeting myocardial calcium cycling. *Proc Natl Acad Sci U S A*. 2004; 101: 5622–5627.

16. Akar JG and Akar FG. Regulation of ion channels and arrhythmias in the ischemic heart. *J Electrocardiol* 2007; 40: S37–S41.

17. Aiello EA, Jabr RI and Cole WC. Arrhythmia and delayed recovery of cardiac action potential during reperfusion after ischemia. Role of oxygen radical-induced no-reflow phenomenon. *Circ Res* 1995; 77: 153–162.

18. Akar FG, Aon MA and Tomaselli GF. The mitochondrial origin of postischemic arrhythmias. *J Clin Invest* 2005; 115: 3527–3535.

19. Brown DA and O'Rourke B. Cardiac mitochondria and arrhythmias. *Cardiovasc Res* 2010; 88: 241–249.

20. Osadchii OE. Mechanisms of hypokalemia-induced ventricular arrhythmogenicity. *Fundam Clin Pharmacol* 2010; 24: 547–559.

21. Koo BK, Lee SP, Lee JH, et al. Assessment of clinical, electrocardiographic, and physiological relevance of diagonal branch in left anterior descending coronary artery bifurcation lesions. *JACC Cardiovasc Interv* 2012; 5: 1126–1132.

22. Zhang S, Deng X, Yang W, et al. The diagonal branches and outcomes in patients with anterior ST- elevation myocardial infarction. *BMC Cardiovasc Disord* 2020; 20: 108.

23. Yamamoto K, Sakakura K, Akashi N, et al. Comparison of clinical outcomes between sufficient versus insufficient diagonal branch flow in anterior acute myocardial infarction. *Heart Vessel* 2019; 34: 1096–1103.

24. Hildick-Smith D, De Belder AJ, Cooter N, et al. Randomized trial of simple versus complex drug-eluting stenting for bifurcation lesions: the British Bifurcation Coronary Study: old, new, and evolving strategies. *Circulation* 2010; 121: 1235–1243.

25. Brener SJ, Cristea E, Kirtane AJ, et al. Intra-procedural stent thrombosis: a new risk factor for adverse outcomes in patients undergoing percutaneous coronary intervention for acute coronary syndromes. *JACC Cardiovasc Interv* 2013; 6: 36–43.

26. Gorgels AP, van den Dool A, Hofs A, et al. Comparison of procainamide and lidocaine in terminating sustained monomorphic

ventricular tachycardia. *Am J Cardiol* 1996; 78: 43–46.

27. Zhang C, Yang J, Feng J, et al. Short-term administration of basic fibroblast growth factor enhances coronary collateral development without exacerbating atherosclerosis and balloon injury-induced vasoproliferation in atherosclerotic rabbits with acute myocardial infarction. *J Lab Clin Med* 2002; 140: 119–125.

28. Billinger M, Kloos P, Eberli FR, et al. Physiologically assessed coronary collateral flow and adverse cardiac ischemic events: a follow-up study in 403 patients with coronary artery disease. *J Am Coll Cardiol* 2002; 40: 1545–1550.

29. Brilakis ES, Mashayekhi K, Tsuchikane E, et al. Guiding principles for chronic total occlusion percutaneous coronary intervention. *Circulation* 2019; 140: 420–433.

30. Pacififico A, Hohnloser SH, Williams JH, et al. Prevention of implantable-defibrillator shocks by treatment with sotalol. d,l-Sotalol Implantable Cardioverter-Defibrillator Study Group. *N Engl J Med* 1999; 340: 1855–1862.

31. Gao D, Van Herendael H, Alshengeiti L, et al. Mexiletine as an adjunctive therapy to amiodarone reduces the frequency of ventricular tachyarrhythmia events in patients with an implantable defibrillator. *J Cardiovasc Pharmacol* 2013; 62: 199–204.

32. Tanner H, Hindricks G, Volkmer M, et al. Catheter ablation of recurrent scar-related ventricular tachycardia using electroanatomical mapping and irrigated ablation technology: results of the prospective multicenter Euro-VT-study. *J Cardiovasc Electrophysiol* 2010; 21: 47–53.

33. Priori SG, Blomström-Lundqvist C, Mazzanti A, et al. 2015 ESC guidelines for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death: the Task Force for the Management of Patients with Ventricular Arrhythmias and the Prevention of Sudden Cardiac Death of the European Society of Cardiology (ESC). Endorsed by: Association for European Pediatrics and Congenital Cardiology (AEPC). *Eur Heart J* 2015; 36: 2793–2867.