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Review Article

Reperfusion Arrhythmia in Acute Myocardial Infarction: Clinical Implication and Management

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ABSTRACT

Reperfusion is a critical component of myocardium survival in acute myocardial infarction to minimize infarct size and improve clinical prognosis. On the other hand, Reperfusion may result in increased and accelerated myocardial injury, a condition known as reperfusion injury. Following reperfusion, several arrhythmias are observed, called reperfusion arrhythmia. Reperfusion arrhythmia is one manifestation of reperfusion injury. Numerous modest studies have evaluated what reperfusion arrhythmias are defined. It is described as an arrhythmia that occurs immediately or within the first minutes after coronary blood flow restoration. Traditionally, accelerated idioventricular rhythm (AIVR) has been seen as a reperfusion arrhythmia. However, reperfusion may reveal any arrhythmia (or none at all); conversely, AIVR may occur in the absence of reperfusion. Calcium excess within the cells is a significant factor in reperfusion arrhythmias development. This may affect the significant delay following depolarization and the regional heterogeneity of regional blood flow restoration inside the ischemic zone, resulting in reperfusion arrhythmia. Some studies mentioned that these arrhythmias might be due to ongoing myocardial cell damage and ischemia. Arrhythmias associated with reperfusion require special attention since hemodynamics can deteriorate quickly. In this review, clinical significance and management of reperfusion arrhythmia and its link with reperfusion injury will be discussed.

1. Introduction

Early reperfusion is required for the myocardium to survive during acute myocardial infarction. Reperfusion of ischemic myocardium tissue with fibrinolysis or percutaneous coronary intervention (PCI) is critical for reducing infarct size and improving outcomes. On the other hand, Reperfusion has been dubbed the double-edged sword due to the possibility it may result in extra myocardial harm beyond that caused by ischemia alone. This occurs in various reperfusion-related diseases collectively referred to as reperfusion injury.[1,2] Reperfusion injury is the damage induced by inflammation, oxidative stress, and electrochemical imbalance when blood flow is restored to previously ischemic tissue.[3]

Reperfusion arrhythmias are often characterized by premature ventricular beats with prolonged coupling intervals and rapid idioventricular rhythms that begin within the first 20 minutes of reperfusion.[3] Numerous modest investigations have been conducted to determine the time course of reperfusion arrhythmias. Calcium excess within the cell is a significant factor in reperfusion arrhythmias development. Traditionally, accelerated idioventricular rhythm (AIVR) has been seen as a marker for reperfusion. However, reperfusion may reveal any arrhythmia (or no arrhythmia); conversely, AIVR may occur without reperfusion.[4] In some studies, it was mentioned that these arrhythmias might be due to ongoing myocardial cell damage and ischemia.[5] Some reperfusion arrhythmias are relieved spontaneously and do not need management, but the others may be associated with circulatory collapse and require immediate treatment. The purpose of this writing is to discuss the clinical implications and management of reperfusion arrhythmia and its relationship to reperfusion injury.

2. Definition of Reperfusion Arrhythmia

Numerous minor studies have been conducted to determine the definition of reperfusion arrhythmias.6 Ilia et al. defined it as AIVR, ventricular tachycardia, or numerous premature ventricular complexes that appeared in the first minute after balloon inflation.[7] Bonnemeier et al. defined it as an arrhythmia that occurs within twenty-four hours following PCI.[8] Terkelsen et al. defined it as any prespecified arrhythmia that occurs up to 90 minutes following the cardiac intervention.[6] European Heart Rhythm Association (EHRA) consensus defined reperfusion arrhythmia as an arrhythmia that occurs during or during the initial minutes following the restoration of coronary blood flow.[9]

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3. Type of Reperfusion Arrhythmia

Terkelsen et al. investigated arrhythmias that occurred 90 minutes after revascularization in patients with ST-elevation myocardial infarction (STEMI) admitted to Aarhus University Hospital, Skejby, Denmark. The study's primary finding was that AIVR is the most frequently observed arrhythmia early after primary PCI. However, contrary to what was previously described, it is not a marker of successful reperfusion.6 The prevalence of reperfusion arrhythmia showed in Table 1.

Another study by Tatli et al. compared recorded arrhythmias following primary PCI and thrombolytic revascularization in STEMI. Arrhythmia was observed for 48 hours following revascularization procedures. As with previous studies, AIVR is the most frequently observed arrhythmia early after revascularization procedures in primary PCI and thrombolytic groups.[10] The comparison of arrhythmia between the procedures is shown in Table 2.

Table 1. Occurrence of Arrhythmias in STEMI Patients After Primary PCI .[6]

Conduction Disturbances	
First-degree AV Block	25% (125
Second-degree AV Block, Mobitz I	3% (13)
Second-degree AV Block, Mobitz II	2% (9)
Third-degree AV Block	5% (24)
Right Bundle Branch Block	8% (40)
Left Bundle Branch Block	1% (7)
Arrhythmias	
Sinus Arrest (>2.5 s)	5% (23)
Sinus Bradycardia <59 beats/min	28% (141)
Sinus Tachycardia ≥ 100 beats/min	22% (112)
Atrial Fibrilattion	9% (47)
Junctional Bradycardia <50 beats/ min	8% (42)
Junctional Rhythm, 50-100 beats/min	8% (38)
AIVR, 50-120 beats/min	42% (210)
Nonsustained VT, > 120 beats/min	26% (129)
Sustained VT, > 120 beats/min	2% (8)
Venticular Fibrillation	2% (10)
Ventricukar Paced Rhythm	1% (7)

4. Spectrum of Rperfusion Injury

• Myocardial stunning.

It is defined as prolonged postischemic mechanical dysfunction of previously ischemic tissue that persists following reperfusion in the absence of irreversible damage, such as myocardial necrosis. This dysfunction lasts significantly longer than the preceding ischemia.[11]

• Reperfusion arrhythmias.

After an ischemic period, reperfusion of the heart may result in potentially fatal arrhythmias. The most frequently encountered reperfusion arrhythmia in humans is AIVR.[3]

• Endothelial dysfunction.

It is characterized by impaired endothelium-dependent vasodilation, accompanied by excessive responses to endothelium-dependent vasoconstrictors. Coronary arteries are constricted due to increased vasoconstrictors like endothelin-1 and oxygen-free radicals. A prothrombotic phenotype, characterized by platelet and neutrophil activation, is also expressed when endothelial dysfunction occurs.[1]

• Microvascular dysfunction.

Microvascular dysfunction is caused by a combination of endothelial dysfunction, microvascular obstruction (downstream platelet microembolism, de novo thrombosis, and neutrophil capillary plugging), edema, and oxidative stress.[1]

4. Pathophysiology of Reperfusion Injury

Intracellular Calcium Overload

Reperfusion of previously ischemic tissue removes extracellular electrolytes and utilizes the H+/Na+ exchanger to fix intracellular acidosis, leading to an elevated intracellular sodium concentration (Figure 1). Due to the continued deficit of adenosine triphosphate (ATP), the adjustment of intracellular sodium concentration via Na+/K+ ATPase is inadequate, and the inverted Na+/Ca2+ exchanger takes over, resulting in intracellular calcium overload.[12,13] Reperfusion augments intracellular calcium release by activating the renin-angiotensin system, which releases angiotensin II, which, when combined with the catecholamines released during ischemia and reperfusion, results in additional intracellular calcium release. Additionally, reperfusion-induced reactive oxygen species (ROS) generation relates substantially to calcium excess via sarcoplasmic reticulum damage. When reactive oxygen species and free fatty acids combined and alpha-1 adrenergic receptors are stimulated, it also results in calcium overload via catecholamine interaction.[1]

Reactive Oxygen Species Production

Large amounts of generating ROS are produced in stressful conditions. Xanthine oxidase and also hypoxanthine is formed during ischemia. After reperfusion, oxygen interacts with xanthine oxidase and hypoxanthine, generating ROS. Neutrophils are a significant source of ROS at the site of reperfusion, both directly and through stimulation of nicotinamide adenine dinucleotide phosphate.[14]

Neutrophil Accumulation

Neutrophils are found at the ischemic tissue's boundary. The buildup of neutrophils in non-perfused myocardial is related to a slow infiltration into the at-risk area within the first 12–24 hours of ischemia, peaks after 2–4 days, and is most prominent near the infarct border zone. However, neutrophil accumulation is accelerated and increased in reperfused myocardium, with concentrations being higher in the subendocardial than in the subepicardial.[15]

Opening Mitochondrial Permeability Transition Pore

The opening of the mitochondrial permeability transition pore (mPTP) due to excessive ROS and intracellular calcium overload has already been recognized as a major stage in reperfusion injury.[13] Due to the inhibitory action of acidosis on the pore, the modest increase in intracellular calcium and ROS produced during ischemia is inadequate to open the pore. Following reperfusion, acidosis resolves and the ROS and intracellular calcium rise, culminating in the mPTP opening. The opening of the mPTP channel results in the influx of additional molecules, increasing the osmotic load and resulting

Table 2. Comparison of the frequency of various reperfusion arrhythmias between primary PCI and thrombolytic treatment groups of patients.[10]

	Treatment		
	Primary PCI (n=54) Mean ± SD (Meidan) n (%)	Thrombolytic (n=97) Mean ± SD (Median) n (%)	
Reperfusion arrythmias*	45 (83.3%)	86 (88.7%)	0.355
AIVR	27 (50%)	71 (73.2%)	0.004
Sustained VT	4 (7.4%)	5 (5.2%)	0.575
Nonsustained VT	31 (57.5)	68 (70.1%)	0.116
Venticular Fibrillation**	2 (3.7%)	0 (0%)	0.126
AV Block	3 (5.6%)	6 (6.2%)	0.875
Frequent PVCs	5 (9.3%)	17 (17.5%)	0.168
Atrial Fibrillation	7 (13%)	26 (26.8%O	0.049

All data were presented by mean SD; AIVR= Accelerated Idioventricular Rhythm, AV Block= Atrioventricular Block; VT=Ventricular Tachycardia PVCs= Premature ventricular contractions.

in mitochondrial swelling in addition to an increase in ROS and intracellular calcium. The swelling eventually ruptures the mitochondria and releases apoptotic proteins (Figure 2).[3]

Additionally, mPTP cleavage and intracellular calcium overload cause oxidative phosphorylation to become uncoupled. Uncoupling oxidative phosphorylation induces apoptosis through ATP hydrolysis, which activates degradative enzymes.[16] Finally, calcium overload within the cell can result in myocyte hypercontracture. Excessive hypercontracture can cause myocytes to tear away from tight intercellular junctions, causing damage to adjacent cells' sarcolemmal membranes and cytoskeletal elements, ultimately leading to apoptosis. On histological examination, this is seen as contraction band necrosis.

5. Pathophysiology Arrhythmia in Ischemia

Significant metabolic changes occur within seconds following ischemia: high-energy phosphates are hydrolyzed, the intracellular pH decrease due to the initiation of the anaerobic process of glycolysis, and the rise of extracellular potassium. As the resting membrane potential approaches the firing threshold, the rate of electrical conduction increases. Additionally, acidosis increases cytosolic calcium, allowing for early and late depolarization. Additionally, ischemia dephosphorylates connexin-43 in gap junctions, affecting the cell-cell electrical connection. Finally, sympathetic activation induces calcium release from the sarcoplasmic reticulum and lipolysis, raising circulating free fatty acid levels and predisposing to arrhythmia.[17,18,19]

Arrhythmia in ischemia may be connected to an autonomic imbalance associated with vagal hyperactivity during the initial several hours of myocardial ischemia, leading to a transitory atrioventricular (AV) conduction slowdown. Myocardial ischemia and necrosis can cause immediate malfunction or irreversible damage to the AV conduction system, leading to the establishment of a new bundle branch block (BBB) or exacerbation of an existing symptomatic high degree AV block.[18,20,21] On the other hand, ischemia may induced ventricular arrhythmia such as ventricular tachycardia (VT) or ventricular fibrillation (VF) in proarrhythmic myocardial cells or tissue (Figure 3).[17]

6. Pathophysiology of Reperfusion Arrhythmia

While the pathophysiology of reperfusion arrhythmias is not well understood, certain essential events are well established. One of them is delayed after depolarisations (DAD). DAD is almost certainly the most common cause of reperfusion arrhythmias. An excess of intracellular calcium causes it. When the threshold of the depolarising

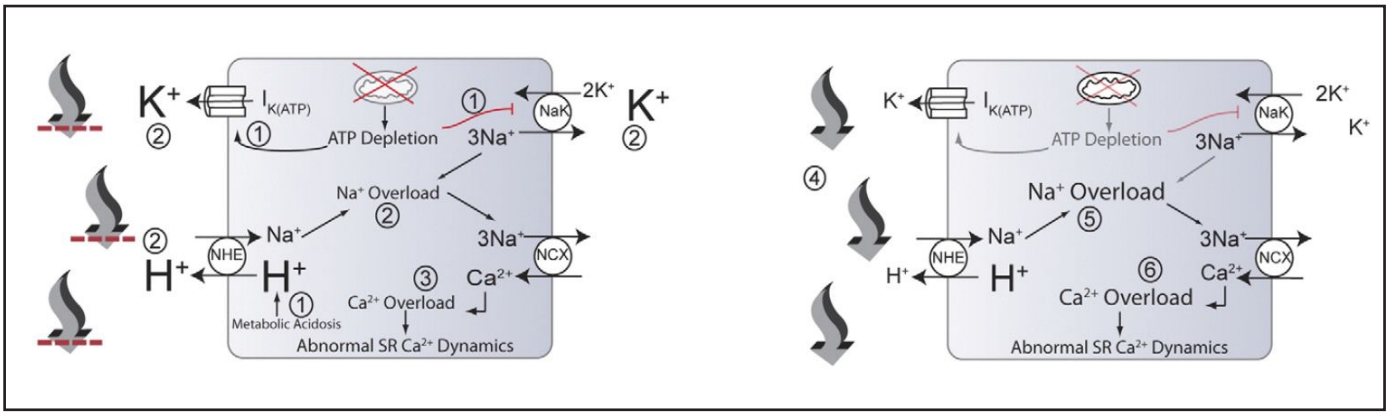

Figure 1. Pathophysiology intracellular calcium overload during ischemia and after reperfusion.12

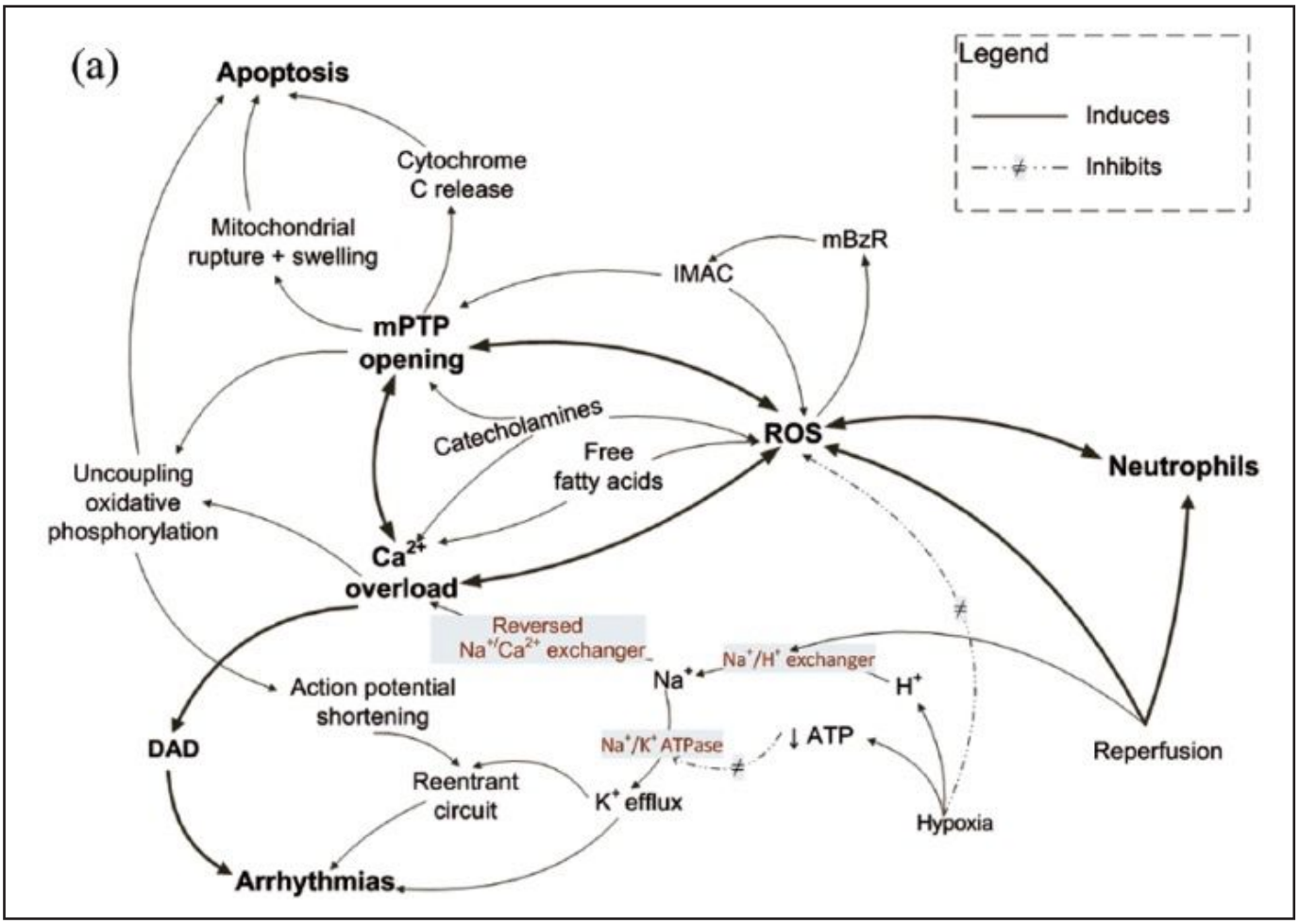

Figure 2. Schematic changes of reperfusion injury and relation with reperfusion arrhythmias.[3]

current is exceeded, a spontaneous action potential arises.16 Again, this action potential can generate an afterpotential, leading to self-sustaining cyclic activity.[22]

Reperfusion in AMI patients results in an increase in intracellular Ca2+ concentration, normalization of extracellular K+ concentrations, and restoration of action potential duration. These changes, but even so, are not uniform, expressing the spatial heterogeneity of regional blood flow restoration within the ischemic zone. This matter results in refractory dispersion, resulting in the formation of re-entry substrate.[23]

On the inferior wall, infarction may manifest as transient bradycardia and hypotension due to reflex activation Bezold–Jarisch reflex (bradycardia, vasodilation, and hypotension) because reperfusion provokes receptors located in the left ventricle's inferior wall.[18] Numerous reperfusion mechanisms can increase susceptibility to atrial fibrillation (AF) by providing either a substrate or a trigger for this arrhythmia. AF can be caused by hemodynamic changes such as pulmonary capillary wedge pressure and left atrial pressure.18 The frequency of reperfusion arrhythmia depends on:

• Early reperfusion: the sooner reperfusion begins, the more likely reperfusion arrhythmias will occur. As a result, reperfusion occurs more frequently with prehospital thrombolytics than intrahospital thrombolytics.

• Reperfusion rate: The faster the reperfusion occurs, the more frequently the reperfusion arrhythmias. As a result, PCI is more frequently associated with reperfusion arrhythmias than fibrinolytics in acute coronary syndrome (ACS).

7. Is it Really Reperfusion?

A study from Bonnemeier et al. showed that 15% of successful primary PCI patients (19 of 125 patients) exhibited AIVR, indicating a poor correlation between thrombolysis in myocardial infarction (TIMI) 2 or 3 flow and occurring of reperfusion arrhythmia.[8] A Study from Gibson et al. demonstrated the development of VT and VF in 3491 STEMI patients following thrombolytic. They found that TIMI 0–2 flow was present in patients with VT or VF. Reperfusion arrhythmia and TIMI flow grades had no statistically significant connection in the primary PCI group.[24] Study from Tatli et al. investigated reperfusion arrhythmias as indicators of coronary artery patency or ongoing ischemia after revascularization in 151 STEMI patients that got thrombolytic therapy and percutaneous coronary intervention. The frequency of reperfusion arrhythmias following revascularization procedures in the first 48 hours after admission was examined. There was no significant difference between the patency rates of each group with and without reperfusion arrhythmias.[10] However, some researchers regard the existence of AIVR as a reliable but significantly weaker ECG predictor of reperfusion, especially when compared to ST-segment resolution.[25]

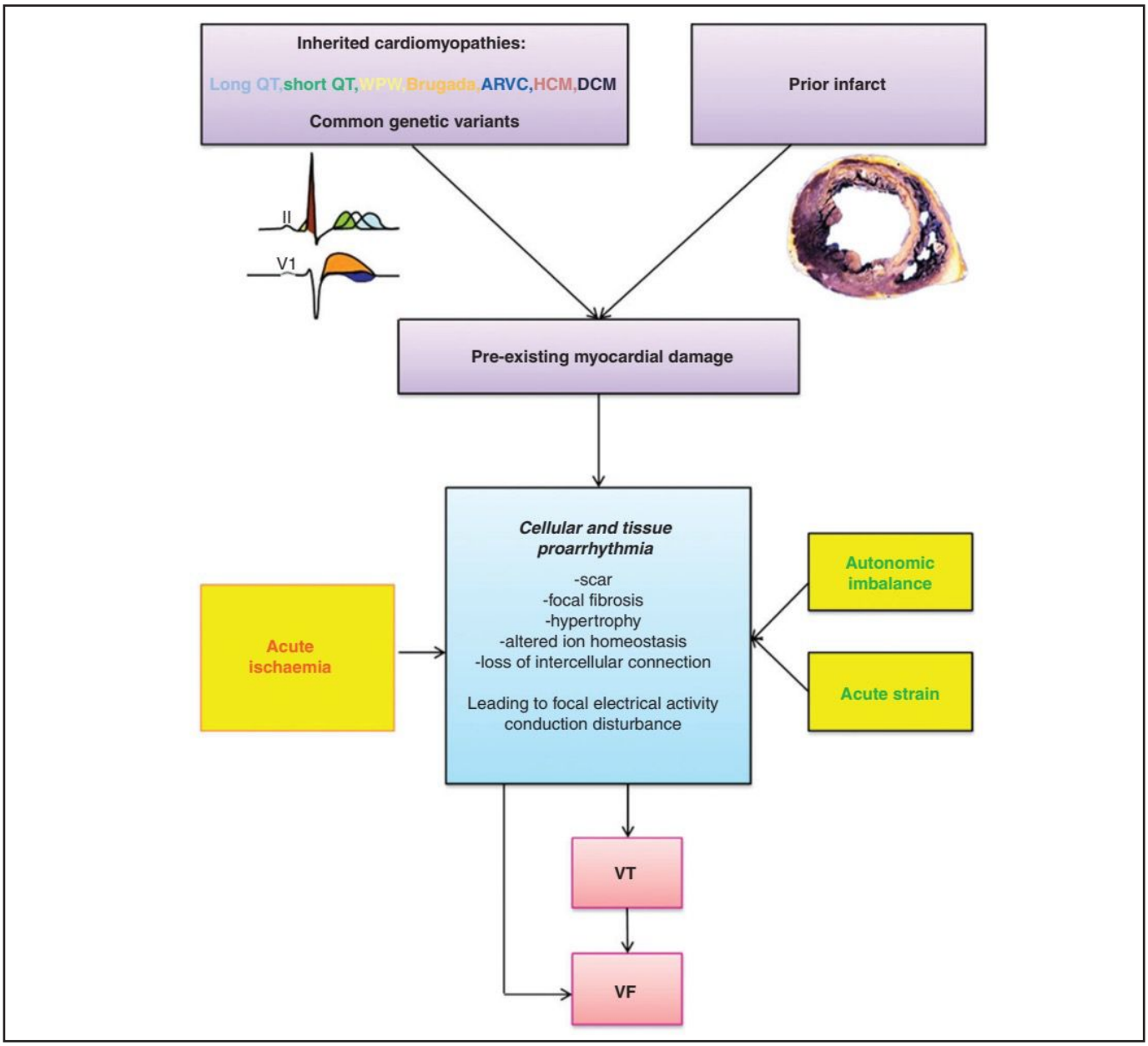

Figure 3. Scheme of drivers for arrhythmias in acute coronary syndromes.17

8. Treatment

As mentioned previously, most reperfusion arrhythmias resolve spontaneously, but some cause significant hemodynamic changes and require management.

Electrical Cardioversion/Defibrillation

If life-threatening ventricular arrhythmias associated with ACS persist despite optimal revascularization, electrical cardioversion/defibrillation should be considered first. Additionally, in atrial arrhythmias such as AF, adverse hemodynamic consequences can rapidly worsen symptoms. When cardiac output is compromised and the hemodynamic become destabilized, immediate cardioversion should be performed to restore sinus rhythm (Figure 4).[18]

Antiarrhythmic Drug (AAD)

Beta-blocker. By inhibiting beta-adrenoreceptors, the heart rate is decreased. The beneficial effects include lowered automaticity, which lowers the chances of triggered ventricular arrhythmias, decreased conduction velocity, and improved the stability of circuits of re-entry. In VT or VF, it should be initiated as first-line therapy. Beta-blocker in patients who have bradycardia or significant right coronary ischemia must be cautious.[23]

Amiodarone. A drug with a predominance of Vaughan-Williams class III activity can treat recurrent VT and VF resistance to beta-blocker. Amiodarone acts via various mechanisms, one of which is the blockade of K+ channels (phase 3 repolarization). Along with this primary effect, amiodarone affects the function of Na+ and Ca2+ channels and weak

beta-blocking properties. Amiodarone's primary anti-arrhythmic action is facilitated by lengthening of the refractory period and suppression of re-entry. However, a decrease in automaticity is also observed.26 Along with beta-blockers, amiodarone should be considered to suppress and prevent recurrent arrhythmias.[18]

Lidocaine. Lidocaine may be used despite Amiodarone. Lidocaine is an antiarrhythmic drug of class IB that blocks fast sodium channels responsible for the rapid phase 0 depolarization. Because calcium currents regulate phase 0 activity in spontaneously depolarizing nodal tissue, class I drugs have no direct impact on sino-atrial or AV nodal features. Na+ blockade generally decreases conduction velocity within atrial and ventricular tissue, which may be effective in downregulating tachyarrhythmias caused by re-entry. This, even so, may come at the expense of increased after-depolarizations and polymorphic VT.[26] Lidocaine therapies following cardiac arrest and successful resuscitation has been shown to have substantial benefits for both ventricular arrhythmia (VA) recurrence and survival.[27]

Flecainide, propafenone, and ajmaline. All work by significantly slowing conduction. However, in ACS, these medications may exacerbate VT/VF. Following the publication of the CAST trial, which demonstrated increased mortality in patients medicated with flecainide or moricizine following MI compared to placebo, additional research into class I AAD and VA was largely abandoned. As a result, these medications should not be used in ACS.[18]

Verapamil. Calcium channel blockers have been shown to alleviate intracellular calcium overload and improve vascular flow. A retrospective study by Kato et al. examined the effectiveness of intracoronary verapamil treatment in AMI to terminate ventricular tachyarrhythmias that occurred after reperfusion. It found that intracoronary verapamil was effective in rapidly terminating all reperfusion-induced arrhythmias except for VF. There were no significant adverse events associated with the intracoronary administration of verapamil, and no recurrences of arrhythmias were observed.[28]

Temporary Pacing

Temporary overdrive pacing could be used if those steps fail to suppress VA in the early post-MI period. A focus may be captured and suppressed automatically, or an exit block may be achieved by rendering the nearby myocardium refractory. Pacing-induced changes in conduction and refractoriness may terminate a tachycardia-induced by a re-entrant mechanism. This measure can be used in patients with refractory VA to avoid repeated cardioversion while waiting for drug treatment to take full effect or prior to further revascularization or catheter ablation.[23]

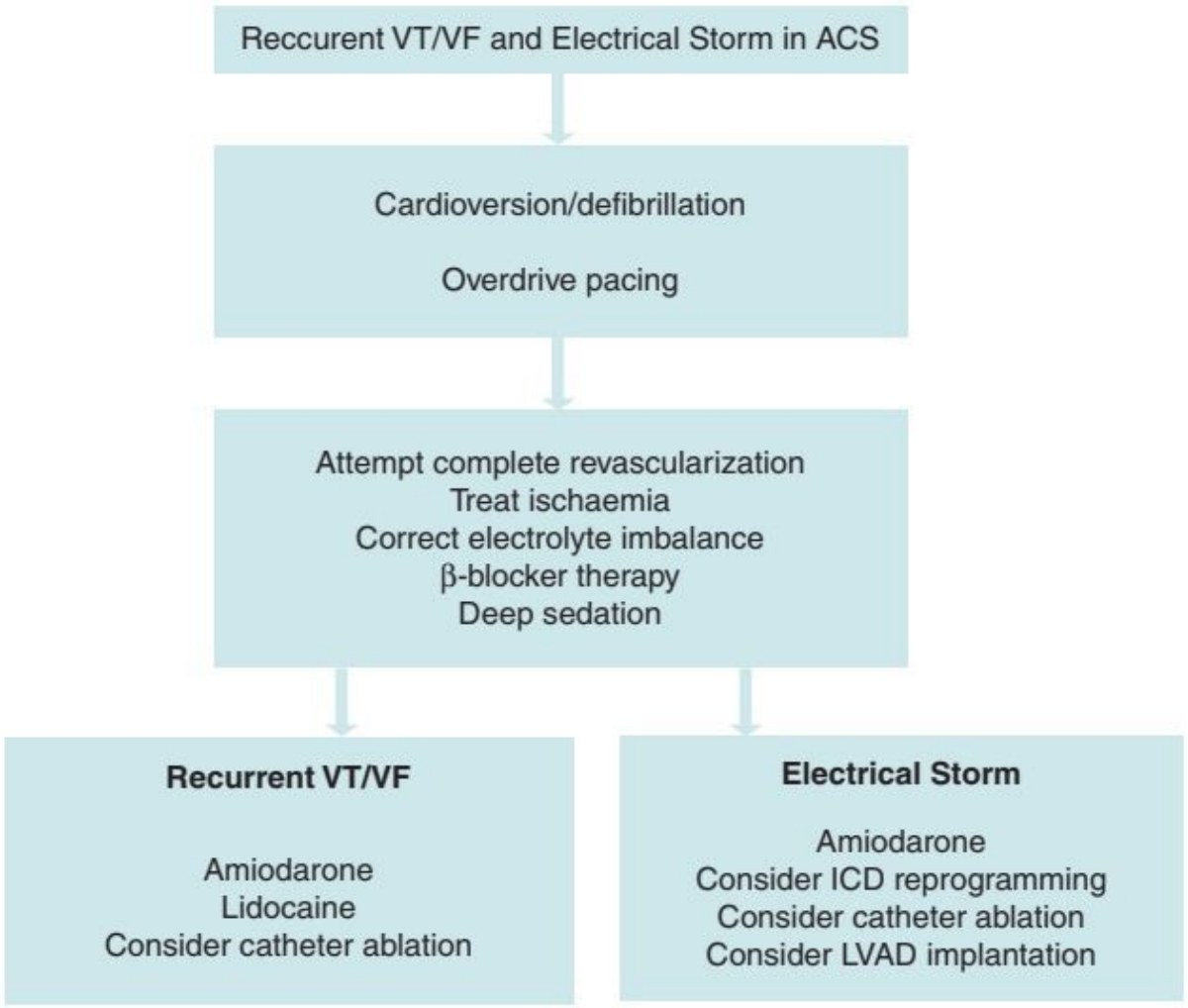

Figure 4. Treatment recommendations for recurrent VT/VF and electrical storm in ACS.18

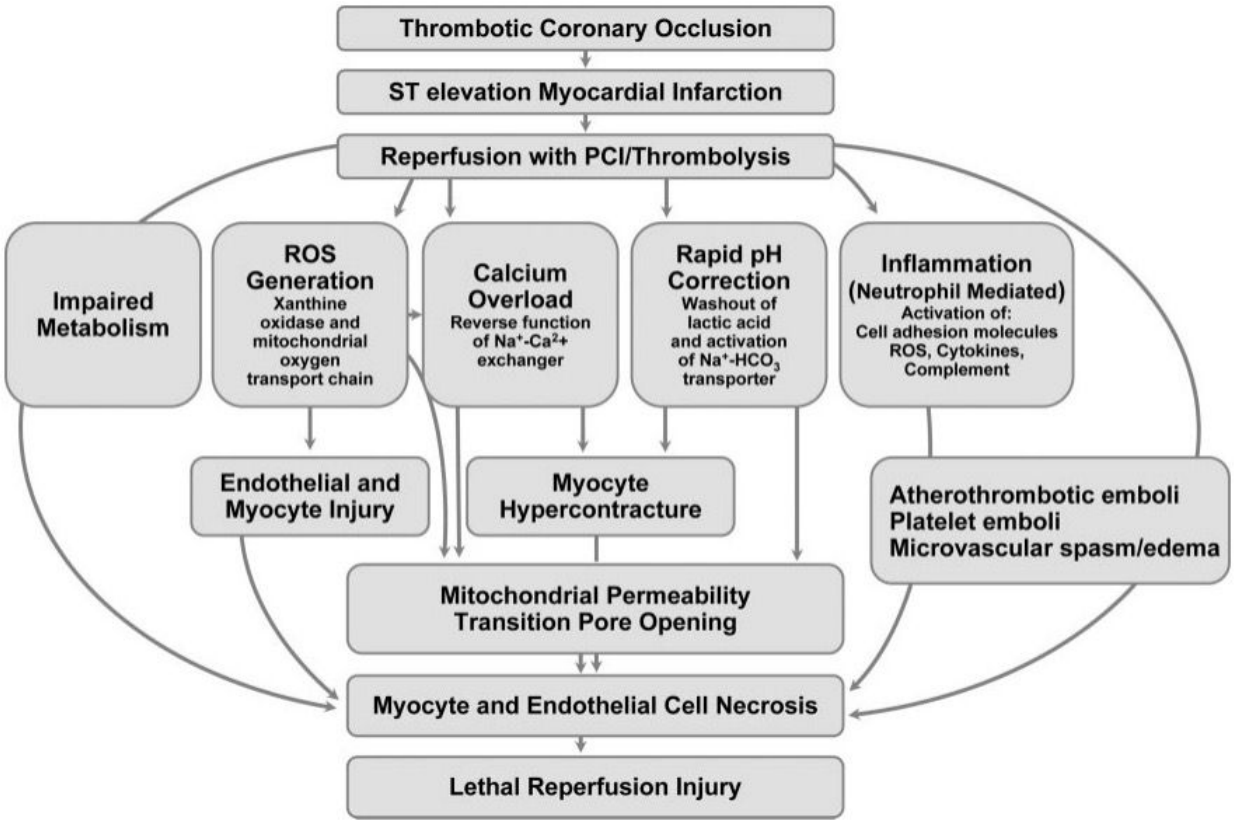

Figure 5. Pathophysiology lethal reperfusion injury.[37]

Sinus bradycardia (as a result of reperfusion) does not require treatment unless it compromises hemodynamics. Firstly, atropine 1–2 mg may be administered. If not responded, temporary pacing may be required. Appropriate hydration, pain control, and reassurance are all beneficial in managing periprocedural vasovagal responses.[18]

Radiofrequency Ablation

Catheter ablation for VA is not routinely performed during the acute phase. The acute success rate is around 70%, but there is a 3% peri-procedural mortality rate in unstable patients. Most ablation takes place subendocardial and in the border zone. The re-entrant circuits in the heterogeneous myocardium and the after-depolarisations and automatic foci formed by Purkinje fibers are the targets. In the appearance of frequent PVCs, activation mapping could be conducted. If PVCs are less frequent, pace mapping could be conducted against previously recorded PVCs. This patient population is frequently hemodynamically unstable, and the procedure's complexity necessitates that it be performed in high-volume centers by experienced electrophysiologists using 3D electroanatomical mapping systems and advanced supportive care.[29]

Mechanical Circulatory Support

VA is a frequent condition of myocardial infarction complicated by cardiogenic shock and the need for inotropes. Inotropes can exacerbate VA, but their dosage can be reduced when used with mechanical support. Apart from assisting with revascularization procedures, mechanical support may assist in maintaining sufficient cardiac output. The intra-aortic balloon pump (IABP) is the most frequently used device. This counter-pulsation device reduces afterload, increases diastolic coronary perfusion, and increases cardiac output. IABP has been used to improve results after primary PCI in high-risk patients by increasing coronary blood flow reserve, decreasing preload and afterload, and augmenting systemic pressure. Prophylactic use of IABP in high-risk patients may reduce the probability of VF, particularly in patients with cardiogenic shock.[30] But, it is unable to provide support in VF, whereas other forms of mechanical support can, like ECMO.[23]

Pharmacological Treatment

ODRF-Scavengers/Antioxidant Numerous ODFR-scavengers or antioxidants are evaluated in research settings, such as superoxide dismutase, catalase, the xanthine oxidase inhibitor allopurinol, the iron-chelator feroxamine, and antioxidants such as vitamin C, vitamin E, and melatonin. But, the evidence of these agents in reperfusion injury is insufficient.[31]

Na+/H+ Exchangers Inhibitors (NHE-Inhibitors). Na+/H+ exchanger has a pivotal role in reperfusion injury. After reperfusion, it allows influx of sodium, and the sodium overload induces the Na+/-Ca2+ exchanger, likely to result in an intracellular Ca2+ overload. Caryopsides inhibit Na+/H+ exchangers, resulting in a decrease in Na+ influx and a subsequent decrease in Ca2+ influx, thereby alleviating Ca2+ overload. However, several studies on the effects of NHE inhibitors on reperfusion injury were inconsistent.[32]

Na/Ca Exchangers Inhibitor. ATP depletion and an acidic environment that occurred in ischemia increase the concentration of Na+, which stimulates the Na+/Ca2+ exchanger, resulting in Ca2+ overload and cell death. Ca2+ influx is prevented by inhibiting the

Na+/Ca2+ exchanger. Clinical trials verifying the favorable impact of Na+/Ca2+ exchangers are not yet available.[1]

Magnesium. Magnesium acts as a physiological calcium antagonist, inhibiting calcium's transmembrane shift and transport across the sarcoplasmic reticulum. Since calcium overload plays a significant part in the development of reperfusion injury, magnesium's channel blocking attributes may be cardioprotective. IV magnesium administration in patients with STEMI is debatable.[1]

Trimetazidine. An anti-ischemic agent prevents fatty acid oxidation in a selective and specific manner. Trimetazidine was hypothesized to have cardioprotective properties by shifting the metabolism of myocytes aside from fatty acid oxidation and toward glucose oxidation. However, a recent large clinical trial found that trimetazidine given prior to or concurrently with thrombolysis did not affect short-term mortality.[33]

Angiotensin-converting enzyme (ACE) inhibitors. It increases the threshold for VF and reduces the frequency of VT and fibrillation episodes in animal experiments. Additionally, ACE inhibitors reduce the size of myocardial infarction.[34] Although the precise mechanism is unknown. This effect strongly suggests that kinins mediate the cardioprotective effect. Kinins are known to be attributed to the increasing number of the endothelium's release of prostaglandins and Nitric Oxide (NO). This increased NO release would enhance superoxide scavenging. Additionally, NO may have an inhibition activity on polymorphonuclear neutrophils.[35]

Statins. Following long-term treatment, statins exhibit a variety of cardioprotective attributes. In recent years, there has been growing evidence to suggest supporting the role of statins in preventing reperfusion injury, regardless of their lipid-lowering impact. Statins also inhibit neutrophil activation and extravasation, which can cause acute heart failure during reperfusion. Statins also positively impact endothelial and cardiac contractile dysfunction caused by ischemia/reperfusion.36 Further clinical research seems to be indicated.

9. Clinical Implication Reperfusion Arrhythmias on Reperfusion Injury

The fundamental mechanism outlined above reveals that reperfusion arrhythmias are caused by intracellular calcium excess. Similarly, intracellular calcium excess is crucial in catastrophic reperfusion injury-induced cell death. Thus, reperfusion arrhythmias and fatal reperfusion damage are likely two separate results of the same mechanism. As a result, reperfusion arrhythmias can be identified and used to diagnose lethal reperfusion injury (Figure 5).[37]

According to Majidi et al., the presence of a 'burst' of ventricular reperfusion arrhythmias (VA burst) is associated with a clinically substantial increase in infarct size. This increase persisted even after accounting for other known factors associated with increased infarct size. The significant difference persisted in the presence of optimal epicardial and microvascular reperfusion. Reperfusion arrhythmias are rarely reported as an electrobiomarker of reperfusion injury in clinical trials centered on infarct size reduction strategies. This study indicated that reperfusion arrhythmias might be a critical early and distinct marker of reperfusion injury. As such, reperfusion arrhythmias can serve as an early marker for risk stratification and the development of methods to reduce reperfusion injury.[38]

10. Conclusion

Reperfusion arrhythmia occurs immediately or within the first minutes after restored coronary blood flow. AIVR is the most commonly occurring reperfusion arrhythmia. Reperfusion arrhythmia is one of the reperfusion injury spectrums. A delay after depolarization and reentry frequently causes reperfusion arrhythmias. Numerous studies established that reperfusion arrhythmias were unrelated to coronary flow. Cardioversion/defibrillation, antiarrhythmic drugs, cardiac pacing, radiofrequency ablation, mechanical circulatory support are all used to treat reperfusion arrhythmias. Reperfusion injury treatment may be beneficial in this process but requires additional research. Reperfusion arrhythmias may serve as an early and distinct marker of reperfusion injury for risk stratification and the development of strategies for reducing reperfusion injury.

11. Declarations

11.1. Ethics Approval and Consent to participate
This study was approved by local Institutional Review Board, and all participants have provided written informed consent prior to involvement in the study.

11.2. Consent for publication
Not applicable.

11.3. Availability of data and materials
Data used in our study were presented in the main text.

11.4. Competing interests
Not applicable.

11.5. Funding source
Not applicable.

11.6. Authors contributions
Idea/concept: HK; Design: HK; Control/supervision: BS, SW, AR; Literature review: HK, BS, SW, AR; Writing the article: HK ; Critical review: BS, SW, AR. Reviewed and approved the final draft and are responsible for the content and similarity index of the manuscript.

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