MicroRNAs (miRNAs and miRs) are endogenous 19–22 nucleotide, small noncoding RNAs with highly conservative and tissue specific expression. They can negatively modulate target gene expressions through decreasing transcription or posttranscriptional inducing mRNA decay. Increasing evidence suggests that deregulated miRNAs play an important role in the genesis of cardiovascular diseases. Additionally, circulating miRNAs can be biomarkers for cardiovascular diseases. MiR-222 has been reported to play important roles in a variety of physiological and pathological processes in the heart. Here we reviewed the recent studies about the roles of miR-222 in cardiovascular diseases. MiR-222 may be a potential cardiovascular biomarker and a new therapeutic target in cardiovascular diseases.

2. MiR-222 Regulates Physiological Function

2.1. MiR-222 Regulates Physiological Function in Cardiomyocytes.

Physical exercise can induce cardiac growth mainly via hypertrophy and renewal of cardiomyocytes [16]. Unlike
Table 1: Summary of physiological and pathological functions of miR-222 in heart.

| Physiological function | Cardiomyocytes proliferation | Cardiac stem/progenitor cells differentiation | Ischemia reperfusion injury | Pathological function | Atherosclerosis | Tetralogy of Fallot | Ventricular septal defect | Peripheral artery disease | Artery damage |
|------------------------|-----------------------------|---------------------------------------------|----------------------------|----------------------|----------------|-------------------|--------------------------|-------------------------|-------------------------|
|                        | Neonatal rat ventricular cardiomyocytes | Mouse ESCs | miR-222 overexpression mice, cardiac ischemia reperfusion surgery | Adult mouse cardiomyocytes, MCECs, and nRCFs | Primary embryonic mouse cardiomyocytes; P19 Cell Line | — | — | — | — |
| Cardiac parameter      | Adult mouse cardiomyocytes | Human ESCs | — | — | — | — | — | — | — |
|                        | Adult mouse noncardiomyocytes | — | — | — | — | — | — | — | — |
|                        | C57BL/6J, exercise, and cardiac ischemia reperfusion surgery | — | — | — | — | — | — | — | — |
|                        | C57BL/6J, cardiac-specific | — | — | — | — | — | — | — | — |
|                        | — | — | — | — | — | — | — | — | — |
|                        | — | — | — | — | — | — | — | — | — |
|                        | — | — | — | — | — | — | — | — | — |
| In vivo                | — | — | — | — | — | — | — | — | — |
| Effects of miR-222     | Cardiomyocytes growth, proliferation, and survival in vitro † | Protecting against cardiac dysfunction after I/R | miR-222 ↓ in HF patients with left ventricular assist devices | Involved in inflammatory pathway | — | ө | ө | ө | ө |
|                        | Necessary for exercise-induced cardiac growth | Inducing heart failure | — | Cardiac viral infection ↑ IFN through miR-222 emerging efficient viral clearance | — | — | ө | ө | ө |
|                        | Sarcomere alignment and calcium handling † | Inhibiting autophagy | HIV Tat protein ↓ miR-222 | — | — | ө | ө | ө |
|                        | Resting membrane potential ↓ | — | — | — | — | ө | ө | ө | ө |
|                        | cardiomyocytes maturation markers † | — | — | — | — | ө | ө | ө | ө |
| References             | [13, 17] | [17] | [19] | [20] | [22] | [23] | [24] | [25] | [26] | [27] |
pathological hypertrophy, which is related to myocardial structural disorder and cardiac dysfunction, physiological hypertrophy is characterized by normal cardiac structure and normal or improved cardiac function [28]. MiR-222 expression levels were found to be commonly increased in two distinct models of exercise, namely, voluntary wheel running and a ramp swimming exercise model as well as the exercise rehabilitation after heart failure in human. MiR-222 was able to promote cardiomyocytes hypertrophy, proliferation, and survival through directly targeting p27, HIPK-1, HIPK-2, and HMBOX1 [17].

2.2. MiR-222 Regulates Physiological Function in Cardiac Stem Cells. Heart has limited regenerative capacity, which might be based on cardiomyocyte division and cardiac stem and progenitor cell activation [29]. Cardiac stem cells (CSCs) are self-renewing, clonogenic, and multipotent, and they can differentiate to mature cardiomyocytes and improve the function and regeneration of the cardiovascular system [30]. CSCs can be activated by physical exercise training [18]. Interestingly, it has been found that the upregulation of miR-222 induced by coculturing human embryonic stem cell-derived cardiomyocytes (m/hESC-CMs) with endothelial cells could increase and promote CSCs transformation to cardiomyocyte [18].

2.3. MiR-222 Regulates Physiological Function in Human Umbilical Vein Endothelial Cells. Human umbilical vein endothelial cells (HUVECs) have unique ability to form capillary-like structures in response to some stimuli. MiR-222 has been reported to exert angiogenesis function through modulating HUVECs angiogenic activity by targeting c-Kit [31, 32].

2.4. Sex-Specific Expression of miR-222. There are differences between men and women in cardiovascular diseases incidence, while studies show that males are more likely to suffer from heart attacks than females [33, 34]. MiR-222 are encoded on the X chromosome in mouse, rat, human and have sex-specific expression. Studies have indicated that miR-222 was specifically decreased in mature female mouse hearts as compared with male mouse hearts [31, 35].
Figure 2: Multiple pathological functions of miR-222 (miR-222 has been found to participate in multiple pathological functions in cardiovascular system. In myocardium, miR-222 could (1) promote cardiomyocyte proliferation and reduce cardiomyocyte apoptosis through P27 after ischemic injury; (2) inhibit autophagy through mTOR; (3) regulate blood vessels remodeling through c-Kit and eNOS; (4) regulate ICAM-1 and IRF-2 to inhibit inflammation. In blood vessels, miR-222 could (1) stable the plaque and suppress the inflammation and (2) inhibited the proliferation of vascular smooth muscle by targeting p27).

3. MiR-222 Regulates Pathological Function

Unraveling the role of miR-222 in regulating cardiac pathological function may foster new therapeutic targets for cardiovascular diseases (Figure 2).

3.1. MiR-222 Regulates Pathological Function in Myocardium

3.1.1. Cardiac Ischemia Reperfusion Injury. Myocardial ischemic reperfusion is a complex process involving numerous mechanisms including reactive oxygen species (ROS) overload, inflammation and calcium overload, energy metabolism dysfunction, and mitochondrial permeability transition pore (mPTP) opening [36–38]. MiR-222 has been reported to be able to protect against cardiac dysfunction after ischemic injury. MiR-222 can promote cardiomyocyte proliferation and reduce cardiomyocyte apoptosis through P27. In addition, miR-222 overexpression mice have well-preserved cardiac function and reduced cardiac fibrosis when subjected to cardiac ischemia reperfusion [17].

3.1.2. Heart Failure. Heart failure is the terminal outcome of the majority of cardiovascular diseases, and it seriously reduces the quality of life. A significant inhibition of autophagy in Tg-miR-222 mice after heart failure was observed, which was through mTOR, a negative regulator of autophagy [19]. Inhibition of autophagy induced by miR-222 may cause accumulation of protein and organelles injury, even the impairment of cardiac function. Angiogenesis has been proposed as a promising therapy for ischemia heart disease and heart failure. miR-221/222 family seemed to inhibit angiogenesis [21]. MiR-222 was significantly decreased in endothelial cells (ECs) when cultured for 24 h with HDL from chronic heart failure (CHF) patients compared to healthy control. The downregulation of miR-222 may be a compensatory mechanism of ECs to counteract cardiovascular adverse events [39].

3.1.3. Viral Myocarditis. Cardiac inflammation is an important cause of dilated cardiomyopathy and heart failure. In young healthy adults, it can cause sudden death. Viral myocarditis is one of cardiac inflammation diseases. MiR-222 has been reported to be able to orchestrate the antiviral and anti-inflammatory response through downregulation of IRF-2 [23]. Inhibition of miR-222 would increase the risk of cardiac injury. HIV-infected cardiomyopathies is another kind of inflammation diseases [22, 40]. MiR-222 can regulate cell adhesion molecules ICAM-1 translation directly or indirectly (through IFN-γ) to inhibit inflammation [22, 41].
3.1.4. Congenital Heart Disease. Tetralogy of Fallot (TOF) is one of the most common congenital heart malformations in children [42]. miR-222 was found to display a high expression level in right ventricular outflow tract (RVOT) tissues compared with controls. Cardiac myocyte proliferation and differentiation is a key event in heart development. Further functional analysis showed that overexpression of miR-222 promoted cell proliferation and regulated cell differentiation by inhibiting the expression of the cardiomycocyte marker genes during the cardiomyogenic differentiation [25]. In another congenital heart disease, ventricular septal defect, the decreased expression of miR-222 also indicated its important role in heart development [20].

3.2. MiR-222 Regulates Pathological Function in Blood Vessels

3.2.1. Atherosclerosis. During the genesis of atherosclerosis, there are various molecules and cellular components that can make atherosclerotic plaque vulnerable and even rupture [43]. Many studies show that miRNAs also participate in this process [44]. MiR-222 derived from ECs may play its protective role by blocking intraplaque neovascularization and suppressing the inflammatory activation of ECs, without enhancing the proliferation of ECs [45, 46].

3.2.2. Peripheral Arterial Disease. Smooth muscle cells (SMCs) constitute the medial layer of arteries and regulate the vascular tone via their contractile apparatus [27]. MiR-222 was reported to take part in the development of neointima and promotes neointima formation after vascular injury by enhancing the proliferation of SMCs. Furthermore, in the peripheral artery disease (PAD) caused by atherosclerosis or inflammation of the peripheral arteries, studies have showed that miR-222 also inhibited the proliferation of vascular smooth muscle cell by targeting p27 [45] to stable the plaque [24] and promoted skeletal muscle regeneration after ischemia. Besides that, under the administration of superoxide dismutase-2 (SOD-2), miR-222 plays its protective role against peripheral artery disease by regulating p57 expression [26] but not P27.

4. Conclusions

In conclusion, miR-222 controls many cardiac physiological functions and its deregulation has been implicated in many cardiovascular diseases. Targeting miR-222 might be a promising therapeutic target for cardiovascular diseases.

Competing Interests

The authors declare there is no conflict of interests.

Authors’ Contributions

Shengguang Ding, Haitao Huang, and Yiming Xu contributed equally to this work.
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