Scientific Research Publishing

Advances in Bioscience and Biotechnology, 2026, 17(11), 671-682
https://www.scirp.org/journal/abb
ISSN Online: 2156-8502
ISSN Print: 2156-8456

A New Era of Coronary Interventional Therapy: Precision Revascularization Strategies and Evidence-Based Innovations in Critical-Care Mechanical Circulatory Support

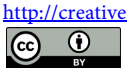
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How to cite this paper: Qin, N. and Qin, J.H. (2026) A New Era of Coronary Interventional Therapy: Precision Revascularization Strategies and Evidence-Based Innovations in Critical-Care Mechanical Circulatory Support. *Advances in Bioscience and Biotechnology*, **17**, 671-682.
https://doi.org/10.4236/abb.2026.1711039

Received: October 14, 2026
Accepted: November 8, 2026
Published: November 11, 2026

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Abstract

Over the past two decades, percutaneous coronary intervention (PCI) for coronary artery disease (CAD) has undergone a precision-oriented transformation from anatomy-guided to physiology- and intracoronary-imaging-guided practice. Iterative application of drug-eluting stents (DES) and drug-coated balloons (DCB) has substantially improved clinical outcomes. Nevertheless, cardiogenic shock complicating acute myocardial infarction (AMI) remains the most lethal complication of CAD, with persistently high mortality exceeding 40%. To date, considerable controversy persists regarding the selection of mechanical circulatory support (MCS) strategies. This narrative review summarizes advances in precision-oriented interventional strategies for CAD, covering fractional flow reserve (FFR)- and quantitative flow ratio (QFR)-guided PCI, stent optimization guided by intravascular ultrasound (IVUS) and optical coherence tomography (OCT), synergistic use of DES and DCB, and interventional breakthroughs for chronic total occlusion (CTO). On this basis, it analyzes MCS strategies for cardiogenic shock, compares clinical evidence for intra-aortic balloon pump (IABP), extracorporeal membrane oxygenation (ECMO) and microaxial flow pump, and discusses prospects for combined circulatory support regimens. This paper also reviews individualized decision-making for dual antiplatelet therapy (DAPT) duration and Chinese original evidence for periprocedural anticoagulation, aiming to provide evidence-based references for precision intervention and critical-care management of CAD.

Keywords

Coronary Artery Disease, Percutaneous Coronary Intervention, Precision

Revascularization, Cardiogenic Shock, Mechanical Circulatory Support, Fractional Flow Reserve, Microaxial Flow Pump, Drug-Eluting Stent

1. Introduction

Coronary artery disease ranks among the leading global causes of mortality and disability. Since the advent of balloon angioplasty, interventional therapy for CAD has experienced four major innovations. The first innovation was marked by widespread adoption of bare-metal stents (BMS), which markedly reduced rates of acute vessel occlusion and restenosis. The second innovation was represented by the introduction of paclitaxel- and everolimus-eluting stents, lowering target-lesion revascularization rates to below 5%. The third innovation featured the maturation of drug-coated balloons, offering a stent-sparing interventional alternative for small-vessel disease and in-stent restenosis. Currently, the fourth innovation, centered on precision medicine, is rapidly evolving. Deep integration of artificial intelligence with FFR, QFR, IVUS and OCT is reshaping decision-making workflows for PCI.

Despite substantial progress in interventional management of stable CAD, AMI-related cardiogenic shock poses a major clinical challenge. Epidemiological data indicate that cardiogenic shock occurs in 7% - 10% of AMI patients, and in-hospital mortality remains above 40% among affected individuals [1]. An analysis of the 2023 US National Inpatient Sample demonstrated that mortality for cardiogenic shock has not declined despite rising utilization of MCS devices [2]. A 2025 study using US Centers for Disease Control and Prevention databases further reported an annual percentage increase of +3.32 in cardiogenic-shock mortality between 2011 and 2021 [2]. These findings highlight an urgent unmet need for improved preventive and therapeutic strategies for cardiogenic shock.

Multiple landmark randomized controlled trials (RCTs) have recently transformed clinical practice. The DanGer Shock trial first demonstrated that microaxial-flow-pump therapy combined with standard care reduced 180-day all-cause mortality in ST-elevation myocardial infarction (STEMI) patients with cardiogenic shock, upgrading the recommendation class for microaxial pumps from IIb to IIa for this indication [3]. The ECLS-SHOCK trial revealed limitations of extracorporeal membrane oxygenation in this patient population, prompting US guideline downgrading to Class III recommendation [4]. The CULPRIT-SHOCK trial established the clinical superiority of an initial culprit-lesion-only revascularization strategy [2]. The FLAVOUR-II trial confirmed that angiography-derived FFR guidance is non-inferior to IVUS guidance for non-complex lesions [5]. The BRIGHT-4 trial generated high-quality evidence for periprocedural anticoagulation in Chinese STEMI patients undergoing primary PCI [6].

This narrative review summarizes contemporary advances in precision revascularization and critical-care management for CAD intervention, synthesizing ev-

idence for physiology-guided approaches, intracoronary-imaging guidance, novel device applications and MCS strategies, and analyzing stratified refined anti-thrombotic management, to deliver comprehensive references for clinical practice.

Review Methods

This article is a narrative review. The authors identified relevant randomized controlled trials and clinical guidelines through searches of PubMed and guideline databases, focusing on studies published through 2025 that addressed physiology-guided and imaging-guided PCI strategies, intracoronary imaging optimization, drug-eluting stents and drug-coated balloons, chronic total occlusion interventions, mechanical circulatory support strategies, and anti-thrombotic therapy. Guidelines from the ACC/AHA, ESC, and other major cardiology societies were included. Trials and guidelines discussed in this review were selected based on their relevance to the topics covered and their impact on contemporary clinical practice. Readers should note that, as a narrative review, this article does not adhere to a predefined systematic search protocol or inclusion/exclusion criteria.

2. Precision-Oriented Strategies in Coronary Interventional Therapy

2.1. Evolution of Physiology-Guided Percutaneous Coronary Intervention

Conventional PCI relies on visual angiographic assessment of coronary stenosis severity. However, coronary angiography has intrinsic limitations for evaluating the physiological significance of lesions [7]. Fractional flow reserve, the gold-standard physiological index for coronary perfusion, quantifies the functional impact of stenosis as the ratio of distal-lesion pressure to aortic pressure. The threshold value of 0.80 has been validated in large-scale RCTs as a reasonable cut-off for revascularization decision-making [7] [8]. The FAME trial by Tonino *et al.* first demonstrated that FFR-guided PCI significantly reduced major adverse cardiovascular events (MACE) compared with angiography-only guidance. In this trial enrolling 1005 multivessel-disease patients, the 1-year composite endpoint rate was 13.2% in the FFR-guided arm versus 18.3% in the angiography-guided arm [7]. The subsequent FAME-II trial by Pijls *et al.* confirmed that FFR-guided revascularization plus optimal medical therapy outperformed medical therapy alone in patients with mild-to-moderate symptoms. Among 888 enrolled patients, the composite primary endpoint (death from any cause, nonfatal myocardial infarction, or urgent target-vessel revascularization) occurred in 12.2% of the FFR-guided group versus 28.3% of the medically-managed group [8].

Quantitative flow ratio is a pressure-wire-free assessment method derived from invasive coronary angiography using computational fluid dynamics to compute FFR-equivalent values, and has accumulated increasing supportive evidence. However, the FAVOR III Europe trial demonstrated that a QFR-based strategy did not meet non-inferiority compared with an FFR-based strategy (12-month primary

endpoint: 6.7% vs 4.2%; HR 1.63, 95% CI 1.11 - 2.41; the upper limit of the 90% CI exceeded the prespecified non-inferiority margin of 3.4%), indicating that while QFR offers a practical advantage by eliminating the need for pressure wires, its clinical equivalence to wire-based FFR remains unestablished. Prespecified subgroup analyses of the FAVOR-III China trial reported hazard ratios (HR) of 0.69 (95% CI 0.51 - 0.92) for 3-year vessel-oriented composite cardiovascular events in left-main or left-anterior-descending-artery lesions, and HR 0.54 (95% CI 0.36 - 0.81) for right-coronary-artery lesions under QFR-guided PCI, indicating consistent clinical benefit across different coronary territories. FLAVOUR-II, a multicenter randomized non-inferiority trial recruiting 1872 patients with ≥50% coronary stenosis, compared angiography-derived FFR guidance against IVUS guidance [5]. Twelve-month MACE rates were comparable (6.3% vs. 6.0%; difference 0.3%, 95% CI −3.2 to 3.8; P for non-inferiority < 0.001, with a prespecified non-inferiority margin of 4.5%), while angiography-derived FFR guidance reduced stent implantation rates by approximately 10%, offering a simpler decision-making tool for interventional cardiologists [5].

2.2. Precision Intervention Guided by Intracoronary Imaging

Intravascular ultrasound and optical coherence tomography represent two mainstream intracoronary-imaging modalities, revealing microstructural features of coronary lesions from distinct dimensions. IVUS employs ultrasound transducers to acquire two-dimensional cross-sectional vessel images with penetration depth of several millimeters, enabling clear visualization of external elastic membrane boundaries, plaque burden and stent apposition. OCT applies near-infrared light interferometry, achieving resolution up to 10 μm, and demonstrates unique advantages in assessing stent apposition, edge dissection, tissue prolapse and in-stent neoatherosclerosis.

A network meta-analysis incorporating 40 RCTs (38,107 patients) compared clinical outcomes across eight PCI guidance modalities. IVUS-guided, OCT-guided and QFR-guided PCI were all associated with significantly lower MACE risk than angiography-only guidance [9]. One-year MACE hazard ratios were 0.66 for IVUS guidance and 0.59 for OCT guidance [9]. These data support improved long-term prognosis with intracoronary-imaging-guided PCI, which should be routinely considered for anatomically complex lesions including left-main disease, true bifurcation lesions and long lesions [9].

2.3. Synergistic Application of Drug-Eluting Stents and Drug-Coated Balloons

By releasing anti-proliferative agents to suppress smooth-muscle-cell proliferation, DES reduced restenosis rates from over 30% in the BMS era to below 5% [10]. Nonetheless, concerns remain regarding delayed endothelial healing and late-stent-thrombosis risk related to permanent polymer matrices. Bioresorbable scaffolds (BRS) were once regarded as a promising solution, designed to degrade

completely after vascular repair and restore native vasomotor function. The ABSORB-IV multicenter RCT compared 5-year outcomes between bioresorbable scaffolds and cobalt-chromium everolimus-eluting stents among 2604 patients with stable coronary artery disease or acute coronary syndrome [11]. Five-year target-lesion failure occurred in 17.5% of the BRS arm versus 14.5% of the metallic-DES arm, driven by increased target-vessel myocardial infarction and ischemia-driven target-lesion revascularization [11]. Notably, excess risks of target-lesion failure and device thrombosis for BRS were concentrated within the first three years (approximate time-point for complete bioresorption); after three-year follow-up, prognosis became comparable between groups [11].

As a representative stent-sparing device, drug-coated balloons deliver anti-proliferative drugs (paclitaxel or sirolimus) directly to the vessel wall upon balloon dilation, avoiding permanent metallic-implant placement [12]. The REC-CAGE-FREE-I trial, however, demonstrated that DCB with rescue stenting failed to demonstrate non-inferiority to intended DES implantation at 2-year follow-up for de-novo coronary lesions, indicating that this trial does not support unrestricted substitution of DCB for DES in de-novo lesions [12]. The updated ACC/AHA guideline recommends DCB for small-vessel lesions, bifurcation lesions, or high-bleeding-risk patients unable to tolerate prolonged DAPT [13].

2.4. Interventional Breakthroughs for Chronic Total Occlusion

Chronic total occlusions account for approximately 30% of all PCI procedures. For decades, CTO intervention was considered a prohibitive frontier due to difficulties advancing guidewires across occluded segments [14]. Retrograde guidewire techniques utilizing collateral circulation to reach the distal occluded segment have substantially improved procedural success rates [14]. Current guidelines recommend retrograde wiring as a preferred strategy for CTO PCI; however, the specific recommendation for an operator volume of no fewer than 20 annual CTO cases should be verified against the relevant society guideline (e.g., SCAI or ACC/AHA PCI guideline) rather than the ACC/AHA ACS guideline [13]. Operators should consult the most recent CTO-specific guidelines for precise recommendations. Intracoronary imaging is gaining increasing importance in CTO intervention; IVUS assists operators in identifying occlusive segment boundaries, lesion length and calcification distribution, optimizing guidewire strategies and stent-selection decisions [14].

3. Mechanical Circulatory Support for Critical Coronary Disease

3.1. Epidemiology and Therapeutic Challenges of Cardiogenic Shock

Cardiogenic shock represents the most severe complication of acute myocardial infarction, pathophysiologically characterized by abrupt pump-function failure leading to end-organ hypoperfusion [1]. Despite broader adoption of reperfusion

therapy lowering overall AMI incidence, cardiogenic-shock prevalence remains 7% - 10% [2]. The EPICOR-Asia registry enrolling 12,922 acute-coronary-syndrome patients across 219 centers in eight Asian countries reported higher cardiogenic-shock incidence in STEMI patients versus non-ST-elevation acute coronary syndrome (NSTE-ACS) patients (12.2% vs. 4.3%). Paradoxically, mortality was higher among NSTE-ACS patients with cardiogenic shock (40.8% vs. 33.1%) [2]. A 2023 American College of Cardiology expert consensus defines cardiogenic shock as a heterogeneous multifactorial syndrome caused by cardiac-driven low cardiac output resulting in persistent clinical and biochemical markers of tissue hypoperfusion [2].

3.2. Evolving Role of Intra-Aortic Balloon Pump

The intra-aortic balloon pump is inserted via the femoral artery; it inflates during diastole to raise coronary perfusion pressure and deflates during systole to reduce left-ventricular afterload, improving myocardial oxygen supply-demand balance [15]. However, the IABP-SHOCK-II RCT enrolling 600 AMI-cardiogenic-shock patients demonstrated that IABP plus early revascularization conferred no reduction in 30-day all-cause mortality compared with early revascularization alone [15]. Consequently, routine IABP use for AMI-related cardiogenic shock has been downgraded to Class III (not recommended) across major guidelines. IABP is currently reserved only for preoperative bridging in patients with mechanical complications such as ventricular septal rupture or papillary-muscle rupture [15].

3.3. Re-Evaluation of Extracorporeal Membrane Oxygenation for Cardiogenic Shock

Venous-arterial extracorporeal membrane oxygenation provides full cardiopulmonary support and was once regarded as an ultimate salvage modality for cardiogenic shock [4]. Nevertheless, the ECLS-SHOCK multicenter RCT across 44 German and Slovenian centers randomized 420 AMI-cardiogenic-shock patients scheduled for early revascularization to receive extracorporeal life support plus conventional medical therapy versus conventional medical therapy alone [4]. Thirty-day all-cause mortality was 47.8% in the ECLS arm versus 49.0% in controls, showing no statistical difference [4]. Importantly, moderate-to-severe bleeding (23.4% vs. 9.6%) and peripheral vascular complications (11% vs. 3.8%) were significantly increased with ECLS [4]. A concurrent individual-patient-data meta-analysis of four RCTs published in The Lancet yielded consistent findings: VA-ECMO failed to reduce 30-day mortality in infarction-related cardiogenic shock and increased major bleeding and vascular-complication risks [4]. This evidence prompted US guidelines to downgrade VA-ECMO from Class IIa (2013) to Class III (not recommended) for routine early deployment in AMI-related cardiogenic shock in 2025 [4]. However, individualized rescue use of VA-ECMO may still be considered in selected patients who remain hemodynamically unstable despite conventional therapy and MCS.

3.4. Paradigm Shift for Microaxial Flow Pumps

Percutaneously deployed microaxial flow pumps deliver active hemodynamic support directly to the left ventricle, unloading left-ventricular workload and augmenting cardiac output via mechanisms fundamentally distinct from ECMO [3]. The international multicenter open-label DanGer Shock trial randomized 360 STEMI-cardiogenic-shock patients to microaxial-pump plus standard-care versus standard-care alone [3]. The 180-day all-cause mortality was 45.8% in the microaxial-pump arm versus 58.5% in the control arm (HR 0.74, 95% CI 0.55 - 0.99, P = 0.04), demonstrating significant mortality reduction with microaxial-pump therapy [3]. However, composite safety-endpoint events were markedly higher in the microaxial-pump group (24.0% vs. 6.2%), and renal-replacement-therapy requirements increased (41.9% vs. 26.7%) [3]. Based on these results, the 2025 US acute-coronary-syndrome guideline upgraded microaxial-pump recommendation for STEMI-related cardiogenic shock from IIb to IIa (reasonable), while emphasizing rigorous patient selection and active complication management [13]. It should be noted that the DanGer Shock trial enrolled a specifically selected STEMI-related cardiogenic shock population, and these findings should not be extrapolated to other shock phenotypes.

3.5. Exploration of Combined Circulatory-Support Strategies

Single MCS devices may be insufficient to sustain tissue perfusion in critically-ill patients, stimulating interest in combination-support regimens; however, reference [3] reports the DanGer Shock trial comparing microaxial pump versus standard care rather than combined-support strategies, and appropriate references for combined-support evidence should be cited. Network meta-analyses of ECMO plus IABP have suggested mortality-reduction benefits for cardiogenic-shock patients, plausibly mediated by IABP-mediated attenuation of left-ventricular afterload induced by retrograde ECMO flow; however, reference [3] reports the DanGer Shock trial (a single-arm comparison of microaxial pump vs standard care) rather than combined-support meta-analyses, and appropriate meta-analytic references should be cited here. Meta-analyses of the ECPELLA strategy (ECMO plus microaxial pump) have also reported reduced all-cause mortality, albeit with elevated hemolysis risk; however, reference [3] reports the DanGer Shock trial rather than ECPELLA meta-analyses, and appropriate references should be cited. The CERAMICS multicenter single-arm registry enrolled 124 cardiogenic-shock patients in centers with on-site MCS escalation capacity [2]. Despite extremely high baseline illness severity (approximately 40% with prior cardiac arrest, 89% STEMI), standardized shock-protocol management including early microaxial-pump implantation, urgent PCI and hemodynamic monitoring yielded a 71% discharge-to-home survival rate; survival reached 71% for SCAI class C/D shock and 60% for the highest-risk SCAI class E shock [2]. These data, derived from an observational single-arm registry and thus subject to limitations inherent to non-randomized designs—including potential selection bias, unmeasured confounding, and

lack of a control group—should be interpreted as descriptive rather than definitive. The CERAMICS registry outcomes suggest that structured cardiogenic-shock care systems may improve patient outcomes, but these findings require confirmation in randomized controlled trials [2].

3.6. Comparison of Major Mechanical Circulatory-Support Strategies

Table 1 summarizes key clinical-trial evidence for three principal MCS modalities for AMI-related cardiogenic shock.

Table 1. Key clinical-trial comparisons of mechanical circulatory-support strategies for acute-myocardial-infarction-related cardiogenic shock.

Trial Name	Device/Strategy	Enrolled Patients	Primary Endpoint	Main Results	Guideline Recommendation Change
IABP-SHOCK II	Intra-aortic balloon pump	600	30-day all-cause mortality	No clinical benefit	Class III (not recommended)
ECLS-SHOCK	Extracorporeal membrane oxygenation	420	30-day all-cause mortality	No survival benefit; increased bleeding complications	Class III (not recommended)
DanGer Shock	Microaxial flow pump (Impella CP)	360	180-day all-cause mortality	Reduced mortality (HR 0.74)	Upgraded to Class IIa

4. Refined Stratified Management of Anti-Thrombotic Therapy

4.1. Individualized Decision-Making for Dual Antiplatelet Therapy Duration

Dual antiplatelet therapy constitutes the cornerstone of post-PCI management to prevent stent thrombosis and cardiovascular events [16]. DAPT duration must balance ischemic-event prevention against bleeding risk [17]. The ULTIMATE-DAPT multicenter, double-blind, placebo-controlled RCT compared ticagrelor monotherapy versus continued DAPT following PCI in patients with acute coronary syndromes who remained event-free during the initial month after PCI [16]. Ticagrelor-monotherapy was non-inferior to standard DAPT among this selected population of ACS patients who remained event-free during the initial month after PCI, while significantly lowering major-bleeding rates [16]. The OPT-BIRISK study further proposed clopidogrel monotherapy for patients with concurrent high-ischemic and high-bleeding risk ("dual-high-risk"), demonstrating favorable profiles for both bleeding and ischemic endpoints [13].

The 2025 ACC/AHA guideline proposes differentiated DAPT strategies stratified by ischemic and bleeding risk [13]. For patients with acute coronary syndromes undergoing PCI, a default DAPT duration of 12 months is recommended following DES implantation, with duration shortened to 1 - 3 months in high-bleeding-risk patients followed by P2Y12 inhibitor monotherapy, as supported by relevant trial evidence [16]. For chronic coronary syndrome patients after DES

implantation, the guideline-supported default DAPT duration is 6 months in the absence of high bleeding risk, with extension to 12 months for high-ischemic-risk patients or shortening to 3 months for high-bleeding-risk patients [13]. After DCB implantation, DAPT for six months is suggested; after bioresorbable-scaffold implantation, 12-month DAPT is recommended—these specific durations should be cited to the exact guideline recommendation section or the relevant trial evidence rather than attributed solely to [13]. DAPT duration may be shortened to one month for patients experiencing bleeding events after stenting [13]. Among patients completing 12-month uneventful DAPT, switching to clopidogrel monotherapy yielded lower endpoint-event rates than aspirin monotherapy, providing evidence for long-term antiplatelet management [13].

4.2. Chinese Evidence Base for Periprocedural Anticoagulation

Periprocedural anticoagulation guarantees procedural safety for PCI [6]. Unfractionated heparin has long served as the default periprocedural anticoagulant, yet it carries risks of heparin resistance and heparin-induced thrombocytopenia in subsets of patients [6]. The BRIGHT-4 investigator-initiated multicenter open-label RCT randomized 6016 STEMI patients undergoing primary PCI within 48 h of symptom-onset to receive bivalirudin single bolus plus post-procedural high-dose extended infusion versus unfractionated-heparin monotherapy [6]. The composite primary endpoint (all-cause death or BARC 3 - 5 major bleeding) at 30 days occurred in 3.06% of the bivalirudin arm versus 4.39% of the heparin arm (HR 0.69). Both all-cause mortality (2.96% vs. 3.92%; HR 0.75, 95% CI 0.57 - 0.99; P = 0.042) and BARC 3 - 5 bleeding (0.17% vs. 0.80%; hr 0.21, 95% CI 0.08 - 0.54; P = 0.0014) were significantly reduced [6]. Notably, definite stent-thrombosis rates were also lower with bivalirudin (0.37% vs. 1.10%), contradicting conventional perceptions that bivalirudin increases stent-thrombosis risk [6]. This high-quality indigenous evidence for periprocedural anticoagulation in Chinese STEMI patients has been incorporated into the 2025 ACC/AHA acute-coronary-syndrome guideline [13].

4.3. Anti-Thrombotic Optimization in Special Populations

Elderly patients, individuals with chronic kidney disease, and patients with concomitant atrial fibrillation represent highly challenging subgroups for anti-thrombotic therapy [13]. The 2025 ACC/AHA guideline recommends simplified interventional strategies for elderly patients, targeting ≤ 2 treated lesions and cumulative stent length ≤ 30 mm, with dose-adjusted antiplatelet regimens [13]. For CAD patients with atrial fibrillation and CHA_2DS_2-VASc ≥ 2 plus HAS-BLED ≤ 2, a brief period of triple antithrombotic therapy (oral anticoagulation plus aspirin and a P2Y12 inhibitor) may be considered, followed by dual therapy with oral anticoagulation plus a P2Y12 inhibitor, with duration tailored to individual bleeding and ischemic risks [13]. DAPT alone does not provide adequate stroke prevention in atrial fibrillation and should not replace oral anticoagulation in patients who meet criteria for anticoagulation—this recommendation should be cited to

the specific AF guideline (e.g., ESC AF guideline or ACC/AHA/HRS AF guideline) rather than the ACS guideline [13]. Anti-thrombotic regimens for these special populations require multidisciplinary collaboration and individualized balancing of ischemic and bleeding risks [13].

5. Conclusions and Outlook

Coronary interventional therapy is undergoing a pivotal transition from anatomy-driven to precision-oriented practice. Integration of physiology-guided assessment, intracoronary imaging and artificial-intelligence-assisted decision-making is shifting PCI away from "one-size-fits-all" approaches toward individualized precision care [5] [7] [8] [11]. Flexible treatment options are enabled by synergistic deployment of DES and DCB tailored to distinct lesion anatomies [11] [12]. Maturation of CTO interventional techniques expands the scope of revascularizable lesions [14].

In critical-care settings, the therapeutic landscape for cardiogenic shock is undergoing profound change. Routine IABP application has been guideline-downgraded [15], ECMO indications have become highly restricted [4], and microaxial pumps have acquired new therapeutic standing supported by positive findings from the DanGer Shock trial [3]. Combined circulatory-support modalities and standardized shock-management pathways offer new hope for the most severely-ill patients [2]. Major advances have been achieved in stratified refined anti-thrombotic therapy balancing ischemic and bleeding risk; multiple original Chinese investigator-led trials are reshaping international guideline recommendations [6] [13].

Several challenges remain for contemporary research. The evidence base for interventional strategies in cardiogenic shock is limited by heterogeneous shock populations with varying aetiologies and severities, restricted trial eligibility criteria that may not reflect real-world clinical practice, and limited randomized evidence specifically addressing combined circulatory support strategies. Head-to-head comparative studies are needed to clarify relative performance of different MCS devices across specific patient subgroups. Translational research bridging basic discoveries to clinical implementation remains insufficient. Future research directions may include: constructing multi-omics- and artificial-intelligence-driven individualized ischemic-bleeding-risk prediction models; developing tissue-specific drug-delivery systems to reduce systemic anti-thrombotic adverse events; exploring mechanisms and clinical value of novel antiplatelet and anticoagulant agents; and evaluating cost-effectiveness of standardized cardiogenic-shock emergency systems. With deeper penetration of precision-medicine principles and continuous innovation in devices and pharmacology, coronary interventional therapy will likely deliver improved survival and quality-of-life benefits for greater numbers of patients.

Author Contributions

Nan Qin conceived and designed the review, performed literature retrieval, screened

clinical trials and guidelines, drafted the main manuscript, and completed revision of critical-care mechanical circulatory-support sections.

Jianhong Qin participated in literature sorting, summarized evidence for precision revascularization and antithrombotic therapy, revised the full-text manuscript, checked tables and reference formatting, and approved the final submitted version of the article.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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