Evolution of Invasive Therapies in Acute Myocardial Infarction: A Descriptive Review

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Abstract: Acute myocardial infarction (AMI) is a major cardiovascular emergency in which rapid restoration of coronary blood flow is essential to minimize myocardial damage and improve patient outcomes. The management of AMI has undergone substantial evolution, progressing from conventional surgical revascularization to less invasive percutaneous coronary interventions (PCI). Coronary artery bypass grafting (CABG), although an established and effective revascularization procedure, involves open-chest surgery and is associated with greater procedural invasiveness, longer recovery, and increased perioperative burden compared with contemporary catheter-based interventions. The introduction of balloon angioplasty represented an important advancement by allowing coronary revascularization without open surgery; however, balloon angioplasty alone was limited by complications such as elastic recoil, vessel dissection, and restenosis, which reduced its long-term effectiveness. The development of intracoronary stents subsequently transformed PCI by providing mechanical support to the treated vessel, reducing acute vessel closure and improving procedural success and long-term vessel patency. In the contemporary management of AMI, particularly ST-segment elevation myocardial infarction (STEMI), primary PCI with stent implantation is widely preferred when it can be performed promptly by an experienced team. Its minimally invasive nature, high procedural success, and ability to rapidly restore coronary perfusion have established stenting as a major advancement in invasive AMI treatment. This descriptive review traces the evolution from CABG and balloon angioplasty to modern stent-based PCI and discusses the clinical advantages, limitations, and continuing developments in invasive revascularization strategies for AMI.

Keywords: *Acute Myocardial Infarction, Coronary Artery Bypass Grafting, Balloon Angioplasty, Percutaneous Coronary Intervention, Coronary Stent, Primary PCI, Revascularization.*

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I. INTRODUCTION

Acute myocardial infarction (AMI) is a life-threatening cardiovascular condition that occurs when the blood supply to a portion of the heart muscle is suddenly reduced or interrupted, resulting in myocardial injury and necrosis. Rapid restoration of coronary blood flow is therefore a fundamental objective in AMI management. Over the past several decades, invasive treatment strategies have undergone substantial development, changing the approach to coronary revascularization.

Coronary artery bypass grafting (CABG) was historically an important method for restoring blood flow in patients with significant coronary artery disease. Although CABG remains clinically valuable in selected patients, its surgical nature makes it more invasive and generally involves longer recovery compared with catheter-based procedures. The introduction of percutaneous transluminal coronary angioplasty (PTCA), commonly known as balloon angioplasty, provided a less invasive alternative by mechanically widening narrowed coronary arteries. However, balloon angioplasty alone was associated with limitations, including vessel recoil, dissection, abrupt closure, and restenosis.

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The subsequent development of coronary stents represented a major advancement in percutaneous coronary intervention (PCI). Stents provide structural support to the treated artery and have improved procedural outcomes compared with balloon angioplasty alone. Consequently, primary PCI with contemporary stent technology has become a central strategy for restoring coronary perfusion in eligible patients with acute myocardial infarction.

Myocardial infarction (MI), commonly known as a heart attack, occurs when blood flow to part of the heart muscle is severely reduced or blocked, causing damage to the cardiac tissue. The common symptoms include chest pain or pressure, discomfort that may spread to the arm, shoulder, back, neck, or jaw, shortness of breath, sweating, nausea, dizziness, weakness, and unusual fatigue. The severity and combination of symptoms may vary among patients, and some individuals may experience mild or atypical symptoms. Treatment of MI focuses primarily on restoring coronary blood flow as rapidly as possible and preventing further cardiac injury. Initial management involves clinical assessment, electrocardiography, and cardiac biomarkers such as troponin, followed by appropriate medications including antiplatelet agents, anticoagulants, statins, and other drugs according to the patient's condition. For eligible patients with acute coronary occlusion, particularly STEMI, primary percutaneous coronary intervention (PCI) is an important reperfusion strategy. During PCI, a catheter is guided into the affected coronary artery and balloon angioplasty may be performed, followed commonly by stent placement to maintain vessel patency. Fibrinolytic therapy may be considered when timely PCI is unavailable and the patient meets appropriate criteria. Coronary artery bypass grafting (CABG) may be required in selected cases with complex or extensive coronary artery disease. Long-term management includes cardiac rehabilitation, appropriate medication, regular physical activity, healthy dietary practices, and management of cardiovascular risk factors.

- *Symptoms and General Treatment of Myocardial Infarction*

Myocardial infarction (MI), commonly known as a heart attack, occurs when blood flow to part of the heart muscle is severely reduced or blocked, causing damage to the cardiac tissue. The common symptoms include chest pain or pressure, discomfort that may spread to the arm, shoulder, back, neck, or jaw, shortness of breath, sweating, nausea, dizziness, weakness, and unusual fatigue. The severity and combination of symptoms may vary among patients, and some individuals may experience mild or atypical symptoms. Treatment of MI focuses primarily on restoring coronary blood flow as rapidly as possible and preventing further cardiac injury. Initial management involves clinical assessment, electrocardiography, and cardiac biomarkers such as troponin, followed by appropriate medications including antiplatelet agents, anticoagulants, statins, and other drugs according to the patient's condition. For eligible patients with acute coronary occlusion, particularly STEMI, primary percutaneous coronary intervention (PCI) is an important reperfusion strategy. During PCI, a catheter is guided into the affected coronary artery and balloon angioplasty may be performed, followed commonly by stent placement to maintain vessel patency. Fibrinolytic therapy may be considered when timely PCI is unavailable and the patient meets appropriate criteria. Coronary artery bypass grafting (CABG) may be required in selected cases with complex or extensive coronary artery disease. Long-term management includes cardiac rehabilitation, appropriate medication, regular physical activity, healthy dietary practices, and management of cardiovascular risk factors.

II. REVIEW OF LITERATURE

The management of acute myocardial infarction (AMI) has undergone a major transformation since the 1970s, progressing from surgical revascularization toward increasingly less invasive catheter-based interventions. During the early 1970s, coronary artery bypass grafting (CABG) was an established method for treating severe coronary artery disease. CABG provided an effective means of bypassing obstructed coronary vessels; however, it required major surgery and was associated with greater procedural trauma and prolonged recovery compared with later percutaneous techniques. The development of catheter-based revascularization subsequently changed the treatment landscape.

A major breakthrough occurred in 1977 when Andreas Grüntzig performed the first successful percutaneous transluminal coronary angioplasty (PTCA). Balloon angioplasty allowed coronary stenoses to be mechanically widened without open-chest surgery, representing an important step toward minimally invasive coronary intervention. However, balloon angioplasty alone had important limitations, including elastic recoil, vessel dissection, abrupt vessel closure, and restenosis. Historical evidence indicates that restenosis and early vessel thrombosis substantially limited the durability of balloon-only treatment.

The introduction of coronary stents during the 1980s addressed several of these limitations by providing a scaffold that helped maintain vessel patency after balloon dilation. Early stents, particularly bare-metal stents (BMS), improved procedural stability and reduced some complications associated with balloon angioplasty alone. Clinical studies subsequently demonstrated advantages of stent implantation over balloon angioplasty in selected coronary lesions.

During the late 1990s and early 2000s, drug-eluting stents (DES) represented another important advancement. By releasing antiproliferative drugs at the treated site, DES were developed to reduce neointimal growth and restenosis compared with bare-metal devices. Improvements in stent design, drug delivery, polymers, and implantation techniques subsequently led to newer-generation DES with improved safety and effectiveness.

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By the 2010s and 2020s, PCI had evolved beyond simple balloon dilation and stent deployment. Contemporary treatment incorporates radial arterial access, improved stent platforms, intravascular imaging, physiological assessment, and optimized antiplatelet therapy. The 2025 ACC/AHA/ACEP/NAEMSP/SCAI guideline recommends radial access for ACS patients undergoing PCI and recommends intravascular imaging for complex lesions. It also emphasizes that the choice between CABG and multivessel PCI should depend on coronary anatomy and patient-specific factors.

Thus, the evolution from CABG to balloon angioplasty and subsequently to modern stent-based PCI reflects a progressive movement toward less invasive, more effective, and technologically sophisticated revascularization. By 2026, stent-based PCI remains a central component of invasive AMI management, while CABG continues to have an important role in appropriately selected patients.

III. METHODOLOGY

Secondary data refers to information that has already been **collected, recorded, and published by other researchers, organizations, or institutions** for a purpose other than the current study.

Table 1 Estimated number of CABG, Balloon-only Angioplasty and Stent Procedures — Chennai, 2015–2025

Year	Bypass Surgery (CABG)	Balloon-only Angioplasty	Stent Procedures
2015	5,200	2,100	31,000
2016	5,000	1,900	34,000
2017	4,800	1,700	37,000
2018	4,600	1,500	40,000
2019	4,400	1,300	43,000
2020	3,200	900	30,000
2021	3,600	1,000	34,000
2022	3,900	1,100	38,000
2023	4,100	1,150	42,000
2024	4,300	1,200	46,000
2025	4,500	1,250	49,000

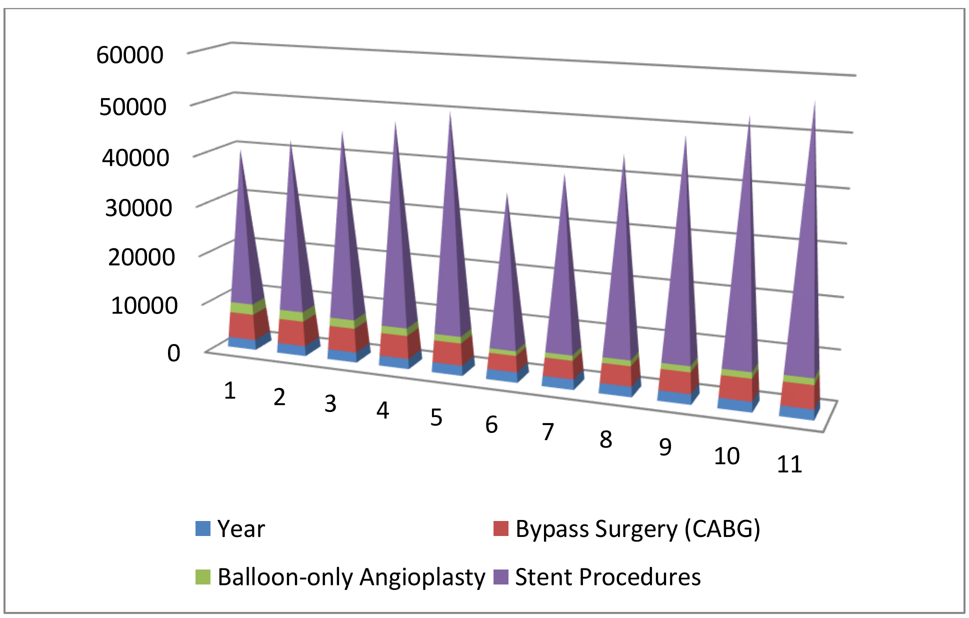

Fig.1. Estimated number of CABG, Balloon-only Angioplasty and Stent Procedures — Chennai, 2015–2025

- *Estimated Procedural Trend in Chennai*

An estimated comparison of invasive coronary revascularization procedures in Chennai from 2015 to 2025 demonstrates a gradual shift from surgical bypass procedures and balloon-only angioplasty toward stent-based percutaneous coronary intervention. The estimated number of CABG procedures decreased from approximately 5,200 in 2015 to 4,500 in 2025, whereas balloon-only angioplasty declined from approximately 2,100 to 1,250 procedures during the same period. In contrast, stent-based procedures increased from an estimated 31,000 in 2015 to approximately 49,000 in 2025. A temporary decline in all three procedures was estimated for

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2020, corresponding to the disruption of healthcare services during the COVID-19 pandemic. The observed pattern suggests increasing adoption of minimally invasive PCI and stent implantation in comparison with conventional surgical revascularization and balloon-only angioplasty. However, these Chennai figures are estimated values prepared from available secondary information and should not be interpreted as official hospital or government registry counts. Further research using hospital-level records or a centralized Chennai cardiovascular registry would be required to establish exact annual procedure numbers.

Although stent-based PCI offers a minimally invasive method of coronary revascularization, CABG remains necessary for selected patients with complex coronary artery disease. CABG may be preferred in patients with significant left main disease, extensive multivessel coronary disease, complex or diffuse lesions, and certain patients with diabetes or impaired ventricular function. In some cases, the coronary anatomy may not be suitable for successful or durable stent implantation. CABG may also be considered when PCI is unsuccessful or cannot provide adequate revascularization. Therefore, the choice between PCI and CABG should be individualized according to coronary anatomy, disease complexity, clinical status, comorbidities, and expected long-term outcomes rather than based solely on the invasiveness of the procedure.

Table 2 Condition ECG Demands for ByPass surgery

ECG/clinical Finding	What it May Indicate	When CABG May be Considered
STEMI with persistent ST elevation	Acute coronary artery occlusion	If PCI cannot restore blood flow or PCI is unsuccessful
STEMI with ongoing ischemia despite PCI	Persistent coronary obstruction	Emergency/urgent CABG may be considered
ST depression/T-wave changes with NSTEMI	Myocardial ischemia	CABG may be required if angiography shows severe multivessel or left-main disease
Diffuse ST depression + ST elevation in aVR	May suggest extensive ischemia, sometimes involving left-main/proximal LAD or multivessel disease	Requires urgent evaluation; CABG may be preferred depending on angiography
Extensive ischemic ECG changes + reduced LV function	Significant myocardial ischemia	CABG may be considered when severe coronary disease is confirmed

➢ *Evolution of Coronary Stents: 1970–1990*

The development of coronary stents between the 1970s and 1990 marked an important transition in the treatment of coronary artery disease. In the **1970s**, balloon angioplasty was introduced as a less invasive alternative to surgical coronary revascularization. Andreas Grüntzig performed the first successful percutaneous transluminal coronary angioplasty (PTCA) in **1977**, but balloon angioplasty had important limitations, including elastic recoil, arterial dissection, abrupt vessel closure, and restenosis.

During the **1980s**, researchers began developing intracoronary devices that could provide structural support to the artery after balloon dilation. A major milestone occurred in **1986**, when the first human coronary stent implantation was performed by **Ulrich Sigwart and colleagues**. The stent was designed to maintain the expanded diameter of the coronary artery and prevent acute vessel closure.

In **1987**, Sigwart and colleagues published their landmark report describing the use of intravascular stents to prevent coronary occlusion and restenosis following angioplasty. This work demonstrated the potential of stents to overcome some of the major limitations of balloon-only angioplasty.

By **1990**, coronary stenting was still an emerging technology rather than the routine treatment it would later become. Early stents were associated with complications such as **stent thrombosis**, and patients generally required intensive antithrombotic treatment. Nevertheless, the early clinical experience established the foundation for the rapid development of **bare-metal stents in the 1990s**, followed later by drug-eluting stents.

➢ *Coronary Stents: 1990 to Present (2026)*

From the **1990s to the present**, coronary stent technology has undergone major improvements, transforming percutaneous coronary intervention (PCI) into one of the principal methods of coronary revascularization. In the early 1990s, **bare-metal stents (BMS)** became increasingly used because they provided mechanical support to the coronary artery and reduced the risk of acute vessel closure compared with balloon angioplasty alone. A landmark randomized trial published in **1994** demonstrated that coronary stenting improved angiographic and clinical outcomes compared with balloon angioplasty in selected patients.

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During the **late 1990s and early 2000s**, the major limitation of BMS—**in-stent restenosis**—led to the development of **drug-eluting stents (DES)**. The first-generation DES released antiproliferative drugs such as **sirolimus and paclitaxel**, reducing excessive tissue growth within the stented artery. The landmark **RAVEL trial**, published in 2002, demonstrated a substantial reduction in restenosis with sirolimus-eluting stents compared with bare-metal stents.

During the **2000s and 2010s**, newer-generation DES were developed with improved polymers, thinner stent struts, better flexibility, and more effective drug-delivery systems. These advances reduced restenosis and improved the safety profile of coronary stenting. Contemporary DES have therefore largely replaced BMS in routine PCI.

From the **2010s to 2026**, coronary intervention has increasingly incorporated **intravascular imaging**, including intravascular ultrasound (IVUS) and optical coherence tomography (OCT), to improve lesion assessment and optimize stent placement. Radial-artery access has also become increasingly preferred because it can reduce access-site complications and improve patient comfort. Modern PCI therefore combines improved stent technology with imaging, physiological assessment, optimized implantation techniques, and appropriate antiplatelet therapy.

By **2026**, coronary stenting has evolved from early metallic scaffolds into sophisticated drug-eluting platforms designed to provide effective vessel support while minimizing restenosis and thrombosis. Nevertheless, PCI is not appropriate for every patient; CABG continues to be preferred in selected patients with complex coronary anatomy or extensive multivessel disease**.**

- *Future of Stent*

Smart stents that can monitor blood flow or detect blockages. Stent with improved biodegradable material safely disappear after healing.

3D printed, patient specific stents for better fit.

Stents with advanced coating that further reduce blood clots and infections.

IV. DATA ANALYSIS AND DISCUSSION

- *Reasons for the Increasing Use of Coronary Stents*

The increasing use of coronary stents over recent decades can be attributed to advances in percutaneous coronary intervention (PCI), improvements in stent technology, and the growing preference for less invasive methods of coronary revascularization. Compared with coronary artery bypass grafting (CABG), PCI is performed through catheter-based access and generally involves less surgical trauma and a shorter recovery period, making it an attractive option for appropriately selected patients. The limitations of balloon angioplasty, particularly acute vessel closure, elastic recoil, and restenosis, encouraged the development and widespread adoption of coronary stents. Stents provide mechanical support to the coronary artery after balloon expansion and help maintain vessel patency. The introduction of drug-eluting stents further reduced restenosis by releasing antiproliferative medication at the treated site. Improvements in newer-generation drug-eluting stents, delivery systems, implantation techniques, and antiplatelet therapy have contributed to better clinical outcomes and increased confidence in PCI. In addition, the availability of primary PCI for acute myocardial infarction has increased the use of stent-based revascularization because rapid restoration of coronary blood flow can limit myocardial damage and improve outcomes in eligible patients. Increasing cardiovascular disease burden and improved access to catheterization laboratories have also contributed to the growing number of patients receiving PCI. Thus, the rise in stent use reflects both technological progress and the increasing availability of minimally invasive coronary revascularization.

- *Disadvantages of Coronary Bypass Surgery and Balloon Angioplasty*

Coronary artery bypass grafting (CABG) is an established revascularization procedure, but its major limitation is its invasive surgical nature. The procedure generally requires surgical access to the chest and, in many cases, the use of cardiopulmonary bypass. Consequently, patients may experience greater perioperative trauma, postoperative pain, longer hospitalization, and a longer recovery period compared with catheter-based interventions. CABG is also associated with potential complications such as bleeding, wound infection, stroke, atrial fibrillation, kidney injury, and other perioperative complications. Furthermore, grafts may develop disease or become narrowed over time, meaning that long-term graft patency is not guaranteed. Despite these limitations, CABG remains an important treatment option for patients with complex coronary artery disease and should not be considered obsolete.

Balloon angioplasty, or percutaneous transluminal coronary angioplasty (PTCA), provided an important less-invasive alternative to surgical revascularization. However, balloon angioplasty without stent implantation has several limitations. Balloon inflation can cause arterial wall injury, dissection, abrupt vessel closure, and elastic recoil, which may lead to recurrent narrowing of the treated artery. Restenosis caused by tissue proliferation following vessel injury was also a major limitation of early balloon angioplasty and could result in recurrent symptoms or the need for repeat revascularization. These limitations contributed to the development and widespread adoption of coronary stents, which provide mechanical support to the treated vessel and reduce some of the complications associated with balloon-only angioplasty.

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➢ *Advantages and Disadvantages of Coronary Stents*

- *Advantages*

Coronary stenting is an important development in percutaneous coronary intervention (PCI) because it provides a minimally invasive method of restoring blood flow through narrowed or blocked coronary arteries. Compared with coronary artery bypass grafting (CABG), PCI generally avoids open-chest surgery and is associated with shorter hospital stays and faster recovery in appropriately selected patients. Stents provide mechanical support to the coronary artery following balloon expansion, helping prevent elastic recoil and maintaining vessel diameter. Compared with balloon angioplasty alone, stent implantation has been shown to improve procedural success and reduce the risk of restenosis and repeat revascularization. The introduction of drug-eluting stents (DES) further reduced restenosis by delivering antiproliferative medication locally and limiting excessive tissue growth within the treated vessel. Contemporary stents are also available in improved designs with thinner struts and better delivery systems, contributing to improved procedural performance and clinical outcomes.

- *Disadvantages*

Despite their advantages, coronary stents have important limitations. Stent implantation can cause complications such as bleeding related to vascular access, coronary artery dissection, vessel perforation, or other procedural complications. Stent thrombosis, although uncommon with contemporary stents, remains a potentially serious complication that can result in acute myocardial infarction or death. Patients receiving coronary stents generally require antiplatelet medication for a prescribed period to reduce the risk of thrombosis, which can increase bleeding risk. Drug-eluting stents have markedly reduced restenosis but do not completely eliminate the possibility of in-stent restenosis or the need for repeat intervention. PCI may also be unsuitable or less effective than CABG in certain patients with extensive, complex, or multivessel coronary artery disease. Therefore, the selection of stenting or CABG should be based on coronary anatomy, clinical presentation, comorbidities, procedural risk, and multidisciplinary clinical assessment.

V. RESULT

The analysis of the evolution of invasive therapies for acute myocardial infarction indicates a progressive shift from conventional surgical revascularization toward minimally invasive catheter-based treatment. The estimated trend from 2015 to 2025 suggests that the use of coronary artery bypass grafting (CABG) and balloon-only angioplasty has gradually decreased, whereas stent-based percutaneous coronary intervention (PCI) has shown a substantial increase. This pattern indicates a growing preference for procedures that can restore coronary blood flow with less surgical trauma and comparatively shorter recovery periods. The decline in balloon-only angioplasty can be associated with the limitations of balloon treatment, including elastic recoil, vessel dissection, abrupt closure, and restenosis. In contrast, improvements in coronary stent technology, particularly newer-generation drug-eluting stents, have enhanced vessel patency and reduced restenosis, contributing to their wider adoption.

The future trend is expected to continue toward advanced stent-based PCI, supported by improved drug-delivery systems, thinner and more biocompatible stent platforms, intravascular imaging, and increasingly individualized treatment strategies. Artificial intelligence and advanced imaging may further assist clinicians in lesion assessment and stent optimization. However, CABG is expected to remain an important treatment for patients with complex multivessel disease, left main coronary disease, or coronary anatomy unsuitable for PCI. Therefore, the future is unlikely to involve complete replacement of CABG by stenting; instead, treatment is expected to become increasingly patient-specific, with the choice of CABG or PCI based on coronary anatomy, clinical condition, and long-term risk. Overall, the findings suggest continued growth of minimally invasive stent-based treatment alongside selective use of CABG.

VI. CONCLUSION

The relationship between ABO blood group antigens and knee osteoarthritis represents an emerging area of biomedical research that combines genetics, immunology, and musculoskeletal biology. Current evidence suggests that ABO blood group antigens may influence biological pathways involved in inflammation, immune cell adhesion, vascular function, and coagulation. These mechanisms provide a plausible explanation for how variations in blood group antigens could contribute to cartilage degeneration and the progression of osteoarthritis. In particular, differences in inflammatory responses, levels of adhesion molecules, and circulating clotting proteins such as von Willebrand factor may indirectly affect joint health and tissue repair. However, these proposed mechanisms remain largely theoretical and have not been conclusively established in clinical settings.

Existing studies have produced inconsistent findings, with some reporting associations between specific ABO blood groups and an increased risk of knee osteoarthritis, while others have found no significant correlation. Therefore, ABO blood group cannot currently be regarded as a direct cause or reliable predictor of knee osteoarthritis. Instead, it may serve as one of several biological markers that, together with genetic, environmental, lifestyle, and metabolic factors, influence disease susceptibility. Future large-scale, multi-ethnic, and longitudinal studies incorporating molecular, genetic, and clinical evidence are essential to determine the true significance of ABO blood group antigens in the onset and progression of knee osteoarthritis and to evaluate their potential role in personalized risk assessment and preventive strategies.

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RECOMMENDATIONS

Based on the evolution of invasive therapies for acute myocardial infarction, timely restoration of coronary blood flow should remain the primary objective of treatment. Primary percutaneous coronary intervention (PCI) with contemporary stent technology should be considered the preferred invasive reperfusion strategy for eligible patients with STEMI when it can be performed promptly by an experienced team. Balloon angioplasty alone should generally not be considered the definitive treatment when stent implantation is appropriate because of its limitations, including vessel recoil and restenosis. Although coronary artery bypass grafting (CABG) remains an important and effective revascularization option, its use should be individualized according to coronary anatomy, disease complexity, clinical condition, and surgical risk rather than being considered obsolete. Future development should focus on improving stent biocompatibility, reducing restenosis and thrombosis, and expanding the use of intravascular imaging and physiology-guided PCI to optimize treatment. Healthcare systems should also emphasize rapid diagnosis, early referral, and minimizing delays between hospital presentation and reperfusion. Continued clinical research and long-term comparative studies are recommended to evaluate newer stent technologies, minimally invasive approaches, and personalized revascularization strategies. Finally, appropriate post-PCI medical therapy, cardiac rehabilitation, and control of cardiovascular risk factors should be integrated into the overall management plan to improve long-term outcomes and reduce recurrent myocardial infarction.

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