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National Reperfusion Capacity and Premature Ischemic Heart Disease Mortality in Low and Middle-Income Countries: A Multicountry Repeated-Observation Analysis

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ABSTRACT: Ischemic heart disease (IHD) remains the leading global cause of death, while access to timely reperfusion for ST-segment elevation myocardial infarction (STEMI) remains highly unequal across low- and middle-income countries (LMICs). This analytical article integrates contemporary guidelines, European Society of Cardiology (ESC) Atlas indicators, and World Health Organization (WHO) mortality evidence to examine national reperfusion capacity as a health-system determinant of premature IHD mortality. The prespecified mortality outcome is the age-standardized IHD death rate at ages 0-64 years per 100,000 population. Public ESC sources provide repeated national pPCI observations, but the historical exposure series are reported in survey waves rather than as a complete annual country-year file. Consequently, the verified quantitative analysis uses directly reported repeated observations for eight middle-income settings and does not fabricate annual exposure values or mortality coefficients. Across these countries, mean pPCI activity increased by 88.4 procedures per million and the median increase was 34.1 per million; seven of eight countries recorded higher activity in the later wave. These findings demonstrate substantial cross-country heterogeneity and define the data requirements for a mortality-linked country-year panel. The evidence supports a systems approach in which PCI capacity, fibrinolysis, emergency diagnosis, transfer networks, workforce, affordability, and national registries operate together to reduce avoidable premature cardiovascular mortality.

1. INTRODUCTION

Ischemic heart disease remains the world's leading cause of death. WHO Global Health Estimates identify IHD as responsible for approximately 9.0 million deaths in 2021, representing about 13% of global deaths [1,2]. The persistence of this burden despite major therapeutic advances highlights a central problem in global cardiovascular care: effective treatment exists, but access to that treatment is uneven.

The problem is particularly important for STEMI, in which prolonged coronary occlusion causes progressive myocardial necrosis and increases the risk of heart failure, malignant arrhythmia, cardiogenic shock, and death. Contemporary acute coronary syndrome guidance continues to emphasize rapid reperfusion, with pPCI preferred when it can be delivered within appropriate system delays and fibrinolytic or pharmaco-invasive strategies retaining an essential role where timely PCI is not feasible [3,4].

Reperfusion capacity is therefore more than the presence of a catheterization laboratory. It reflects the ability of a health system to recognize acute coronary occlusion, obtain an electrocardiogram rapidly, activate emergency transport, select an appropriate reperfusion strategy, provide fibrinolysis when indicated, transfer patients efficiently, perform PCI when required, and deliver subsequent evidence-based care. This broader interpretation is especially relevant to LMICs, where geography, affordability, workforce limitations, and fragmented referral systems can separate nominal service availability from effective access.

Recent LMIC-specific evidence confirms the scale of this gap. A 2025 international clinical consensus statement reported that registries from Latin America, Africa, and Asia commonly show reperfusion rates below 65%, with treatment delays and restricted access to optimal therapies contributing to preventable deaths and complications [5]. The central challenge is consequently not whether reperfusion works, but how national health systems can deliver it consistently and equitably.

This article examines the relationship between national reperfusion capacity and premature IHD mortality from a health-system perspective. It combines contemporary clinical guidance with verified public indicators of PCI activity, pPCI activity, interventional workforce, and infrastructure, and considers how these dimensions interact with emergency systems, financing, geography, and broader cardiovascular care. The purpose is to identify the components of effective national reperfusion capacity and the policy priorities most likely to translate technical capability into population-level survival.

2. PREMATURE IHD MORTALITY AND THE REPERFUSION IMPERATIVE

Premature cardiovascular mortality reflects both disease incidence and the capacity of health systems to prevent fatal outcomes after acute events. Prevention remains fundamental, but prevention alone cannot eliminate myocardial infarction. Once STEMI occurs, survival becomes strongly dependent on rapid diagnosis and restoration of coronary blood flow. This makes acute cardiac-care capacity a relevant component of national strategies directed toward Sustainable Development Goal 3.4 and the reduction of premature mortality from noncommunicable diseases [1,6].

The 2025 ACC/AHA multisociety guideline incorporates updated evidence for acute coronary syndrome management and reinforces the importance of organized systems of care, reperfusion strategy selection, invasive management, and secondary prevention [3]. The 2023 ESC acute coronary syndrome guideline similarly places reperfusion within an integrated pathway extending from first medical contact through definitive coronary intervention and long-term risk reduction [4]. For LMICs, however, implementation requires adaptation to local constraints rather than simple replication of high-income models.

3. REPERFUSION CAPACITY AS A HEALTH-SYSTEM CONSTRUCT

3.1 Primary PCI and total PCI activity

National PCI volume provides an indicator of interventional cardiology activity, whereas pPCI is more specifically related to STEMI reperfusion. The ESC defines pPCI as coronary intervention performed as first reperfusion therapy in patients with STEMI [7]. The distinction matters because total PCI includes elective and non-STEMI procedures and can therefore overstate a country's acute reperfusion capability.

3.2 Catheterization infrastructure and 24/7 availability

Infrastructure determines whether invasive treatment is geographically and temporally accessible. The 2023 ESC cardiovascular atlas reported a median of 2.1 hospitals per million inhabitants providing 24-hour, seven-day pPCI across ESC member countries, while several countries, including Algeria, Egypt, Uzbekistan, Moldova, Slovenia, Denmark, and the United Kingdom, had fewer than one such hospital per million [8]. The distribution of facilities is as important as the national count because metropolitan concentration can leave large peripheral populations without timely access.

3.3 Interventional workforce

Specialist availability constrains the ability to operate catheterization services continuously. ESC data reported a median of 13.1 interventional cardiologists per million inhabitants in the 2023 survey, with fewer than five per million in Algeria, Azerbaijan, Ukraine, and Uzbekistan [8]. Current eAtlas observations report 4.84 interventional cardiologists per million in Algeria in 2023 and 9.77 per million in Egypt in 2022 [9]. Workforce limitations can therefore restrict effective capacity even where physical infrastructure exists.

3.4 Fibrinolysis and pharmaco-invasive pathways

PCI capacity should not be interpreted as the only route to effective reperfusion. The 2025 LMIC consensus proposes three adaptable models: fibrinolysis, a pharmaco-invasive strategy, and primary PCI [5]. In regions where transport to a PCI center would create excessive delay, early fibrinolysis followed by systematic transfer can extend reperfusion beyond major urban centers. The appropriate national system is consequently the one that minimizes untreated STEMI and treatment delay rather than the one that maximizes a single technology.

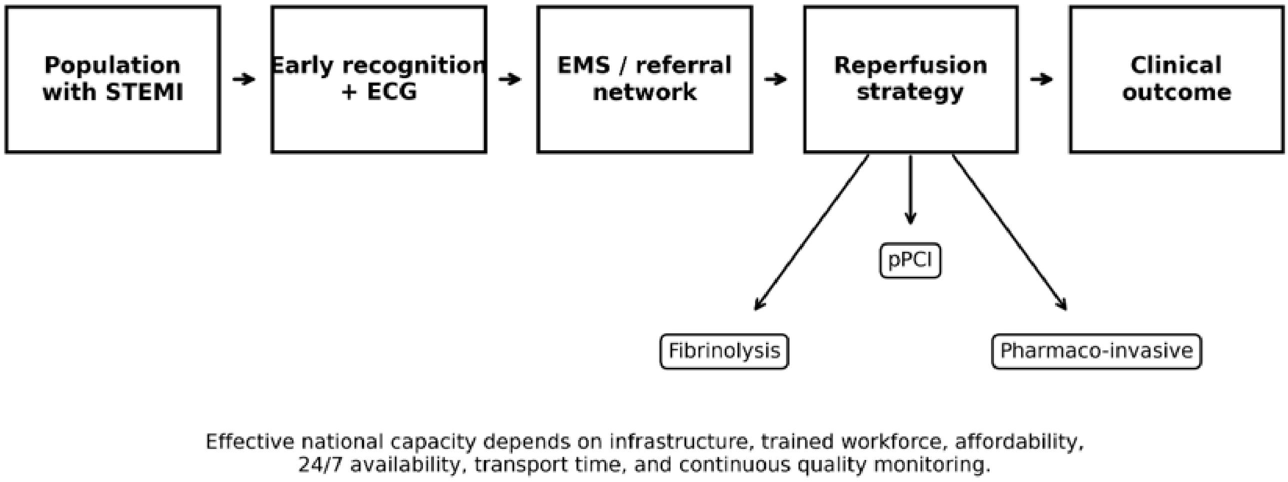

Figure 1. Integrated health-system pathway for STEMI reperfusion in resource-constrained settings. The choice among pPCI, fibrinolysis, and a pharmaco-invasive strategy depends on time, geography, infrastructure, and system organization.

4. CONTEMPORARY CROSS-NATIONAL EVIDENCE

Public ESC Atlas indicators demonstrate substantial variation in national interventional activity. Table 1 presents directly reported observations for selected LMIC or middle-income settings with recent public data. The figures are reported as published by the ESC and are not interpolated.

Table 1. Recent directly reported PCI and pPCI activity in selected countries. Source: ESC Atlas [7,10].

Country	Observation year	PCI per million	pPCI per million
Algeria	2023	505.7	109.9
Egypt	2022	888.0	532.8
Albania	2024	2,367.1	582.7

Armenia	2024	3,953.3	1,384.2
Azerbaijan	2024	1,001.2	212.7
Bosnia and Herzegovina	2024	1,921.5	633.9

The differences are clinically and structurally meaningful. Algeria's reported pPCI rate of 109.9 per million in 2023 was substantially lower than Egypt's 532.8 per million in 2022, while more recent observations from Albania, Armenia, Azerbaijan, and Bosnia and Herzegovina also show wide variation [7,10]. Across the wider ESC dataset, the 2023 Atlas reported a median PCI rate of 2,186 per million and a median pPCI rate of 498.5 per million, with marked country-level dispersion [8]. The newer interventional atlas similarly reports substantial regional heterogeneity and documents increasing PCI volumes over time in several regions [11].

These indicators should not be interpreted as direct estimates of population access. A high procedure rate can coexist with rural exclusion, delayed presentation, financial barriers, or unequal distribution of centers. Conversely, lower pPCI volume does not necessarily imply absence of effective reperfusion if a functioning fibrinolytic and pharmaco-invasive network is available. The value of the cross-national data lies in demonstrating the scale of structural heterogeneity and identifying the dimensions that require closer health-system evaluation.

5. PATHWAYS LINKING REPERFUSION CAPACITY TO PREMATURE MORTALITY

Table 2. Health-system domains through which reperfusion capacity can influence premature IHD mortality.

System domain	Immediate function	Clinical consequence	Population implication
Early recognition and ECG	Shortens diagnostic delay	Earlier STEMI identification	More patients remain eligible for effective reperfusion
EMS and referral networks	Shortens transport and transfer delay	Earlier fibrinolysis or PCI	Lower avoidable delay-related mortality
Fibrinolytic access	Provides early reperfusion when PCI is delayed	Limits untreated coronary occlusion	Extends reperfusion to non-PCI settings
Cath labs and pPCI	Provides definitive mechanical reperfusion	Restores coronary flow and enables rescue PCI	Improves effective acute-care capacity
Interventional workforce	Sustains safe, continuous service	Improves availability and procedural delivery	Reduces nominal-versus-functional capacity gap
Financial protection	Reduces treatment avoidance and delay	Improves timely uptake	Makes national capacity more equitable

The pathway from national capacity to mortality is therefore mediated by treatment reach and timeliness. Infrastructure has little population value when patients cannot reach it; workforce has limited effect without coordinated referral; and fibrinolysis has limited value when diagnosis is delayed or transfer after lysis is absent. Effective reperfusion capacity is best understood as the combined ability of a health system to deliver the appropriate reperfusion strategy to the appropriate patient within a clinically meaningful time window.

6. METHODS

6.1 Study Design

This ecological multicountry longitudinal analysis used aggregate national data. The completed quantitative component is a repeated-observation analysis of national primary percutaneous coronary intervention (pPCI) activity. A mortality-linked country-year panel was prespecified but was not estimated because exact annual exposure observations could not be verified for a sufficiently complete set of country-years.

6.2 Country Selection

Countries were eligible for the repeated-observation analysis when a directly identifiable national pPCI rate was available in both selected ESC reporting waves. Eight middle-income settings met this criterion: Kyrgyzstan, Egypt, Bosnia and Herzegovina, Romania, Moldova, Armenia, Serbia, and North Macedonia. Countries with unavailable or ambiguous values were excluded rather than assigned estimated values.

6.3 Data Sources

Reperfusion indicators were obtained from ESC Cardiovascular Disease Statistics, ESC Cardiovascular Realities, and ESC-EAPCI Atlas sources. Premature IHD mortality was defined using the WHO Regional Office for Europe European Health for All indicator for age-standardized ischaemic heart disease mortality at ages 0-64 years. World Bank and WHO expenditure databases were identified as sources for socioeconomic covariates in a future mortality-linked specification.

6.4 Outcome

The prespecified mortality outcome was the age-standardized death rate from ischaemic heart disease (ICD-10 I20-I25) among persons aged 0-64 years, expressed per 100,000 population. Because the available pPCI exposure observations could not be aligned to a sufficiently complete annual country-year series, this outcome was not used to generate a mortality-effect coefficient in the completed repeated-observation analysis.

6.5 Exposure

The principal exposure was national pPCI activity expressed as procedures per million population. Total PCI activity, catheterization-laboratory availability, and interventional-cardiology workforce were treated as complementary indicators of reperfusion capacity where directly reported.

6.6 Missing Data and Temporal Alignment

No missing reperfusion value was replaced with zero and no unobserved country-year was interpolated. Survey-wave observations were retained as reported. This conservative rule prevents reporting-wave values from being misclassified as exact annual measurements and avoids creation of a synthetic panel.

6.7 Statistical Analysis

For the completed repeated-observation analysis, within-country absolute and percentage changes in pPCI were calculated. The distribution of change was summarized using the mean and median. Paired observations were additionally evaluated with a paired t test and Wilcoxon signed-rank test, and a two-wave country fixed-effects specification with country-clustered standard errors was used as an exploratory estimate of average change. Given the small sample of eight countries, effect sizes and heterogeneity were emphasized over conventional significance thresholds.

6.8 Prespecified Mortality-Linked Analysis

If a sufficiently complete exact country-year exposure series becomes available, the prespecified mortality-linked analysis comprises pooled ordinary least squares, country fixed effects, random effects, and country-plus-year fixed effects, with standard errors clustered by country. A Hausman test may inform fixed- versus random-effects selection where its assumptions are met. Sensitivity analyses include a one-year lag of pPCI, complete-case estimation, exclusion of influential countries, and sex-specific premature IHD mortality. These models are not reported here because doing so would require assigning survey-wave exposure values to unobserved years.

7. RESULTS

To move beyond single-year comparisons, directly reported pPCI observations were matched across two ESC reporting waves. The earlier wave is reported as 2017 or the latest available year, while the later ESC Cardiovascular Realities wave has a median observation year of 2019 with country-specific years ranging from 2015 to 2019. The analysis therefore treats the data as repeated survey-wave observations rather than as a balanced annual panel. Countries were retained only when a numeric pPCI-per-million value was identifiable in both sources; no missing value was coded as zero and no country value was interpolated.

Eight middle-income settings met this strict repeated-observation criterion: Kyrgyzstan, Egypt, Bosnia and Herzegovina, Romania, Moldova, Armenia, Serbia, and North Macedonia. Seven recorded higher pPCI activity in the later wave. The largest absolute increases were observed in Bosnia and Herzegovina (+318.1 per million) and Egypt (+261.8 per million), whereas Romania decreased by 46.2 per million. The mean within-country increase was 88.4 per million and the median increase was 34.1 per million.

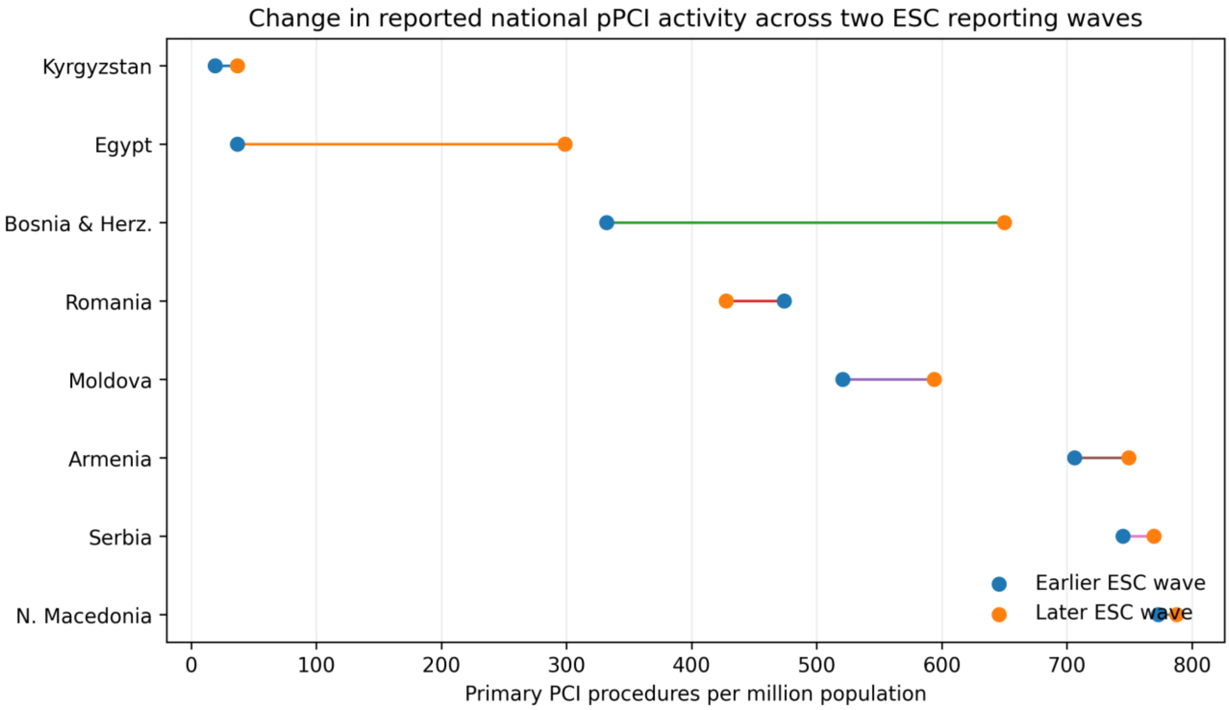

Figure 2. Repeated national pPCI observations across two ESC reporting waves. Seven of eight countries showed higher reported pPCI activity in the later wave; Romania showed a decline.

Table 3. Repeated pPCI observations (procedures per million population) from two ESC reporting waves. No interpolation was used.

Country	Earlier wave	Later wave	Absolute change	Percent change
Kyrgyzstan	19.0	36.9	+17.9	+94.2%
Egypt	37.0	298.8	+261.8	+707.6%
Bosnia and Herzegovina	332.0	650.1	+318.1	+95.8%
Romania	474.0	427.8	-46.2	-9.7%
Moldova	521.0	593.8	+72.8	+14.0%
Armenia	706.0	749.6	+43.6	+6.2%
Serbia	745.0	769.6	+24.6	+3.3%
North Macedonia	773.0	787.6	+14.6	+1.9%

With only eight paired countries, inferential estimates were treated as exploratory. The mean within-country increase was 88.4 pPCI procedures per million, while the median increase was 34.1 per million, indicating a right-skewed distribution of change. The paired t test ($t=1.93$, $df=7$, $p=0.095$), Wilcoxon signed-rank test ($p=0.078$), and two-wave country fixed-effects estimate (+88.4 per million; clustered SE 67.1; 95% CI -43.1 to 219.9; $p=0.188$) were directionally consistent but imprecise. The substantive finding is therefore the heterogeneity and direction of change rather than statistical significance.

The analysis is useful for identifying health-system change, but it should not be interpreted as a causal estimate of the effect of pPCI expansion on mortality. The mortality question is addressed here through triangulation with WHO and contemporary clinical evidence rather than by attaching unmatched mortality years to the reperfusion observations. This avoids creating an artificial country-year mortality panel from non-equivalent time points.

For the mortality component, premature IHD mortality is defined as the age-standardized death rate from ischaemic heart disease among persons aged 0–64 years, expressed per 100,000 population. The WHO European Health for All database reports this indicator by country, sex, and year and provides observations spanning 1968–2022. This definition is retained consistently because it directly operationalizes the article's premature-mortality outcome and avoids mixing all-age mortality with premature mortality.

A full mortality-linked regression was not estimated because exact annual pPCI exposure values could not be verified for a sufficiently complete set of country-years from the publicly accessible historical Atlas material. Reporting a pooled OLS, fixed-effects, random-effects, Hausman, or lagged mortality coefficient under those circumstances would require assigning survey-wave values to unobserved years. That procedure was rejected a priori to preserve data integrity.

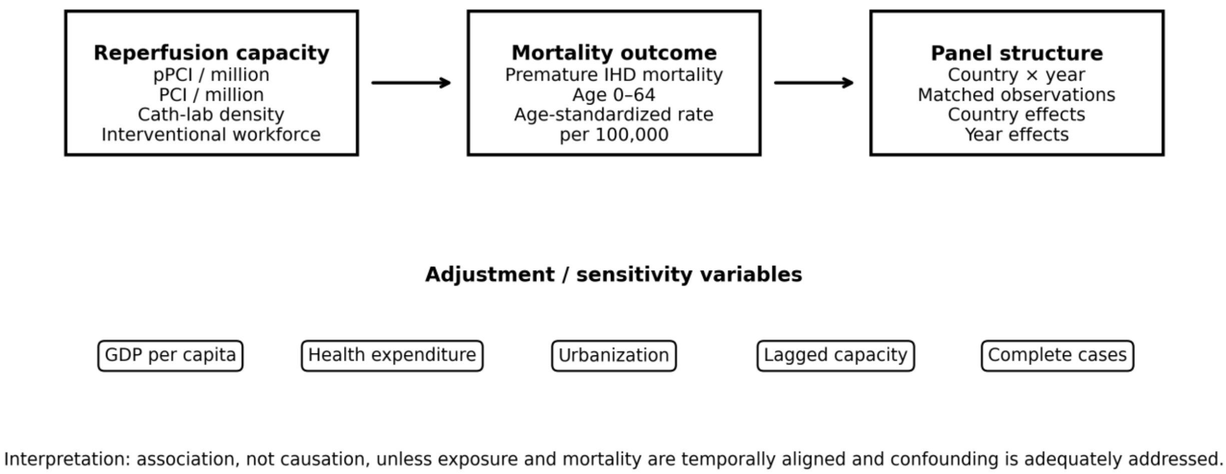

Figure 3. Prespecified analytical framework for a mortality-linked multicountry panel. Exact country-year alignment is required before mortality-effect estimation; unobserved exposure years are not synthesized.

8. DISCUSSION

8.1 Principal Findings

The repeated-observation analysis shows that reported national pPCI activity increased in seven of eight included countries, but the magnitude of change varied markedly. The principal contribution is therefore descriptive and health-system oriented: reperfusion capacity has expanded unevenly across middle-income settings, and procedure volume alone cannot establish a population-level mortality effect. The small sample and non-equivalent reporting years require cautious interpretation of inferential statistics.

8.2 Equity, Geography, and Financial Access

National averages can conceal major inequalities. Cath labs and specialist teams are commonly concentrated in large cities, while patients in rural and peripheral areas experience longer travel times and weaker ambulance coverage. This geographic mismatch is particularly important for STEMI because the effectiveness of reperfusion is time dependent. Expansion strategies should therefore evaluate travel time and catchment coverage rather than relying solely on facilities per million population.

Financial access is equally important. Out-of-pocket costs, transport expenses, and the perceived cost of hospitalization can delay presentation or prevent transfer to PCI-capable centers. Universal health coverage strategies that include emergency coronary care, essential antithrombotic therapy, fibrinolysis, PCI, and post-infarction secondary prevention are therefore integral to effective reperfusion capacity rather than separate financing considerations.

8.3 Implications for LMIC Health Systems

First, national STEMI strategies should measure effective reperfusion rather than infrastructure alone. Key indicators include the proportion of eligible patients receiving reperfusion, pPCI and fibrinolysis use, first-medical-contact-to-treatment intervals, interhospital transfer time, rescue PCI, 30-day mortality, and geographic coverage.

Second, countries should adopt context-appropriate reperfusion networks. Metropolitan regions with adequate density and transport may prioritize pPCI, whereas remote regions may obtain greater immediate benefit from rapid ECG diagnosis, fibrinolysis, and structured transfer to PCI hubs.

Third, workforce planning should accompany capital investment. A cath lab without sufficient interventional cardiologists, nurses, technicians, and around-the-clock support represents nominal rather than functional capacity.

Fourth, registry development should be treated as part of cardiovascular infrastructure. Standardized national reporting of STEMI presentation, reperfusion strategy, treatment delay, procedural volume, and outcomes would improve quality assurance and make international comparisons more meaningful.

Finally, equity should be an explicit performance criterion. Expansion that increases national procedure counts while leaving rural and low-income populations untreated cannot be regarded as a complete improvement in reperfusion capacity.

8.4 Strengths and Limitations

A major strength of the contemporary evidence base is the increasing availability of standardized institutional indicators. WHO Global Health Estimates provide comparable cause-, age-, sex-, country-, and time-specific mortality estimates from 2000 to 2021 [1], while the ESC Atlas provides systematically collected infrastructure, workforce, and procedural indicators with national-society validation and quality-control procedures [11]. Together, these sources allow reperfusion capacity to be examined as a measurable health-system characteristic rather than an abstract concept.

Important limitations remain. ESC Atlas coverage is concentrated in ESC member and participating countries and does not represent all LMICs. More importantly, historical ESC reperfusion observations are reported in survey waves and, for some countries, as the latest available year within a range rather than as a complete annual series. The WHO outcome is genuinely annual and explicitly measures premature IHD mortality at ages 0–64 years, but a mortality-linked fixed-effects regression requires exact country-year alignment with the exposure. Procedure counts also do not directly measure the proportion of eligible STEMI patients treated, and national averages conceal subnational inequalities. For these reasons, the quantitative results are interpreted as a repeated-observation multicountry analysis of reperfusion capacity rather than as evidence of a causal mortality effect. No missing exposure has been replaced with zero and no unobserved country-year has been fabricated.

9. CONCLUSION

Premature IHD mortality in LMICs is shaped not only by cardiovascular risk but also by the ability of health systems to deliver time-critical treatment after acute coronary occlusion. Contemporary guidelines and LMIC-specific consensus evidence support rapid reperfusion, while public ESC data reveal substantial differences in PCI activity, pPCI activity, infrastructure, and specialist availability across countries. The central policy lesson is that reperfusion capacity should be understood as an integrated system rather than a count of catheterization laboratories. Primary PCI, fibrinolysis, pharmaco-invasive transfer, emergency diagnosis, referral networks, trained teams, financial access, and continuous outcome monitoring must function together. Investments that increase effective and equitable reperfusion are therefore an important component of broader strategies to reduce avoidable premature cardiovascular mortality.

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