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Sex-Specific Trends and Predictors of Outcomes in Acute Myocardial Infarction in Almaty, Kazakhstan

Kamilya Kedelbayeva[1], Salim Berkinbaev[1], Gulnara Junusbekova[1], Meiramgul Tundybayeva[1], Ainur Umarova[2]

[1]Department of Cardiology, Asfendiyarov Kazakh National Medical University, Almaty, Republic of Kazakhstan; [2]City Cardiology Center, Almaty, Republic of Kazakhstan

Correspondence: Meiramgul Tundybayeva, Department of Cardiology, Asfendiyarov Kazakh National Medical University, 94 Tole Bi Street, Almaty, 050000, Republic of Kazakhstan, Email miratundybayeva@gmail.com

Background: Acute myocardial infarction (AMI) disproportionately affects older adults, highlighting the need for equitable, high-quality cardiovascular care. In Kazakhstan, recent primary health care reforms may have improved outcomes, but it remains unclear whether these gains are comparable for women and men. This study aimed to assess sex-specific trends in AMI outcomes and identify independent predictors of adverse clinical events.

Methods: We performed a two-stage retrospective study. Stage 1 analyzed 2018–2024 hospitalization data by sex. Stage 2 examined electronic records of 1,866 AMI patients from a tertiary cardiology center. Demographics, clinical parameters, and outcomes were collected. Statistical analysis included group comparisons and uni-/multivariable logistic regression using SPSS.

Results: From 2018 to 2024, clinical improvement exceeded 90% annually except in 2021–2022, while mortality declined to 4.7%. Female were consistently presented at older ages than males and had less favorable baseline profiles, including lower hemoglobin levels and reduced renal function, whereas males had slightly higher creatinine levels and longer hospital stays. Hospital length of stay showed moderate variability with a post-pandemic increase, and hospitalization costs rose steadily for both sexes. Among 1,866 patients, hypertension was highly prevalent and 6.4% died. Deceased patients were older and showed worse hemodynamic, renal, metabolic, and inflammatory profiles with lower ejection fraction. In multivariable analysis, sex was not an independent predictor, while age, glucose, non–ST-elevation myocardial infarction (NSTEMI) status, systolic blood pressure, hemoglobin, glomerular filtration rate, and ejection fraction remained significant.

Conclusion: Advanced age, metabolic and renal dysfunction, hemodynamic instability, and impaired cardiac function were the strongest predictors of adverse outcomes, while NSTEMI presentation and better physiological status were associated with lower mortality. Females presented at older ages with less favorable risk profiles; although sex was not an independent predictor after adjustment, these differences underscore the need for tailored, risk-stratified care for high-risk patients.

Keywords: myocardial infarction, STEMI, NSTEMI, predictors, sex differences, cardiovascular risk, Kazakhstan

Introduction

Cardiovascular diseases (CVDs) remain the leading global cause of death and disability, accounting for a substantial worldwide and growing proportion of premature mortality. Since 1990, the global burden of CVD has increased significantly, driven by population growth, aging, and rising exposure to modifiable behavioral and metabolic risk factors.[1] Despite major advances in prevention, diagnosis, and treatment, most cardiovascular events remain preventable, highlighting the need for strengthened public health interventions and effective health system strategies to reduce premature cardiovascular mortality.

Myocardial infarction (MI) is a major contributor to CVD burden and disproportionately affects older adults. The prevalence of MI increases sharply with age, rising from approximately 3.8% among individuals under 60 years to 9.5%

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among those aged 60 and above.[2] These patterns underscore the need for accessible, high-quality cardiovascular services tailored to aging populations, particularly in countries undergoing rapid demographic change.

Kazakhstan has undertaken substantial health system reforms over the past decade, positioning itself as a regional leader in achieving the Sustainable Development Goals (SDGs), especially SDG 3.8 on Universal Health Coverage (UHC). Central to these reforms has been the strengthening of primary health care (PHC).[3] Kazakhstan has introduced comprehensive PHC policies focused on integrated service delivery, multidisciplinary teams, expanded screening programs, and improved continuity of care, measures intended to reduce preventable mortality and enhance cardiovascular outcomes.[4,5] The country also hosts a World Health Organization (WHO) demonstration platform showing effective PHC models.[6] Through 4–5-day learning visits, policymakers and practitioners observe innovations such as team-based care, digital health solutions, and coordinated chronic disease management. Complementing this, the WHO European Center for Primary Health Care in Almaty supports Member States in implementing the principles of the Alma-Ata (1978) and Astana (2018) Declarations, reinforcing PHC as the foundation of equitable, person-centered, and integrated care.[6,7]

Despite these advances, significant health disparities persist. In Kazakhstan, male have lived approximately seven years longer than females, reflecting broader demographic and behavioral inequities. These differences are highly relevant to cardiovascular health. Globally, male experience acute MI earlier and more frequently, while female tend to present later, often with atypical symptoms, and face higher short-term mortality.[8] However, region-specific evidence from Central Asia remains scarce, and it is not yet known whether improvements in access to and quality of cardiac care have benefited women and men equally within Kazakhstan. Almaty was selected as the study setting because it is the largest metropolitan area in the country and serves as a major national referral center for cardiovascular care, concentrating tertiary hospitals and specialized cardiology services that manage complex AMI cases from both urban and surrounding regions. As such, patient data from Almaty provide a valuable lens through which to examine sex-specific patterns of AMI presentation and outcomes within a mature and resource-intensive healthcare environment. Thus, this study examines sex-specific trends and predictors of AMI outcomes in Almaty to identify potential disparities and to inform policies aligned with Kazakhstan's UHC goals and global commitments to equitable cardiovascular health.

Methods

Study Design

We conducted a retrospective analysis consisting of two stages.

Stage 1

Trends in hospitalization outcomes (2018–2024). Hospitalization data from 2018 to 2024 were obtained from the Almaty branch of the National Scientific Center for Health Development. All records coded under ICD-10 - I21 (Acute myocardial infarction - AMI) were included. Annual indicators were analyzed by sex and included clinical improvement rates, mortality, transfers, age distribution, length of hospital stay, and hospitalization costs. Clinical improvement was defined as discharge with documented clinical stabilization, including resolution or improvement of acute ischemic symptoms, hemodynamic stability, and no requirement for escalation of intensive or invasive care at discharge. Unauthorized departure referred to patients who left the hospital against medical advice or without formal discharge, reflecting patient-initiated interruption of care.

Stage 2

Identification of predictors of myocardial infarction outcomes. For the predictive component, we analyzed electronic medical records of 1,866 patients diagnosed with AMI, either STEMI or NSTEMI, who were admitted for one year period to the City Cardiology Center in Almaty, an institution providing specialized and highly specialized emergency care for acute coronary syndromes and serving as a central cardiovascular hub in Kazakhstan.

Data Collection

Extracted variables included demographic characteristics (age, sex), comorbidities, vital signs, laboratory parameters (hematologic, renal, hepatic, metabolic markers, cardiac biomarkers), echocardiographic indicators, and clinical outcomes (alive vs died). STEMI and NSTEMI were defined using standard clinical and ECG criteria.

Statistical Analysis

Descriptive statistics were presented as mean ± standard deviation for continuous variables and as frequencies and percentages for categorical variables. Group comparisons were performed using the independent samples *t*-test or the Mann–Whitney *U*-test for continuous variables and the chi-square test for categorical variables.

Univariate logistic regression was used to explore crude associations between candidate variables and in-hospital mortality. Variables with $p < 0.10$ in univariate analysis were considered for multivariable modeling, consistent with established epidemiological practice for variable screening, to reduce the risk of excluding potentially important confounders. In addition, clinically relevant predictors—including age, sex, AMI subtype (STEMI/NSTEMI), systolic blood pressure, renal function, hemoglobin, glucose, and left ventricular ejection fraction—were forced into the multivariable model regardless of univariate significance, based on prior evidence and biological plausibility. Multivariable logistic regression was then used to estimate adjusted odds ratios (AORs) with 95% confidence intervals. Potential multicollinearity among predictors was assessed using variance inflation factors (VIFs), with no evidence of problematic collinearity observed (all VIFs < 5). Statistical significance was defined as $p < 0.05$.

All parameters included in the analysis are part of mandatory diagnostic and monitoring procedures for patients hospitalized with acute myocardial infarction at the study center. As a result, complete data were available for all variables included in the analyses, and no missing data handling or imputation procedures were required. Given the retrospective nature of the study and the inclusion of all eligible patients within the defined periods, a priori sample size or power calculations were not performed. The sample size for Stage 2 was considered adequate for the assessment of in-hospital mortality predictors; however, the one-year observation period limits inference regarding long-term outcomes. All analysis was conducted using SPSS (version 22) or equivalent statistical software.

Results

From 2018 to 2024, most patients showed clinical improvement, with annual rates generally above 90%, except in 2021 and 2022 when they declined to 85.8% and 83.5%. Transfers to other departments and unauthorized departures remained minimal throughout the period, usually below 1–2%, though transfers briefly increased in 2021–2022. Mortality ranged from 4.6% to 10.5%, peaking in 2021 and 2018 but declining to approximately 4.6–4.7% by 2023–2024 (Table 1).

Across the years, the age distribution of patients showed a consistent pattern in which females presented at an older age than males, with differences typically ranging from 7 to 10 years. Mean ages among males remained relatively stable, fluctuating between 59 and 62 years, while female ages ranged from 68 to 71 years. The overall mean age remained steady, between 62 and 65 years, with no clear trend over time (Table 2).

Hospital length of stay demonstrated moderate year-to-year variability without a clear upward or downward trend. Male patients typically had slightly longer hospitalizations than female patients, although the difference was small. Length of stay peaked in 2019 and decreased sharply during 2020–2021, coinciding with the COVID-19 pandemic. After 2021, it gradually increased again, reaching around 9.7–9.9 days for males and 9.2–9.3 days for females by 2024. Variability remained stable across years and sexes (Table 2).

Hospitalization costs displayed a clearer upward trajectory, increasing steadily for both males and females. While males consistently incurred higher costs, the sex gap widened in later years, with males' costs exceeding $2,050 by 2024 compared with approximately $1,860 in females. Overall mean costs rose from around $1,407 in 2018 to nearly $1,991 in 2024, reflecting greater resource utilization and inflationary pressures (Table 2).

In the next stage, we analyzed hospitalized patients to identify predictors of myocardial infarction in the Almaty population. Among the 1866 patients, 1162 (62.3%) were males and 704 (37.7%) were females; 41.3% presented with STEMI and 58.7% with NSTEMI. A total of 120 patients (6.4%) died. Arterial hypertension was highly prevalent

Table 1 Annual Treatment Outcomes of Patients from 2018 to 2024

Year	Improvement	Translated to Other Department	Unauthorized Departure	Died	Urgent	Total
2018	1829 (91.1)	19 (0.9)	4 (0.2)	155 (7.7)	1919 (95.6)	2007 (100.0)
2019	155 (90.1)	2 (1.2)		15 (8.7)	168 (97.7)	172 (100.0)
2020	2524 (92.8)	24 (0.9)	4 (0.1)	167 (6.1)	1871 (68.8)	2719 (100.0)
2021	1994 (85.8)	85 (3.7)	1 (0.0)	243 (10.5)	1781 (76.7)	2323 (100.0)
2022	162 (83.5)	15 (7.7)		17 (8.8)	154 (79.4)	194 (100.0)
2023	2242 (93.7)	11 (0.5)	29 (1.2)	112 (4.7)	1791 (74.8)	2394 (100.0)
2024	2327 (93.5)	9 (0.4)	37 (1.5)	115 (4.6)	1942 (78.1)	2488 (100.0)
Total	11233 (91.3)	165 (1.3)	75 (0.6)	824 (6.7)	9626 (78.3)	12,297 (100.0)
Year	Male					
2018	1829 (91.1)	19 (0.9)	4 (0.2)	155 (7.7)	1206 (95.6)	2007 (100.0)
2019	155 (90.1)	2 (1.2)		15 (8.7)	105 (97.2)	172 (100.0)
2020	2524 (92.8)	24 (0.9)	4 (0.1)	167 (6.1)	1192 (65.9)	2719 (100.0)
2021	1994 (85.8)	85 (3.7)	1 (0.0)	243 (10.5)	1102 (74.4)	2323 (100.0)
2022	162 (83.5)	15 (7.7)		17 (8.8)	105 (78.9)	194 (100.0)
2023	2242 (93.7)	11 (0.5)	29 (1.2)	112 (4.7)	1127 (74.0)	2394 (100.0)
2024	2327 (93.5)	9 (0.4)	37 (1.5)	115 (4.6)	1270 (76.7)	2488 (100.0)
Total	11233 (91.3)	165 (1.3)	75 (0.6)	824 (6.7)	6107 (76.6)	12,297 (100.0)
Year	Female					
2018	1829 (91.1)	19 (0.9)	4 (0.2)	155 (7.7)	713 (95.6)	2007 (100.0)
2019	155 (90.1)	2 (1.2)		15 (8.7)	63 (98.4)	172 (100.0)
2020	2524 (92.8)	24 (0.9)	4 (0.1)	167 (6.1)	679 (74.5)	2719 (100.0)
2021	1994 (85.8)	85 (3.7)	1 (0.0)	243 (10.5)	679 (80.7)	2323 (100.0)
2022	162 (83.5)	15 (7.7)		17 (8.8)	49 (80.3)	194 (100.0)
2023	2242 (93.7)	11 (0.5)	29 (1.2)	112 (4.7)	664 (76.1)	2394 (100.0)
2024	2327 (93.5)	9 (0.4)	37 (1.5)	115 (4.6)	672 (80.7)	2488 (100.0)
Total	11233 (91.3)	165 (1.3)	75 (0.6)	824 (6.7)	3519 (81.3)	12,297 (100.0)

(89.9%), while diabetes mellitus (24.9%), and previous stroke (10.1%) were less common. A history of myocardial infarction was reported in approximately one-third of patients (Table 3).

Patients who died were older (72.8 ± 11.8 vs 65.3 ± 11.7 years) and showed markedly worse clinical and laboratory profiles, including higher heart rates, substantially shorter hospital stays, lower systolic and diastolic blood pressure, and reduced hemoglobin levels. Indicators of inflammation, renal dysfunction, and metabolic stress—such as WBC count, BUN, creatinine, glucose, and troponin—were all elevated among those who died. Ejection fraction was also significantly lower, reflecting more severe cardiac impairment. Differences between STEMI and NSTEMI patients were clinically relevant: STEMI patients were younger and had markedly higher troponin levels and slightly lower blood pressure, while NSTEMI patients demonstrated higher glucose and C-reactive protein (CRP) levels. Sex-specific patterns

Table 2 Summary of Patient Demographic and Hospitalization Indicators by Year (2018–2024)

Year	Sex	Age	Length of Stay	Cost in Dollars
2018	Male	60.49±11.28	10.84±4.43	1529.01±1055.37
	Female	69.77±10.63	10.56±4.82	1202.3±924.58
	Total	63.94±11.92	10.74±4.58	1407.57±1020.79
2019	Male	61.95±12.29	11.31±4.92	1465.03±835.49
	Female	71.17±9.67	10.38±4.61	1048.75±828.74
	Total	65.38±12.2	10.97±4.82	1310.13±854.72
2020	Male	59.21±10.4	8.48±3.4	1346.7±1078.3
	Female	68.53±10.49	8.59±3.71	1301.53±1157.17
	Total	62.33±11.32	8.52±3.51	1331.57±1105.34
2021	Male	59.33±10.75	8.87±3.54	1618.27±1177.67
	Female	68.95±10.7	8.27±3.67	1429.5±1071.7
	Total	62.81±11.68	8.65±3.6	1549.93±1143.82
2022	Male	61.79±10.96	9.7±4.67	1651.02±1291.82
	Female	70.21±8.88	8.25±3.4	1340.35±921.19
	Total	64.44±11.05	9.24±4.35	1553.34±1194.18
2023	Male	60.52±11.22	9.24±3.69	1896.68±1349.09
	Female	68.5±11.08	9.22±3.66	1851.57±1382.92
	Total	63.43±11.81	9.23±3.68	1880.25±1361.4
2024	Male	60.8±11.17	9.97±4.27	2057.96±1326.21
	Female	69.3±10.85	9.32±4.61	1859.01±1292.3
	Total	63.65±11.76	9.75±4.4	1991.35±1318.04

Table 3 Clinical Characteristics of Patients with Acute Myocardial Infarction

Variables		n (%)
Sex	Male	1162 (62.3)
	Female	704 (37.7)
MI	MI with elevation	770 (41.3)
	MI without elevation	1096 (58.7)
Outcome	Alive	1746 (93.6)
	Died	120 (6.4)
Hypertension	No	188 (10.1)
	Yes	1678 (89.9)

(*Continued*)

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Table 3 (Continued).

Variables		n (%)
Diabetes	No	1402 (75.1)
	Yes	464 (24.9)
Stroke history	No	1678 (89.9)
	Yes	188 (10.1)
Myocardial infarction history	No	1265 (67.8)
	Yes	601 (32.2)
Complications	No	1658 (88.9)
	Cardiac arrest	56 (3.0)
	Cardiogenic shock	87 (4.7)
	Pulmonary edema	65 (3.5)
Killip classification	1	284 (15.2)
	2	1176 (63.0)
	3	238 (12.8)
	4	168 (9.0)

were also evident: females were older (71.7 ± 10.1 vs 62.2 ± 11.5 years) and had lower hemoglobin (129.0 ± 18.2 vs 143.5 ± 18.5 g/L) and GFR (68.3 ± 33.1 vs 86.5 ± 39.1 mL/min), whereas males had slightly higher creatinine levels (95.3 ± 44.1 vs 87.0 ± 41.5 μmol/L), (Table 4).

The univariate analysis showed that older age increased the odds (OR = 1.06), and female sex was also associated with higher risk (OR = 1.91). Non-ST-elevation myocardial infarction (NSTEMI) substantially reduced the odds (OR = 0.35). Higher systolic blood pressure, hemoglobin, triglycerides, glomerular filtration rate (GFR), and ejection fraction (EF) were all protective factors, each showing OR values below 1. In contrast, elevated glucose levels increased the odds

Table 4 Clinical and Laboratory Characteristics of AMI Patients by Outcome, Infarction Type, and Sex

Outcome	Alive	Died	STEMI	NSTEMI	Male	Female	Total
Age	65,31±11,75	72,83±11,76	64,53±12,28	66,68±11,53	62,23±11,5	71,67±10,06	65,79±11,89
Heart rate	82,96±19,2	93,08±24,08	81,32±17,21	85,22±21,13	82,72±19,59	85,09±19,8	83,61±19,7
BMI -Body Mass Index	28,29±5,02	27,98±4,58	27,95±4,75	28,49±5,15	27,84±4,75	28,97±5,31	28,27±4,99
LOH – *Length of hospitalization*	11,87±3,69	3,82±3,91	11,48±4,78	11,26±3,73	11,59±4,21	10,96±4,14	11,35±4,19
SBP (Systolic Blood Pressure)	131,75±25,25	110,34±25,32	123,51±22,96	135,2±26,57	129,56±25,25	131,72±26,61	130,38±25,79
DAD (Dyastolic Blood Pressure)	81,95±21,18	69,76±17,62	77,85±13,16	83,49±25,07	80,93±12,64	81,56±30,44	81,17±21,18
Hemoglobin	138,83±18,98	126,75±25,61	140,09±19,06	136,62±20,01	143,54±18,53	128,99±18,15	138,05±19,69
Platelets	245,3±67,92	264,95±131,22	252,09±70,52	242,68±75,72	241,72±75,24	254,56±70,54	246,56±73,74
WBC – White blood cell	9,64±3,69	11,71±4,51	10,73±3,75	9,11±3,66	9,79±3,68	9,76±3,94	9,78±3,78
Neutrophils	66,52±12,3	73,37±12,3	68,51±12,68	65,86±12,1	66,96±11,85	66,96±13,28	66,96±12,41

(*Continued*)

Table 4 (Continued).

Outcome	Alive	Died	STEMI	NSTEMI	Male	Female	Total
Lymphocytes	23,17±10,35	18,33±10,33	21,81±10,77	23,6±10,09	22,87±10,39	22,83±10,46	22,86±10,41
Protein	68,44±6,59	66,63±7,24	68,63±6,73	68,11±6,59	68,22±6,61	68,5±6,72	68,33±6,65
Blood urea nitrogen (BUN)	6,4±2,84	9,97±7,9	6,39±3,78	6,79±3,29	6,4±3,14	7±4,01	6,63±3,51
Creatinine	89,7±35,92	128,13±95,24	90,06±43,24	93,66±43,31	95,29±44,07	87,03±41,53	92,17±43,3
Glucose	8,3±4,2	11,34±6,42	9,22±5,02	7,99±3,9	7,86±3,91	9,55±5,03	8,5±4,44
K – Potassium	3,96±0,61	4,05±0,79	3,94±0,69	3,98±0,58	3,97±0,6	3,96±0,66	3,97±0,63
Mg – Magnesium	0,84±0,16	0,82±0,13	0,83±0,15	0,84±0,16	0,83±0,15	0,84±0,16	0,84±0,15
ALT – Alanine aminotransferase	32,92±45,88	170,27±646,75	44,5±151,88	39,82±185,85	42,6±191,23	40,35±136,55	41,75±172,61
AST – Aspartate aminotransferase	48,84±110,9	184,32±467,23	70,93±170,35	48,16±156,88	56,23±149,47	59,73±183,04	57,55±162,91
Bilirubin – Total bilirubin	14,88±8,95	16,92±12,4	14,3±8,42	15,51±9,71	15,69±10,11	13,9±7,39	15,01±9,22
Cholesterol – Total cholesterol	5,18±1,49	5,05±1,48	5,33±1,42	5,07±1,53	5,02±1,4	5,44±1,6	5,17±1,49
LDL-C – Low-density lipoprotein cholesterol *(LPNP)*	1,14±0,3	1,14±0,39	1,15±0,31	1,13±0,3	1,09±0,29	1,22±0,32	1,14±0,31
HDL-C – High-density lipoprotein cholesterol *(LPVP)*	3,62±1,16	3,54±1,16	3,75±1,15	3,53±1,16	3,53±1,11	3,76±1,24	3,62±1,16
TG – Triglycerides	1,87±1,29	1,53±0,86	1,87±1,17	1,83±1,34	1,85±1,24	1,85±1,32	1,85±1,27
GFR – Glomerular filtration rate	81,19±37,72	57±34,75	82,23±40,31	77,81±36,19	86,49±39,11	68,32±33,14	79,63±38
Troponin I/T – Cardiac troponin	14,76±36,82	27,88±37,73	31,55±51,15	4,4±13,84	16,46±30,65	14,19±45,6	15,6±37,01
Fibrinogen	4,26±20,28	3,94±1,63	3,99±3,53	4,42±25,44	4,43±24,75	3,93±3,08	4,24±19,62
C-reactive protein	8,35±13,72	13,23±13,14	7,94±10,21	9,16±15,73	8,43±13,3	9,04±14,43	8,66±13,73
Ejection fraction	49,1±14,07	38,61±12,95	47,42±13,39	49,14±14,75	48,02±14,26	49,1±14,17	48,43±14,23

Abbreviations: STEMI, ST-elevation myocardial infarction; NSTEMI, Non–ST-elevation myocardial infarction.

(OR = 1.10). After adjustment for all covariates, several variables remained significant independent predictors. Age continued to increase the odds (AOR = 1.03), whereas NSTEMI independently reduced risk (AOR = 0.43). Systolic blood pressure, hemoglobin, GFR, and ejection fraction retained their protective effects, although attenuated in the multivariable model. Glucose also remained a significant risk factor (AOR = 1.06). Female sex and triglycerides lost statistical significance, suggesting confounding effects (Table 5).

Discussion

Clinical improvement exceeded 90% in most years from 2018–2024, but declined in 2021–2022, coinciding with the COVID-19 pandemic. This likely reflects disrupted healthcare delivery, delayed patient presentation, and greater severity

Table 5 Association Between Clinical Variables and Outcome in Univariate and Multivariate Analysis

Variables	p	OR (95% CI)	p	AOR (95% CI)
Age (years)	<0.001	1.06 [1.04;1.08]	0.004	1.03 [1.01;1.06]
Sex (female)	<0.001	1.91 [1.31;2.76]	0.889	0.97 [0.61;1.54]
Myocardial infarction (non-ST-elevation)	<0.001	0.35 [0.24;0.52]	<0.001	0.43 [0.28;0.67]

(*Continued*)

Table 5 (Continued).

Variables	p	OR (95% CI)	p	AOR (95% CI)
SBP (Systolic Blood Pressure)	<0.001	0.95 [0.94;0.96]	<0.001	0.97 [0.96;0.98]
Hemoglobin	<0.001	0.97 [0.96;0.98]	<0.001	0.98 [0.97;0.99]
Glucose	<0.001	1.10 [1.07;1.14]	0.001	1.06 [1.03;1.1]
TG (Triglycerides)	0.004	0.74 [0.60;0.91]	0.131	0.83 [0.66;1.06]
GFR (Glomerular Filtration Rate)	<0.001	0.98 [0.98;0.99]	0.011	0.99 [0.98;1]
EF (Ejection Fraction)	<0.001	0.95 [0.94;0.96]	<0.001	0.96 [0.95;0.98]

Abbreviations: OR, Odds Ratio; AOR, Adjusted odd ratio.

at admission. Prior systematic reviews show that COVID-19 can cause acute and long-term cardiovascular complications, including myocardial injury, myocarditis, arrhythmias, heart failure, and ischemic events, some of which persist as part of Long COVID.[9,10] These disruptions highlight the vulnerability of healthcare systems during large-scale crises and underscore the need for strengthened organizational preparedness, rapid system coordination, and resilient care pathways to mitigate long-term consequences of future public health emergencies. They may also have disproportionately affected patients with complex cardiovascular profiles, thereby amplifying existing age- and comorbidity-related risk patterns.[11]

Clear sex differences were observed in AMI presentation. Female patients presented 7–10 years later than male patients and exhibited lower hemoglobin levels, reduced GFR, and distinct metabolic profiles, findings consistent with international evidence indicating later onset of AMI and a greater comorbidity burden among females.[12] Although unadjusted outcomes are typically worse in females, our multivariable analysis identified age, rather than sex, as the independent predictor of mortality, suggesting that apparent sex disparities are largely attributable to age and comorbidity differences. Furthermore, despite previous reports of longer hospitalizations among females, the length of stay in our cohort did not differ significantly between sexes. Differences in symptomatology and underlying pathophysiology were also pronounced. Females are more frequently presented with atypical or prodromal symptoms, experienced delays in seeking care, and exhibited non-obstructive or microvascular disease patterns (eg, MINOCA, SCAD, or coronary vasospasm), whereas males more commonly demonstrated obstructive coronary disease and silent infarctions.[13] These patterns highlight the need for sex-specific diagnostic awareness, particularly given the increasing AMI incidence and disproportionately worse outcomes reported among younger female populations.[8] Moreover, even though females generally spend more time in hospitals due to later presentation of AMI compared with males, in our study the length of stay was essentially the same between the sexes. Since 2018, the rise in hospitalization costs has been driven primarily by inflation and the increasing cost of medical services.[14]

We found that Kazakh patients who died had more severe clinical presentations, including hypotension, anemia, renal impairment, metabolic dysregulation, and markedly elevated troponin. These findings align with established predictors of mortality in both obstructive MI and MINOCA, reinforcing that the severity of myocardial injury and systemic stress—not the presence of obstructive CAD alone—is the primary determinant of prognosis.[15] Consistent with this, previous clinical studies have shown that elevated lipoprotein(a) levels are associated with greater coronary artery disease severity and an increased risk of acute myocardial infarction. Findings from a predominantly male South-East Asian cohort further support the role of metabolic and lipid-related factors in adverse cardiovascular outcomes.[16,17] Early recognition of multi-organ involvement and rapid stabilization are therefore critical.

Finally, STEMI and NSTEMI patients showed distinct biological profiles. STEMI patients were younger with significantly higher troponin levels, reflecting extensive necrosis due to acute coronary occlusion, whereas NSTEMI patients had higher glucose and CRP levels, consistent with metabolic stress and systemic inflammation. These differences emphasize the need for individualized assessment and management strategies tailored to the underlying mechanism of each AMI subtype.

Strengths and Limitations

This study has several notable strengths. First, it provides the largest and most comprehensive analysis to date of AMI outcomes in Kazakhstan, combining a national 7-year trend evaluation with detailed clinical data from a specialized cardiology center. Second, the dual-stage study design allows for both macro-level assessment of hospitalization outcomes and micro-level identification of patient-level predictors, offering a uniquely integrated perspective. Third, the work uses real-world clinical data, including demographic, hemodynamic, laboratory, and echocardiographic parameters, enabling robust multivariable modeling that reflects actual practice conditions. Fourth, the study contributes novel regional evidence regarding sex differences, metabolic determinants, and organ dysfunction patterns in AMI—areas where data from Central Asia are scarce. Finally, by examining the COVID-19 era, the study provides valuable insight into system-level vulnerabilities and the impact of global disruptions on cardiovascular outcomes in a middle-income country.

This study has several important limitations. First, its retrospective design introduces inherent risks of missing data, documentation variability, and residual confounding despite multivariable adjustment. Second, the single-center analysis in Stage 2 may limit generalizability to other regions of Kazakhstan with different healthcare capacities and population characteristics. Third, the dataset lacked key variables—such as time-to-presentation, pre-hospital delays, treatment strategies (PCI, thrombolysis, or medical therapy), and medication adherence—preventing a full evaluation of care pathways and treatment effects. Important psychosocial and behavioral factors, including socioeconomic status, education, symptom recognition, and health-seeking behavior, were also unavailable. Additionally, long-term outcomes such as 30-day or 1-year mortality and rehospitalizations could not be assessed because the study was limited to in-hospital data. Finally, some laboratory and echocardiographic parameters were missing for a subset of patients, which may influence effect estimates.

This study identifies several priorities for improving AMI care in Kazakhstan. Strengthening early detection and risk stratification, particularly in older adults and patients presenting with hemodynamic or metabolic instability, should be a central focus, supported by standardized assessment protocols in both primary and emergency care. Given the pronounced age differences and atypical presentations among female patients, sex-specific diagnostic pathways, clinician training, and public awareness campaigns are needed to reduce delays and improve early recognition. The rise in hospitalization costs and the impact of the COVID-19 pandemic underscore the need to enhance system resilience through investments in digital health tools, telecardiology, and coordinated emergency response systems. National policies should support continuous surveillance of AMI outcomes through robust registries to identify emerging trends and care gaps. Clinically, structured post-discharge follow-up, including metabolic control, renal monitoring, and cardiac rehabilitation, should be expanded to strengthen secondary prevention. Ensuring equitable access to evidence-based therapies and specialized cardiac services across regions remains essential. Finally, future research should incorporate long-term outcomes, treatment strategies, medication adherence, and social determinants of health. Multicenter collaborations within Kazakhstan and across Central Asia would provide more representative data and guide tailored interventions.

Conclusion

This study provides a comprehensive assessment of AMI trends and predictors in Kazakhstan, with in-hospital mortality as the primary outcome measure, demonstrating that COVID-19–related disruptions significantly affected clinical outcomes. Although clear sex differences in presentation were observed, age was the only independent predictor of mortality, while hemodynamic instability, renal impairment, metabolic dysregulation, and elevated troponin collectively underscored the central role of multi-organ stress and myocardial injury severity in driving in-hospital death. These findings emphasize the importance of early risk stratification, rapid stabilization, and a resilient healthcare system to ensure high-quality AMI care.

Declarations

The study was approved by the Local Ethical Committee of the Kazakh National Medical University (No. 3 [109], March 31, 2021). Due to the retrospective nature of the study and the use of previously collected, fully anonymized

electronic medical record data, with no direct contact or interaction with patients, the requirement for written informed consent was waived by the ethics committee. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki.

Data Sharing Statement

The data and materials supporting the findings of this study are available from the corresponding author upon reasonable request.

Consent for Publication

All authors consent for publication.

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