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Original Article

Comparative clinical outcomes and mortality risk in coronary artery bypass grafting, valve surgeries, and percutaneous interventions

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Abstract: Objectives: Coronary artery disease and valvular heart disease are leading causes of mortality globally. This study aimed to investigate the correlation between expected mortality rates (EMRs) and observed mortality rates (OMRs) for common cardiac interventions using recent national data on percutaneous coronary intervention (PCI), coronary artery bypass grafting (CABG), and cardiac valve surgeries. Methods: This multi-institutional, retrospective observational study analyzed in-hospital/30-day mortality outcomes for 106,836 patients who underwent PCI, CABG, or cardiac valve procedures across 64 non-federal hospitals in New York State between December 2012 and November 2015. The procedures included emergency and non-emergency PCI, CABG, valve or valve-CABG surgeries, and transcatheter aortic valve replacement (TAVR). Results: Among the 106,836 patients, a 3.21% 30-day mortality rate was observed (n=3,436). To assess the disparity between OMR and EMR, a one-sample t-test was performed. Effect sizes were determined using Cohen's d and Hedges' correction. With a 95% confidence interval, the t-value for the OMR (mean difference =2.037±1.728, CI: 1.95-2.12) was 47.270, whereas the EMR (mean difference =1.930±1.284, CI: 1.86-1.99) yielded a t-value of 60.279. The OMR was significantly greater than the EMR (P<0.001). Conclusion: The OMR was significantly greater than the EMR across all cardiac procedures, suggesting potential influences from patient demographics, comorbidities, and variations in hospital practices. Further research is needed to understand these factors and improve the quality of cardiac care.

Keywords: Percutaneous coronary intervention, coronary artery bypass graft, valve surgery, coronary artery disease, transcatheter aortic valve replacement, expected mortality rate, observed mortality rate, coronary artery disease, myocardial infarction, risk-adjusted mortality rate, left main coronary artery

Introduction

Coronary artery disease (CAD) and valvular heart disease continue to be the leading causes of mortality worldwide. In the United States, CAD is responsible for one in every six deaths, with an American suffering a coronary event every 25 seconds and dying from it every minute on average [1].

The Coronary Artery Bypass Grafting (CABG) program refers to a structured clinical approach involving preoperative risk assessment, surgical intervention, and postoperative management to optimize patient outcomes. It integrates standardized protocols for patient selection, perioperative care, and long-term follow-up to enhance surgical success and reduce complications.

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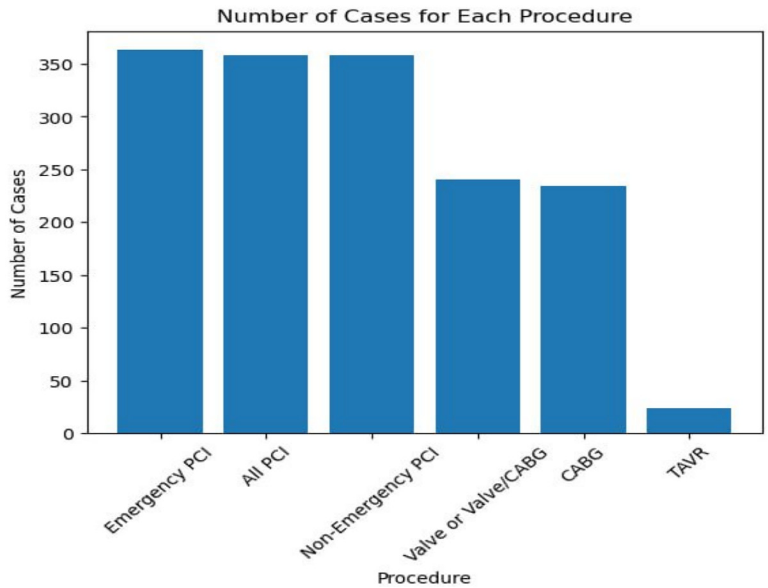

Figure 1. Number of cases for each procedure.

Coronary revascularization is the primary treatment for unprotected left main coronary artery (ULMCA) disease, with coronary artery bypass grafting (CABG) surgery traditionally being the standard approach. However, recent evidence indicates that percutaneous coronary intervention (PCI) can be a noninferior option for certain patient populations [2, 3].

CABG and PCI differ significantly in their potential to reduce the incidence of myocardial infarctions (MIs). With its focus on flow-limiting lesions, most MIs occur at sites of non-flow-limiting stenosis, suggesting that the incidence of new MIs will not be greatly reduced with PCI. In contrast, CABG may offer "collateralization" through the bypass of multiple coronary lesions that can prevent MIs caused by plaque rupture or rapid progression of plaques that are not flow-limiting at the outset [4, 5].

There is also a need to evaluate outcomes for emergency PCI and PCI. These subcategories represent differing clinical scenarios with unique challenges and risk profiles [6]. Emergency PCI is typically performed in acute settings, such as during a myocardial infarction [7], whereas non-emergency PCI is planned and executed under more controlled circumstances [8].

Furthermore, combined valve/CABG surgeries and transcatheter aortic valve replacement (TAVR) procedures are integral components of contemporary cardiac care. Combined valve/CABG surgeries address both coronary artery disease and valvular dysfunction in a single procedure, presenting unique complexities and risks [9]. TAVR, an innovative minimally invasive procedure, has emerged as a crucial alternative for high-risk patients ineligible for traditional valve surgery [10].

While combined valve/CABG surgery allows the simultaneous correction of both coronary and valvular disorders, it is associated with greater procedural complexity, extended surgical durations, and an increased risk of perioperative complications, including acute kidney injury and atrial fibrillation. However, the procedure might lead to long-term advantages, such as sustained hemodynamic improvement and a reduced need for reintervention [10]. On the other hand, TAVR provides a less invasive option, which is especially beneficial for individuals with severe aortic stenosis who are at high or prohibitive surgical risk [11]. Studies have shown its noninferiority to surgery in intermediate-risk patients, with advantages such as lower transfusion requirements and a reduced incidence of acute kidney injury [12, 13]. Nevertheless, TAVR has been associated with higher rates of residual aortic regurgitation and the need for pacemaker implantation, potentially affecting long-term outcomes [12].

Whereas there are many investigations into individual procedural outcomes, there is a great need for comprehensive studies comparing mortality rates across cardiac intervention modalities using more nuanced risk-adjustment methodologies.

This study aims to conduct a rigorous, multi-institutional analysis of cardiac intervention outcomes, providing unprecedented insights into mortality risk stratification and procedural performance across diverse cardiac intervention modalities.

Table 1. In-hospital and 30-day observed, expected, and risk-adjusted mortality rates for PCI in New York State, 2015

Hospitals	Cases	Deaths	All Cases			95% CI for RAMR	Non-Emergency	
			OMR	EMR	RAMR		Cases	RAMR
Albany Med. Ctr	695	18	2.59	1.35	2.18*	(1.29, 3.45)	516	1.52
Arnot Ogden Med Ctr	336	1	0.30	0.93	0.37	(0.00, 2.03)	249	0.53
Bassett Medical Center	538	5	0.93	1.11	0.95	(0.31, 2.22)	442	0.24
Bellevue Hospital Ctr	415	7	1.69	1.88	1.02	(0.41, 2.10)	313	0.52
Bronx-Lebanon-Concourse	137	5	3.65	2.52	1.65	(0.53, 3.84)	70	0.00
Brookdale Univ Hosp Med Ctr	183	2	1.09	1.55	0.80	(0.09, 2.90)	112	0.55
Brookhaven Memorial	352	5	1.42	1.04	1.56	(0.50, 3.63)	272	1.95
Buffalo General Hosp	1522	22	1.45	1.17	1.40	(0.88, 2.12)	1087	0.82
Cayuga Med Ctr Ithaca	160	2	1.25	1.93	0.74	(0.08, 2.66)	81	0.00
Champ-Valley Phys Hosp	572	8	1.40	0.93	1.71	(0.74, 3.37)	437	1.37
Crouse Hospital	311	6	1.93	1.20	1.84	(0.67, 4.00)	220	1.18
Ellis Hospital	470	9	1.91	1.22	1.78	(0.81, 3.39)	278	1.85
Elmhurst Hospital Ctr	427	2	0.47	0.89	0.60	(0.07, 2.16)	305	0.00
Faxton - St. Luke’s	157	3	1.91	1.22	1.78	(0.36, 5.19)	131	0.89
Glens Falls Hospital	180	0	0.00	1.19	0.00	(0.00, 1.94)	108	0.00
Good Sam - Suffern	575	10	1.74	1.80	1.10	(0.53, 2.02)	399	0.59
Good Sam - West Islip	1059	3	0.28	0.79	0.41	(0.08, 1.19)	969	0.42
Huntington Hospital	502	4	0.80	1.07	0.85	(0.23, 2.17)	395	0.24
Jamaica Hosp Med Ctr	302	1	0.33	1.50	0.25	(0.00, 1.40)	157	0.00
Lenox Hill Hospital	1856	15	0.81	0.80	1.15	(0.65, 1.90)	1741	0.81
Long Island Jewish MC	1039	12	1.15	0.94	1.40	(0.72, 2.44)	903	1.28
Lutheran Medical Ctr	187	2	1.07	2.04	0.60	(0.07, 2.15)	144	0.35
Maimonides Medical Ctr	1056	8	0.76	1.89	0.46**	(0.20, 0.90)	832	0.40
Mercy Hospital	1108	18	1.62	1.11	1.66	(0.98, 2.62)	860	1.12
Montefiore - Moses	944	7	0.74	1.1	0.76	(0.31, 1.57)	799	0.40
Montefiore - Weiler	584	8	1.37	1.3	1.2	(0.52, 2.36)	442	0.00**
Mount Sinai Beth Israel	1721	12	0.7	1.01	0.79	(0.41, 1.37)	1591	0.43
Mount Sinai Hospital	3610	14	0.39	0.74	0.6**	(0.33, 1.00)	3483	0.37**
Mount Sinai St. Lukes	489	12	2.45	1.61	1.74	(0.90, 3.03)	413	1.15
NYP-Brooklyn Methodist	1251	23	1.84	0.95	2.19*	(1.39, 3.29)	1130	1.08
NYP-Columbia Presby	2360	17	0.72	0.9	0.91	(0.53, 1.45)	2227	0.65
NYP-Lawrence Hospital	113	0	0	0.95	0	(0.00, 3.90)	93	0.00
NYP-Queens	778	10	1.29	0.77	1.9	(0.91, 3.49)	623	1.17
NYP-Weill Cornell	1056	11	1.04	1.23	0.96	(0.48, 1.72)	946	0.48
NYU Hospitals Center	1634	6	0.37	0.75	0.55	(0.20, 1.20)	1539	0.42
NYU Winthrop Hospital	1041	9	0.86	1.41	0.7	(0.32, 1.32)	887	0.49
North Shore Univ Hosp	2370	23	0.97	1.19	0.93	(0.59, 1.39)	2034	0.72
Olean General Hosp	149	3	2.01	1.54	1.48	(0.30, 4.34)	71	0.00
Orange Regional Med Ctr	508	4	0.79	1.09	0.82	(0.22, 2.11)	350	0.84
Richmond Univ Med Ctr	119	1	0.84	0.96	0.99	(0.01, 5.53)	89	2.20
Rochester General Hosp	1625	21	1.29	1.15	1.28	(0.79, 1.95)	1301	0.77
Samaritan Hospital	215	2	0.93	1.09	0.97	(0.11, 3.51)	119	1.41
Saratoga Hospital	87	3	3.45	1.41	2.78	(0.56, 8.11)	71	2.21
South Nassau Com. Hosp	420	10	2.38	1.1	2.46*	(1.18, 4.52)	300	2.28*
Southside Hospital	703	6	0.85	0.96	1.01	(0.37, 2.21)	604	0.99

St. Barnabas Hospital	164	4	2.44	1.03	2.69	(0.72, 6.90)	129	0.96
St. Catherine of Siena	299	3	1	1.33	0.86	(0.17, 2.50)	234	0.42
St. Elizabeth Med Ctr	763	14	1.83	1.27	1.64	(0.90, 2.75)	616	1.14
St. Francis Hospital	2768	37	1.34	1.04	1.46	(1.03, 2.01)	2592	0.94
St. Joseph's Hospital	1960	26	1.33	1.35	1.11	(0.73, 1.63)	1505	0.96
St. Lukes Cornwall Hosp	259	3	1.16	1.31	1	(0.20, 2.93)	173	0.56
St. Peters Hospital	856	11	1.29	0.92	1.59	(0.79, 2.84)	659	1.15
Staten Island Univ Hosp	710	5	0.7	0.77	1.04	(0.34, 2.44)	583	0.84
Strong Memorial Hosp	910	14	1.54	1.21	1.45	(0.79, 2.43)	612	1.21
UHS-Wilson Med Ctr	747	11	1.47	1.29	1.3	(0.65, 2.33)	556	0.90
Unity Hospital	282	2	0.71	1.71	0.47	(0.05, 1.70)	207	0.00
Univ. Hosp-Brooklyn	280	5	1.79	2.25	0.9	(0.29, 2.11)	185	0.25
Univ. Hosp-Stony Brook	1431	24	1.68	1.48	1.29	(0.82, 1.92)	1074	0.93
Univ. Hosp-Upstate	186	6	3.23	1.8	2.04	(0.75, 4.44)	106	3.23
Vassar Bros Med Ctr	683	12	1.76	1.62	1.24	(0.64, 2.16)	478	0.62
Westchester Med Ctr	393	7	1.78	1.91	1.06	(0.43, 2.19)	232	0.55
White Plains Hospital	419	4	0.95	1.27	0.86	(0.23, 2.19)	338	0.34
Statewide Total	49035	558	1.14				40412	0.74

*Risk adjusted mortality rate significantly higher than statewide rate based on 95 percent confidence interval. **Risk adjusted mortality rate significantly lower than statewide rate based on 95 percent confidence interval.

Methods

Study population and ethical considerations

The State of New York provides a variety of data, datasets, information, content, files, documents, and materials on the OPEN-NY website (https://data.ny.gov/). This platform promotes the sharing, utilization, and reuse of Open Data (https://data.ny.gov/download/77gx-ii52/application/pdf). Data files are available for download in aggregated form at the hospital and operator levels on the institutional website (https://health.data.ny.gov/). We obtained datasets for "Adult Cardiac Surgery" and "Percutaneous Coronary Interventions (PCIs)" in New York State from 2013-2015 from this website.

This multicenter, retrospective observational study was conducted at 64 non-federal hospitals in New York State, with comprehensive institutional review board approval. The strong methodological approach was strictly followed to ensure adherence to ethical research standards and the maintenance of patient confidentiality.

Study population

The study cohort comprised 106,836 patients who underwent comprehensive cardiac interventions between December 1, 2012, and November 30, 2015. The inclusion criteria were meticulously defined to capture a representative patient population, as follows: (1) Patients who underwent percutaneous coronary interventions (emergency and non-emergency); (2) CABG procedures; (3) Cardiac valve surgeries (isolated and combined); (4) TAVR.

Exclusion criteria: (1) Patients residing outside the United States; (2) Patients with multiple concurrent cardiac procedures within 30-day periods; (3) Patients experiencing cardiogenic shock.

Data collection and management

This study analyzed 40 predefined clinical risk factors, including patient demographics (age, sex, BMI), comorbidities (diabetes, hypertension, renal disease, prior stroke), procedural characteristics (emergency status, surgical complexity), and laboratory values (creatinine, hemoglobin levels). These factors were collected from cardiac catheterization laboratories and validated using multi-source cross-referencing with hospital records.

Data collection involved a comprehensive, standardized approach: 1. Demographic and clinical data acquisition: (1) Approximately 40 detailed risk factors collected for each patient; (2) Information sourced from cardiac catheter-

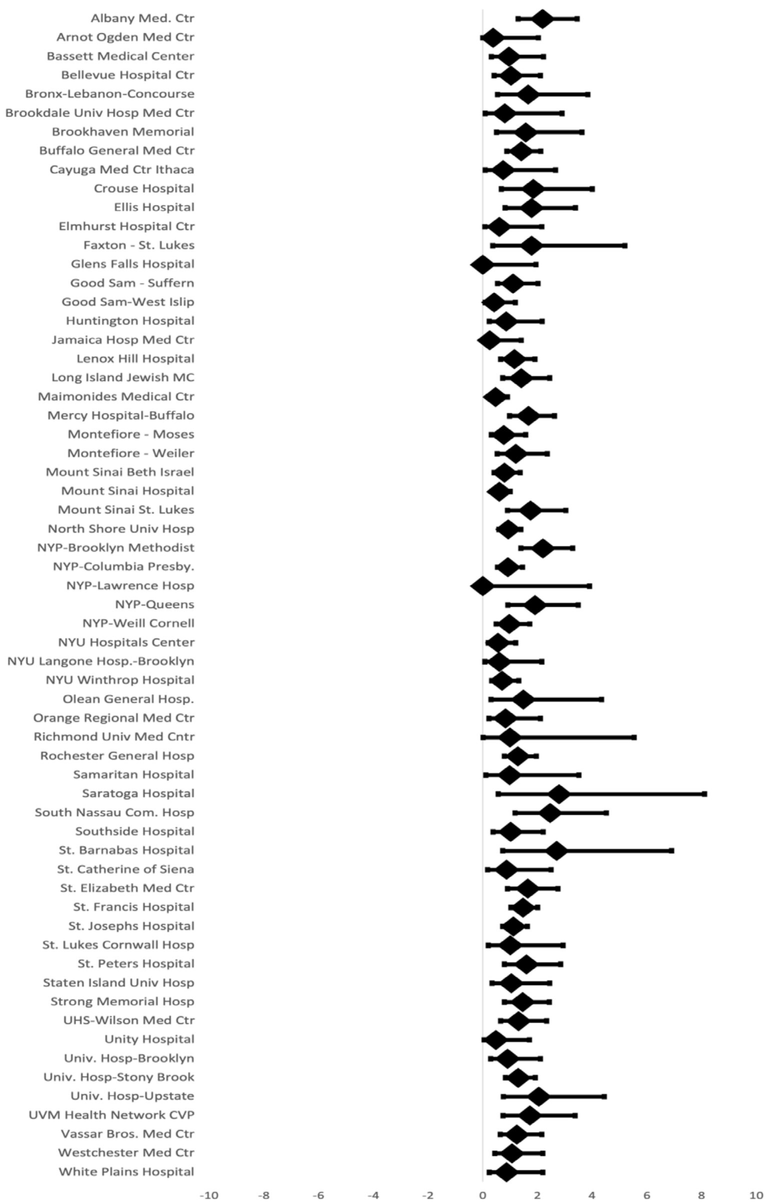

Figure 2. RAMR with 95% confidence intervals for PCI-all cases (year 2015).

ization laboratories; (3) Comprehensive patient characterization, including hospital, physician, and discharge status details. 2. Data validation protocols: (1) Cross-verification through multiple departments of health databases; (2) Detailed medical record reviews for a selected case sample; (3) Rigorous validation processes ensuring consistent data interpretation across participating institutions.

Statistical analysis

Data analysis was carried out in SPSS, STATA, and Python 3 environments to explore the relationships among variables, including estimation of pooled risk ratios and visualizations of the data. For the results to be reported, one-sample t-tests shall be in the form of means ± SDs [SD: standard deviation] at 95% confidence intervals, whereas the effect sizes were derived by Cohen's d with Hedges' correction. A *P*-value <0.05 was considered statistically significant.

Ethical and regulatory compliance

To enhance quality of cardiac interventions, the New York State Department of Health annually publishes aggregated public data on mortality following PCI and cardiac surgery procedures. This research, which relies on data reported at the provider and operator levels, did not require informed consent or approval from a local ethics committee.

Results

A total of 106,836 patients from 64 hospitals in New York State were included in this study based on the defined inclusion criteria. The study examined six types of cardiac procedures (all PCI, CABG, emergency PCI, non-emergency PCI, combined Valve/CABG, and TAVR).

Participant demographics

A total of 106,836 patients from 64 hospitals in New York State met the inclusion criteria and were included in the analysis. The cohort included 49,035 PCI cases (25,735 emergency PCI, 40,412 non-emergency PCI), 8,356 isolated CABG procedures, 22,129 valve or valve/CABG surgeries, and 5,554 TAVR procedures (**Figure 1**).

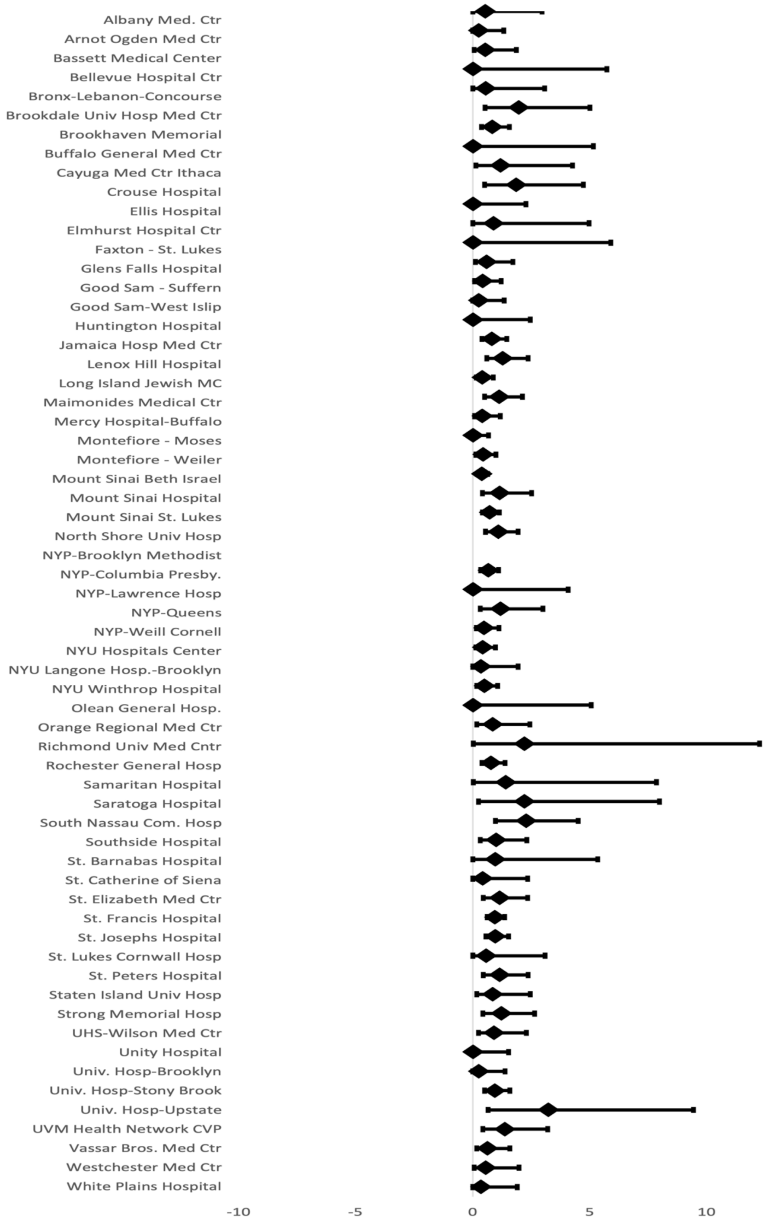

Figure 3. RISK-ADJUSTED MORTALITY RATES with 95% confidence for Non-emergency PCI (year 2015).

General findings

Overall mortality rate: Across all procedures, the 30-day mortality rate was 3.21%, corresponding to 3,436 deaths.

PCI analysis (2015): **Table 1** and **Figure 2** present the PCI mortality results for 62 hospitals: (1) The observed mortality rate (OMR) was 1.14% for 49,035 PCI patients. (2) Range: 0.00% to 3.65%. (3) Expected mortality rate (EMR): 0.74% to 2.52%. (4) Risk-Adjusted Mortality Rates (RAMRs): 0.00% to 2.78%.

Three hospitals (Albany Medical Center, NYP-Brooklyn Methodist, and South Nassau Community Hospital) had RAMRs that were significantly higher than the statewide average, whereas two hospitals (Maimonides Medical Center in Brooklyn and Mount Sinai Hospital) had RAMRs that were significantly lower.

Non-emergency PCI analysis (2015): **Figure 3** shows the results for non-emergency PCI procedures: (1) OMR: The statewide in-hospital/30-day mortality rate for non-emergency cases is 0.74%. (2) Range: 0.00% to 3.23%.

One hospital (South Nassau Community Hospital) had a RAMR that was significantly higher than the statewide average. Two hospitals (Montefiore Medical Center - Weiler Division in Bronx and Mount Sinai Medical Center in Manhattan) had RAMRs that were significantly lower than the statewide rate.

CABG analysis (2015): **Table 2** and **Figure 4** present the CABG surgery results for 38 hospitals: (1) OMR: 1.56% for 8,356 CABG surgeries. (2) Range: 0.00% to 16.67%. (3) EMR: 0.82% to 2.28%. (4) RAMR: 0.00% to 12.60%.

University Hospital - Brooklyn had a significantly higher RAMR compared to the statewide average.

TAVR analysis (2013-2015): **Table 3** and **Figure 5** present the TAVR results for 24 hospitals from 2013 to 2015: (1) OMR: 4.75% for 5,554 TAVR procedures. (2) Range: 0.00% to 8.41%. (3) EMR: 3.44% to 7.45%. (4) RAMR: 0.00% to 8.07%.

One hospital (Mount Sinai Hospital in Manhattan) had a RAMR that was statistically

Table 2. In-hospital and 30-day observed, expected, and risk-adjusted mortality rates for isolated CABG surgery in New York State, 2015 discharges

Hospital	Cases	Deaths	OMR	EMR	RAMR	95% CI for RAMR
Albany Med. Ctr	260	3	1.15	1.66	1.08	(0.22, 3.16)
Arnot Ogden Med Ctr	80	1	1.25	0.82	2.37	(0.03, 13.16)
Bassett Medical Center	74	2	2.70	1.02	4.13	(0.46, 14.91)
Bellevue Hospital Ctr	113	2	1.77	0.95	2.89	(0.32, 10.42)
Buffalo General Hosp	474	10	2.11	1.25	2.62	(1.26, 4.82)
Ellis Hospital	185	4	2.16	1.58	2.12	(0.57, 5.44)
Good Sam - Suffern	108	2	1.85	1.10	2.63	(0.29, 9.48)
Good Sam-West Islip	199	2	1.01	1.39	1.12	(0.13, 4.05)
Lenox Hill Hospital	259	8	3.09	1.84	2.61	(1.12, 5.14)
Long Island Jewish MC	97	0	0.00	1.48	0.00	(0.00, 3.98)
Maimonides Medical Ctr	255	8	3.14	2.28	2.14	(0.92, 4.22)
Mercy Hospital	391	5	1.28	1.42	1.40	(0.45, 3.27)
Montefiore - Moses	176	0	0.00	1.24	0.00	(0.00, 2.61)
Montefiore - Weiler	194	4	2.06	1.41	2.28	(0.61, 5.84)
Mount Sinal Beth Israel	210	1	0.48	1.26	0.59	(0.01, 3.28)
Mount Sinal Hospital	398	5	1.26	1.69	1.16	(0.37, 2.70)
Mount Sinal St. Lukes	146	1	0.68	1.57	0.68	(0.01, 3.78)
NYP-Brooklyn Methodist	110	1	0.91	1.91	0.74	(0.01, 4.12)
NYP-Columbia Presby.	387	8	2.07	2.06	1.56	(0.67, 3.08)
NYP-Queens	117	0	0.00	0.83	0.00	(0.00, 5.88)
NYP-Weill Cornell	196	2	1.02	1.56	1.02	(0.11, 3.69)
NYU Hospitals Center	183	2	1.09	1.18	1.45	(0.16, 5.22)
NYU Winthrop Hospital	208	1	0.48	1.32	0.57	(0.01, 3.15)
North Shore Univ Hosp	421	4	0.95	1.70	0.87	(0.23, 2.23)
Rochester General Hosp	355	8	2.25	1.60	2.19	(0.94, 4.31)
Southside Hospital	170	1	0.59	0.97	0.95	(0.01, 5.27)
St. Elizabeth Med Ct	166	5	3.01	1.57	2.98	(0.96, 6.94)
St. Francis Hospital	481	9	1.87	1.88	1.54	(0.70, 2.93)
St. Josephs Hospital	382	6	1.57	1.59	1.54	(0.56, 3.36)
St. Peters Hospital	344	1	0.29	1.05	0.43	(0.01, 2.39)
Staten Island Univ Hosp	185	4	2.16	1.83	1.84	(0.49, 4.70)
Strong Memorial Hosp	203	2	0.99	1.75	0.88	(0.10, 3.17)
UHS-Wilson Med Ctr	142	2	1.41	1.34	1.63	(0.18, 5.90)
Univ. Hosp-Brooklyn	36	6	16.67	2.06	12.6*	(4.60, 27.43)
Univ. Hosp-Stony Brook	297	3	1.01	1.88	0.84	(0.17, 2.45)
Univ. Hosp-Upstate	31	1	3.23	1.06	4.75	(0.06, 26.44)
Vassar Bros. Med Ctr	174	2	1.15	1.57	1.14	(0.13, 4.10)
Westchester Med Ctr	149	4	2.68	2.15	1.94	(0.52, 4.97)
Statewide Total	8356	130	1.56			

higher than the statewide rate, whereas one hospital (NY Presbyterian at Columbia in Manhattan) had a RAMR that was statistically lower.

The provided image, a forest plot, shows the effect sizes and 95% confidence intervals for different hospitals performing TAVR between 2013 and 2015. Hospitals such as Albany Medical Center, Buffalo General Medical Center, and others are included, demonstrating the overall effect size and variation among institutions.

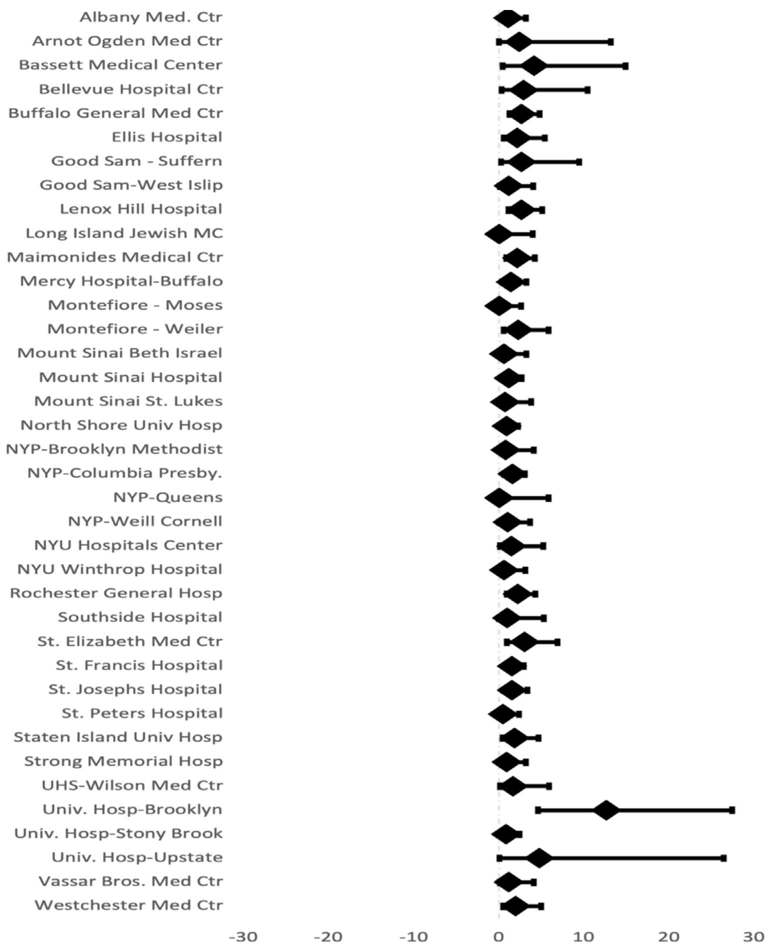

Figure 4. RISK-ADJUSTED MORTALITY RATES with 95 percent confidence interval for CABG (year 2015).

Emergency PCI analysis (2013-2015): **Figure 6** shows the results for emergency PCI procedures between 2013 and 2015: (1) OMR: The statewide in-hospital/30-day mortality rate for emergency PCI cases during this period was 3.04%. (2) Range: 0.00% to 7.20%. (3) RAMR: 0.00% to 6.70%.

Two hospitals (Buffalo General Hospital and NYP-Brooklyn Methodist Hospital) had RAMRs significantly above the statewide average for emergency cases. Two hospitals (Maimonides Medical Center in Brooklyn and NYU-Winthrop Hospital in Mineola) had RAMRs significantly below the statewide average for emergency cases.

Combined valve/CABG analysis (2013-2015): **Table 4** and **Figure 7** present the results for combined valve-only and valve/CABG surgeries performed at 40 hospitals from 2013 to 2015: (1) OMR: 3.03% for 22,129 combined procedures. (2) Range: 0.00% to 11.11%. (3) EMR: 1.33% to 4.41%. (4) RAMR: 0.00% to 10.88%.

Five hospitals (Mercy Hospital in Buffalo, St. Elizabeth Medical Center in Utica, Strong Memorial Hospital in Rochester, United Health Services - Wilson in Johnson City, and University Hospital - Brooklyn) had RAMRs that were significantly higher than the statewide rate. Four hospitals (Long Island Jewish in New Hyde Park, Maimonides Medical Center in Brooklyn, St. Joseph's Hospital in Syracuse, and Vassar Brothers Medical Center in Poughkeepsie) had significantly lower RAMRs.

Statistical analysis

To assess the difference between OMR and EMR, a one-sample t-test was conducted (**Table 5** and **Figure 8**): (1) OMR: Mean difference =2.037±1.728 (95% CI: 1.95-2.12), t=47.270. (2) EMR: Mean difference =1.930±1.284 (95% CI: 1.86-1.99), t=60.279. (3) Significance: P<0.001 for both OMR and EMR, indicating a significant difference between the observed and expected mortality rates.

Effect sizes: 1. OMR: (1) Cohen's d: 1.178 (95% CI: 1.115-1.242). (2) Hedges' correction: 1.178 (95% CI: 1.114-1.241). 2. EMR: (1) Cohen's d: 1.503 (95% CI: 1.431-1.574). (2) Hedges' correction: 1.502 (95% CI: 1.431-1.573).

These analyses demonstrate that the OMR is significantly greater than the EMR, highlighting the need for further investigations into the factors influencing these rates.

Discussion

Summary of findings

Modern cardiac interventions create a clinical quagmire, as the confluence of factors is deter-

Table 3. In-hospital/30-day observed, expected, and risk-adjusted mortality rates for TAVR in New York State, 2013-2015 (Alphabetically by Hospital)

Hospital	Cases	Deaths	OMR	EMR	RAMR	95% CI for RAMR
Albany Med. Ctr	339	13	3.83	4.19	4.35	(2.31, 7.44)
Buffalo General Hosp	238	9	3.78	4.52	3.97	(1.81, 7.55)
Lenox Hill Hospital	128	8	6.25	4.91	6.05	(2.60, 11.92)
Long Island Jewish MC	141	5	3.55	4.94	3.41	(1.10, 7.96)
Maimonides Medical Ctr	151	7	4.64	4.16	5.29	(2.12, 10.90)
Mercy Hospital	7	0	0.00	5.40	0.00	(0.00, 46.14)
Montefiore - Moses	115	7	6.09	5.24	5.52	(2.21, 11.38)
Montefiore - Weiler	17	1	5.88	3.47	8.07	(0.11, 44.88)
Mount Sinai Hospital	452	33	7.30	4.78	7.26*	(4.99, 10.19)
NYP-Brooklyn Methodist	40	3	7.50	4.73	7.54	(1.52, 22.04)
NYP-Columbia Presby.	959	34	3.55	5.63	2.99**	(2.07, 4.18)
NYP-Weill Cornell	329	16	4.86	4.31	5.37	(3.06, 8.71)
NYU Hospitals Center	322	12	3.73	3.44	5.15	(2.66, 8.99)
NYU Winthrop Hospital	537	20	3.72	4.45	3.97	(2.43, 6.14)
North Shore Univ Hosp	323	16	4.95	4.77	4.94	(2.82, 8.02)
Rochester General Hosp	4	0	0.00	7.45	0.00	(0.00, 58.52)
Southside Hospital	116	4	3.45	3.79	4.33	(1.16, 11.08)
St. Francis Hospital	542	26	4.80	4.87	4.68	(3.06, 6.86)
St. Josephs Hospital	278	18	6.47	4.74	6.50	(3.85, 10.27)
St. Peters Hospital	68	5	7.35	4.33	8.07	(2.60, 18.84)
Strong Memorial Hosp	159	13	8.18	5.20	7.47	(3.97, 12.78)
UHS-Wilson Med Ctr	38	0	0.00	4.19	0.00	(0.00, 10.94)
Univ. Hosp-Stony Brook	107	9	8.41	4.99	8.01	(3.66, 15.21)
Westchester Med Ctr	144	5	3.47	5.55	2.97	(0.96, 6.94)
Statewide Total	5554	264	4.75			

*Risk adjusted mortality rate significantly higher than statewide rate based on 95 percent confidence interval. **Risk adjusted mortality rate significantly lower than statewide rate based on 95 percent confidence interval.

mined to influence patient outcomes and mortality. A landmark comprehensive study of 106,836 patients at 64 non-federal hospitals across New York State provides an unprecedented glimpse into the complex dynamics of risk-adjusted mortality in different cardiac procedures. This study is unique in that all cardiac interventions were studied simultaneously, including all PCI, CABG, valve surgeries and TAVR.

Mortality rate discrepancies and systemic insights

The findings suggest that institutional factors, procedural complexity, and patient-specific variables play a critical role in determining mortality rates. In our view, optimizing patient selection criteria and developing standardized perioperative protocols could mitigate some of the observed disparities. Further, targeted quality improvement initiatives at hospitals with high risk-adjusted mortality rates may help enhance overall patient outcomes.

The statistically significant difference in mortality rates, particularly for Emergency PCI, is a scientifically important finding that contradicts current medical knowledge. A growing body of research demonstrates that the intricate physiological mechanisms involved in emergency cardiac interventions give rise to a distinctive risk profile that is fundamentally different from planned procedures [14]. The increased mortality rates cannot be explained by a single factor but arise from the complex interplay of acute cardiovascular stress, inadequate preprocedural stabilization, and inherent patient vulnerability [15].

Numerous studies have underscored the importance of risk-adjusted mortality rates as

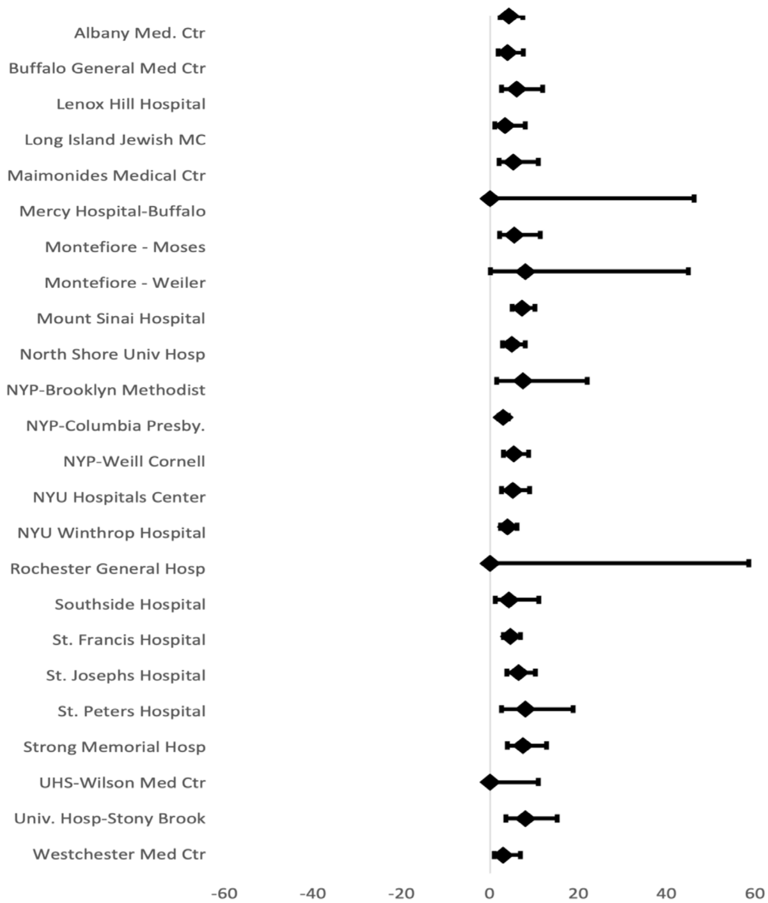

Figure 5. RISK-ADJUSTED MORTALITY RATES with 95 percent confidence interval for TAVR (years 2013-2015).

a benchmark for evaluating hospital performance in cardiac surgeries. For example, an article declared that hospitals with higher volumes of cardiac procedures tend to have lower mortality rates, suggesting a volume-outcome relationship [16]. Despite advancements in surgical techniques and postoperative care, our findings indicate that the observed mortality rates remain higher than expected. This discrepancy could be due to various factors, including patient demographics, comorbidities, and differences in hospital practices.

Institutional performance variations

Our findings dramatically highlight the important impact of institutional practices on surgical outcomes and show that hospital-specific factors can influence patient survival to a great extent. Whereas traditionally, medical performance was assumed to be homogeneous, this research shows considerable variation in risk-adjusted mortality rates among different healthcare institutions. The differences likely stem from differences in the experience of the surgical team, technological capabilities, postoperative care protocols, and quality improvement mechanisms at the institutional level [17, 18].

Adelborg et al. (2017) examined long-term mortality after CABG surgery and reported that patients had a higher mortality rate compared to the general population, particularly within the first 30 days post-surgery [19]. This aligns with our findings, suggesting that immediate postoperative care is crucial in reducing mortality.

Procedural complexity and mortality patterns

Unique mortality rates for the different cardiac procedures, with TAVR at 4.75% and combined valve/CABG at 3.03%, highlight the nuanced complexity of cardiac surgical interventions. Such variations indicate that procedure-specific protocols and specialized expertise are critical in the optimization of patient survival [20]. Subtle differences among interventions further emphasize the need for tailored, precision-based approaches in cardiac surgical care [21].

Conversely, a study published in JAMA Network Open (2023) reported that sex and the presence of postoperative atrial fibrillation significantly influence long-term mortality after cardiac surgery [22]. This study highlighted that specific patient factors could impact outcomes, which may explain some of the variations observed in our study.

Technological and professional development implications

This research compels a fundamental reimagining of cardiac surgical risk assessment and management strategies. Advanced risk prediction models have emerged as promising ave-

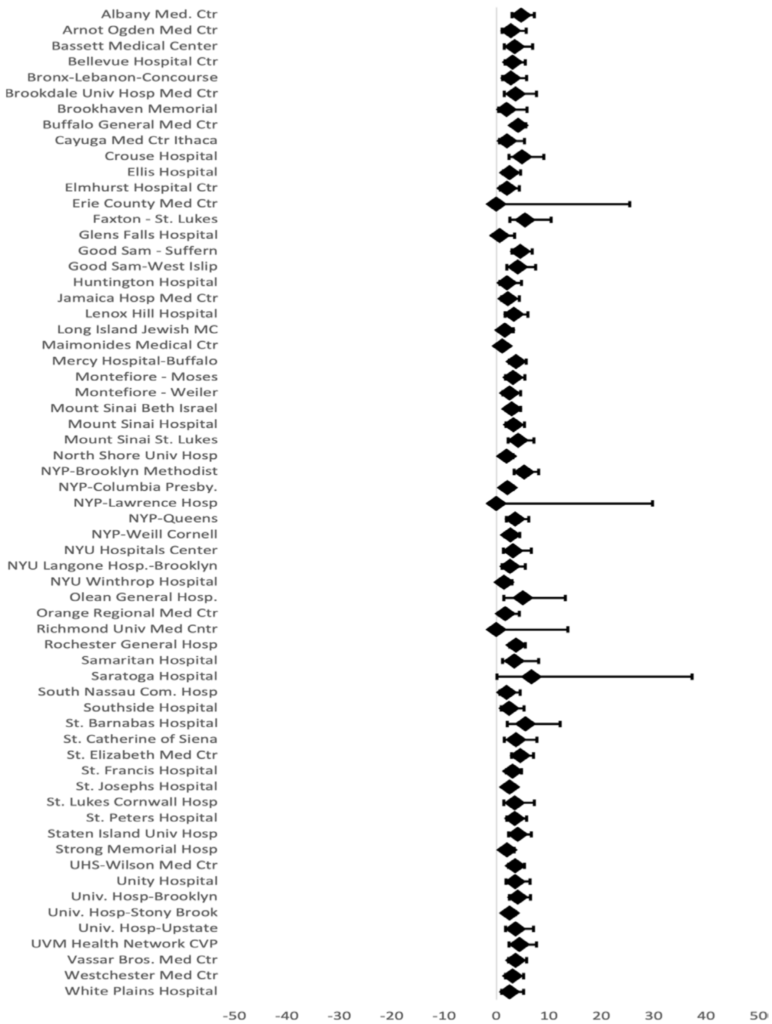

Figure 6. RISK-ADJUSTED MORTALITY RATES with 95 percent confidence interval for emergency (years 2013-2015).

nues for enhancing surgical decision-making, requiring sophisticated algorithms that can integrate multiple patient and institutional variables [23]. The future of cardiac care demands continuous investment in technological infrastructure, surgical team training, and a culture of perpetual learning and professional development.

Additionally, a study by Stanford Medicine (2019) reported that invasive procedures like PCI and CABG did not significantly reduce long-term mortality rates compared to medical therapy alone [24]. This finding differs from our results, suggesting that the benefits of invasive procedures might be more nuanced and dependent on patient selection and procedural timing.

Comparative scientific context

Our findings resonate with and simultaneously challenge existing cardiac surgery research. Previous investigations have confirmed elevated mortality risks within the initial 30 days post-surgery [25], while recent studies have highlighted the nuanced impact of patient-specific factors [26-28]. This research provides a rich, multidimensional framework for understanding the complex interplay between patient characteristics, procedural specifics, and institutional practices.

A comprehensive review by Hardiman et al. (2022) revealed numerous factors affecting mortality after CABG surgery, including patient characteristics, disease severity, and preoperative health status [29]. This review supports our findings by emphasizing the importance of patient-related factors in determining surgical outcomes.

Clinical practice and policy implications

Our findings underscore the necessity for a fundamental change in the integration of procedural risks and institutional capabilities into clinical decision-making for cardiac procedures. Although existing guidelines focus mostly on patient-related factors, our results indicate that institutional performance measurements, including risk-adjusted mortality rates (RAMRs), should play a more significant role in determining referral patterns and quality enhancement strategies. The wide range of RAMRs among hospitals, especially for high-risk procedures such as emergency PCI and combined valve/CABG surgeries, highlights the impact of institutional variables beyond patient selection and clinical performance. These variations indicate differences in hospital preparedness for complications, the efficacy of multidisciplinary team collaboration, and the willingness to follow

Table 4. In-hospital and 30-day observed, expected, and risk-adjusted mortality rates for valve or Valve/CABG surgery in New York State, 2013-2015 discharges

Hospital	Cases	Deaths	OMR	EMR	RAMR	95% CI for RAMR
Albany Med. Ctr	668	27	4.04	2.89	4.25	(2.80, 6.18)
Arnot Ogden Med Ctr	66	2	3.03	1.8	5.12	(0.57, 18.47)
Bassett Medical Center	137	4	2.92	2.23	3.97	(1.07, 10.16)
Bellevue Hospital Ctr	244	3	1.23	2.08	1.79	(0.36, 5.24)
Buffalo General Hosp	779	21	2.70	2.46	3.32	(2.05, 5.08)
Champ.Valley Phys Hosp	21	1	4.76	1.33	10.88	(0.14, 60.52)
Ellis Hospital	284	9	3.17	2.61	3.68	(1.68, 6.99)
Erie County Med Ctr	4	0	0.00	1.89	0.00	(0.00, 100.0)
Good Sam - Suffern	132	6	4.55	2.68	5.15	(1.88, 11.20)
Good Sam-West Islip	147	4	2.72	2.75	3.01	(0.81, 7.69)
Lenox Hill Hospital	444	12	2.70	2.5	3.28	(1.69, 5.74)
Long Island Jewish MC	416	6	1.44	3.75	1.16**	(0.43, 2.54)
Maimonides Medical Ctr	461	11	2.39	4.41	1.64**	(0.82, 2.93)
Mercy Hospital	538	25	4.65	2.27	6.21*	(4.02, 9.17)
Montefiore - Moses	448	21	4.69	3.6	3.95	(2.44, 6.04)
Montefiore - Weiler	340	12	3.53	4.09	2.62	(1.35, 4.57)
Mount Sinai Beth Israel	229	13	5.68	3.06	5.63	(3.00, 9.63)
Mount Sinai Hospital	2151	51	2.37	3.09	2.33	(1.73, 3.06)
Mount Sinai St. Lukes	275	6	2.18	2.67	2.48	(0.91, 5.40)
NYP-Brooklyn Methodist	180	2	1.11	3.68	0.92	(0.10, 3.30)
NYP-Columbia Presby.	2103	55	2.62	3.17	2.50	(1.88, 3.25)
NYP-Queens	101	3	2.97	2.38	3.79	(0.76, 11.07)
NYP-Weill Cornell	1200	28	2.33	3.08	2.30	(1.53, 3.32)
NYU Hospitals Center	1330	25	1.88	1.86	3.07	(1.99, 4.53)
NYU Winthrop Hospital	517	12	2.32	3.05	2.30	(1.19, 4.02)
North Shore Univ Hosp	879	26	2.96	3.53	2.54	(1.66, 3.72)
Rochester General Hosp	1081	39	3.61	3.28	3.33	(2.37, 4.55)
Southside Hospital	362	12	3.31	3.64	2.76	(1.43, 4.83)
St. Elizabeth Med Ctr	288	15	5.21	2.31	6.82*	(3.82, 11.25)
St. Francis Hospital	1474	52	3.53	3.18	3.36	(2.51, 4.41)
St. Josephs Hospital	1356	35	2.58	3.61	2.17**	(1.51, 3.02)
St. Peters Hospital	869	33	3.80	3.09	3.73	(2.57, 5.24)
Staten Island Univ Hosp	171	4	2.34	2.78	2.55	(0.69, 6.53)
Strong Memorial Hosp	629	30	4.77	2.54	5.69*	(3.84, 8.12)
UHS-Wilson Med Ctr	230	14	6.09	2.06	8.96*	(4.89, 15.03)
Univ. Hosp-Brooklyn	90	10	11.11	3.24	10.41*	(4.98, 19.14)
Univ. Hosp-Stony Brook	669	25	3.74	3.33	3.40	(2.20, 5.02)
Univ. Hosp-Upstate	71	3	4.23	2.43	5.27	(1.06, 15.40)
Vassar Bros. Med Ctr	436	5	1.15	2.76	1.26**	(0.41, 2.94)
Westchester Med Ctr	309	9	2.91	3.64	2.43	(1.11, 4.61)
Statewide Total	22129	671	3.03			

*Risk adjusted mortality rate significantly higher than statewide rate based on 95 percent confidence interval. **Risk adjusted mortality rate significantly lower than statewide rate based on 95 percent confidence interval.

improved surgical protocols. Therefore, we suggest an organized approach to cardiac care that correlates procedural complexity with institutional proficiency, ensuring that high-risk procedures are centralized in hospitals that demonstrate consistently superior outcomes.

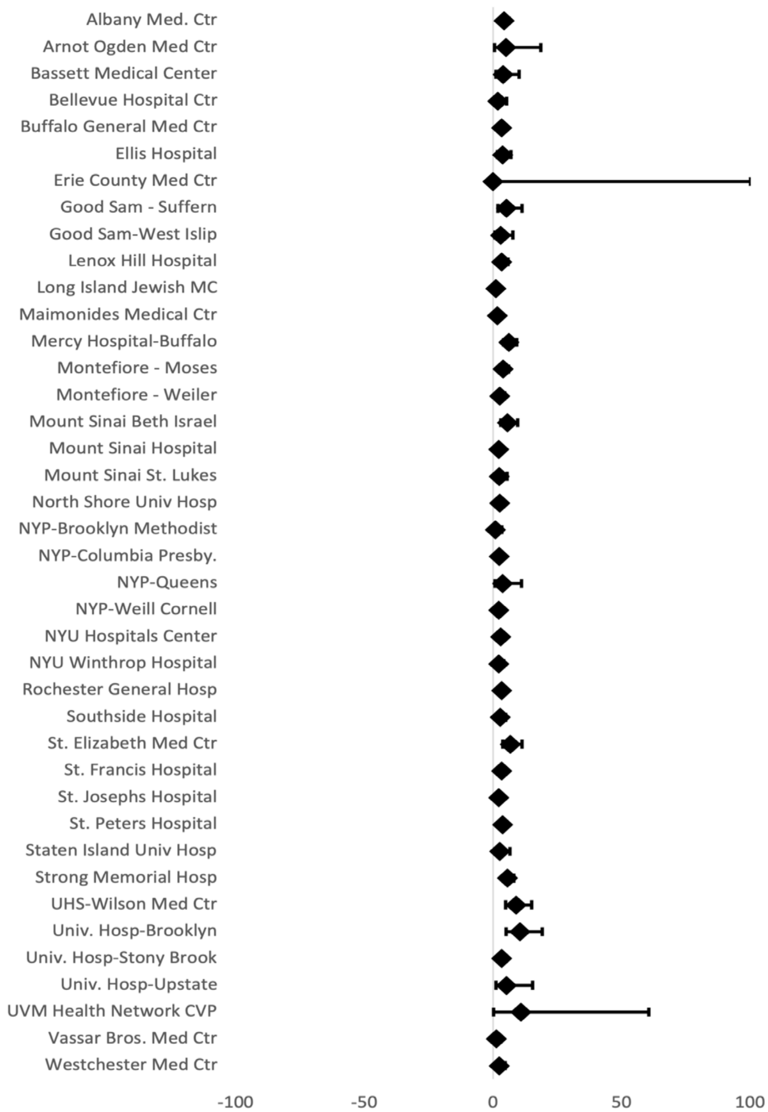

Figure 7. RISK-ADJUSTED MORTALITY RATES with 95 percent confidence interval for Valve or Valve/CABG surgery (years 2013-2015).

These results have significant implications for clinical practice and healthcare policy. Hospitals should use efficient procedures and evidence-based protocols to enhance the quality of treatment for patients undergoing cardiac surgery. Improving preoperative evaluation to identify high-risk patients and optimizing postoperative management can significantly enhance recovery and reduce complications. Furthermore, investing in training as well as recruiting experienced surgical teams and support personnel is essential, as their expertise and quality of care significantly influence patient outcomes. Continuous professional development and keeping up with the latest clinical guidelines will guarantee that healthcare professionals are adequately prepared to manage the complexities of cardiac procedures.

Furthermore, our findings challenge the assumption that technological advancements are the only reason for improved outcomes in cardiac procedures. Instead, they underscore the critical role of continuous quality evaluations and constant protocol refinement in increasing patient survival. Institutions with outlier RAMRs should conduct organized investigations and targeted interventions, including simulation-based training and real-time mortality review committees, to address systemic vulnerabilities. Policymakers and healthcare administrators should use these findings to develop strategies for enhancing cardiac care at both the state and national levels. Investments in evidence-based methods, infrastructure improvement, and inter-institutional collaboration can increase care quality and survival rates.

By focusing on these aspects, healthcare systems can work toward lowering mortality disparities and guarantee that all patients have the highest standard of care in cardiac procedures. The observed mortality rates exceeding the expected values across many modalities (P<0.001) highlight the critical need for fundamental changes to enhance patient outcomes beyond just technical advancements. A dual focus on improving patient-centered medical care and demanding institutional accountability through transparent outcome reporting is crucial for developing significant improvements in cardiac surgical interventions.

Study strengths and limitations

Some of the strengths of this study include a large sample size that enhances generalizability. The inclusion of multiple cardiac procedures

Table 5. Comparative analysis of the difference between the observed mortality rate (OMR) and the expected mortality rate (EMR) for PCI and cardiac surgery procedures

A.

	N	Mean	Std. Deviation	Std. Error Mean
Observed Mortality Rate	1609	2.307	1.72854	0.04309
Expected Moratality Rate	1609	1.9301	1.2844	0.03202

B.

	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Differences	
					Lower	Upper
Observed Mortality Rate	47.27	1608	<.001	2.03698	1.9525	2.1215
Expected Mortality Rate	60.28	1608	.000	1.93014	1.8673	1.9929

Test Value = 0

C.

		Standardizer*	Point Estimate	95% Confidence Interval	
				Lower	Upper
Observed Mortality Rate	Cohen's d	1.72854	1.178	1.115	1.242
	Hedges' correction	1.72935	1.178	1.114	1.241
Expected Mortality Rate	Cohen's d	1.28440	1.503	1.431	1.574
	Hedges' correction	1.28500	1.502	1.431	1.573

*The denominator used in estimating the effect sizes. Cohen's d uses the sample standard deviation. Hedges' correction uses the sample standard deviation, plus a correction factor.

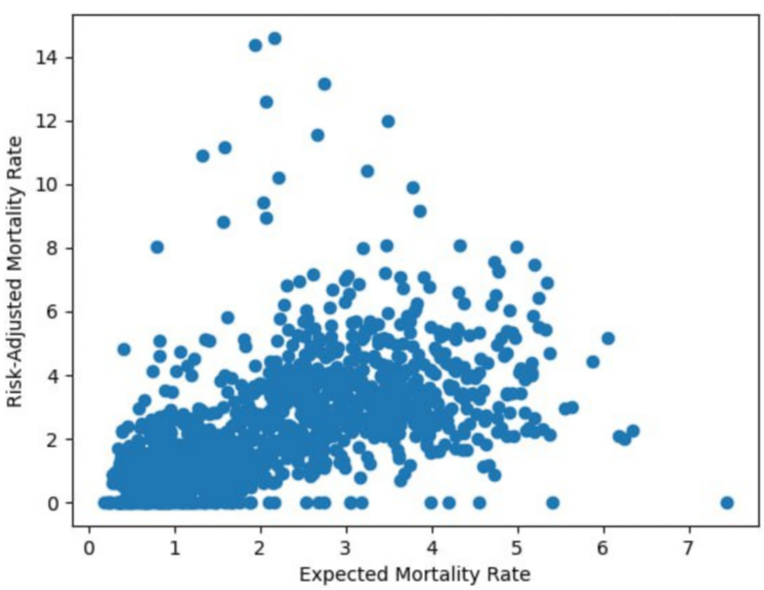

Figure 8. Expected mortality rate vs. risk adjusted mortality rate.

provides an overview of comprehensive hospital performance. This is an observational study and, as such, cannot determine causation. Risk-adjusted mortality rates may not be fully accounted for with respect to patient-related factors, including socioeconomic status and access to follow-up care. Additionally, the data are limited to non-federal hospitals in New York State, and this might not be applicable to other areas. Unmeasured confounding variables, such as hospital staffing levels and the availability of advanced technologies, could also influence outcomes.

While the study offers very valuable insight, it equally recognizes these inherent limitations. Future research should overcome these problems by covering a wide range of variables and using sophisticated analytical techniques.

Future research directions

Future studies need to elucidate specific factors that contribute to the observed higher mortality rates. This may involve examining hospital-specific variables, such as staffing levels and adherence to clinical guidelines, and patient-related factors, including comorbidities and access to healthcare services. Longitudinal studies tracking long-term outcomes and the development of comprehensive risk prediction models are critical next steps. Moreover, the assessment of various interventions using randomized controlled trials and other strong study designs would provide high-quality evidence in order to improve patient outcomes.

Conclusion

This comprehensive investigation offers a critical overview of cardiac surgical mortality rates, emphasizing the complex interplay of patient characteristics, institutional practices, and surgical interventions. Shedding light on these complex relationships, this study lays the foundational framework for targeted improvement initiatives in cardiac care delivery for more personalized, more precise, and more effective medical interventions across various cardiac procedures, including all PCI, CABG, emergency PCI, Non-emergency PCI, combined valve/CABG, and TAVR.

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Disclosure of conflict of interest

None.

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