RESEARCH PAPER

A Value Management Framework for Improving Operational Efficiency, Safety, and Cost-Effectiveness in Cardiac Catheterization Laboratory Services: Evidence from a Saudi Tertiary Cardiac Center

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Abstract

Cardiac catheterization laboratory (CCL) services are resource-intensive and highly sensitive to scheduling inefficiency. Case cancellation and unplanned day-case-to-inpatient crossover generate substantial avoidable cost without commensurate clinical benefit, yet documented, statistically rigorous evidence on structured efficiency interventions in this specific service line — particularly outside the United States and Europe — remains scarce. Prior to 2023, the CCL at Madinah Cardiac Center (MCC), a tertiary cardiac referral center in the Kingdom of Saudi Arabia, experienced an elective cancellation rate exceeding one-third of scheduled cases and a substantial day-case crossover rate, prompting implementation of a structured value management framework under the Center for National Health Insurance's "Efficiency Improvements at the Point of Care" Learning and Improvement Collaborative. This study undertook a retrospective and concurrent, single-group, before-and-after evaluation of that framework, using routinely collected operational data spanning November 2021 to December 2024 across five outcome domains — Quality, Safety, Capacity, Experience, and Cost — supplemented by inferential statistical testing (chi-square tests, Cochran–Armitage trend tests, and statistical process control p-charts) to distinguish genuine improvement from random variation, following the SQUIRE 2.0 reporting guideline. The overall cancellation rate fell from a 2022 median of 22% to a 2024 median of 4% (≈82% relative reduction; elective cancellation: $\chi^2(1) = 1388.56$, $p < .001$). The Day Patient Unit-to-inpatient crossover rate declined significantly across the available case-level monitoring window ($\chi^2(1) = 10.67$, $p = .0011$), non-invasive (SPECT) diagnostic volume expanded to 398 cases in 2024, staff time-utilization and patient satisfaction (92%→100%) and employee satisfaction (62%→87%) improved directionally, and the framework was associated with an estimated cumulative cost saving of approximately SAR 10.5 million. These findings indicate that a structured, multidisciplinary value management framework, anchored by a formally documented risk-based day-case categorization policy and iterative Plan-Do-Study-Act cycles, can produce statistically significant, sustained efficiency and safety gains achieved concurrently with increased clinical activity, and contribute a documented, transferable implementation model for procedural units within the Saudi healthcare system.

Keywords: value-based healthcare; quality improvement; cardiac catheterization laboratory; PDSA; SQUIRE 2.0; statistical process control; Saudi Arabia

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1. Introduction

Health systems worldwide face rising costs, ageing and increasingly complex populations, workforce shortages, and persistent inequities in access and outcomes [1,2]. In the United States alone, health expenditure is projected to reach US$5.6 trillion by 2025 (≈19.6% of gross domestic product), of which roughly one-quarter is attributable to waste from poor care coordination, overtreatment, and administrative complexity [3]. Value-Based Healthcare (VBHC), introduced by Porter and Teisberg [4] and further developed by Porter [5], reframes this problem by defining value as the health outcomes achieved per unit of cost expended, aligning with the Institute for Healthcare Improvement's Triple Aim of simultaneously reducing cost, improving population health, and enhancing patient experience [6], later extended to a Quintuple Aim incorporating equity and provider experience [3].

VBHC implementation has, however, remained conceptually contested and geographically uneven. Khalil et al. [1] found the United States accounts for 65% of published VBHC research, reflecting the framework's American origin and the natural-experiment opportunities created by Medicare's Center for Medicare and Medicaid Innovation; European adoption has instead emphasized quality-indicator-led, publicly governed models [2,7], while evidence from low- and middle-income countries remains comparatively scarce despite the acute relevance of value-optimization principles in resource-constrained settings [8]. At the operational level, core VBHC mechanisms — time-driven activity-based costing (TDABC) for granular cost visibility [9,10], bundled payment models [11,12], Integrated Practice Units, and structured outcome measurement — have been most extensively applied in surgical and procedural specialties, where episodes of care are well-delimited and outcomes are readily measurable [13,14]. Within cardiovascular care specifically, van der Nat et al. [15] documented one of the few rigorously evaluated cardiac Integrated Practice Unit implementations, in Dutch heart centers, finding that sustained gains followed an initial period of concentrated redesign rather than continuous incremental change. Møberg [7] similarly observed that public-hospital VBHC initiatives are often guided by locally defined quality indicators rather than externally imposed cost benchmarks, and that ambiguity over whether initiatives prioritize outcomes or costs can undermine coherent implementation.

Three research gaps motivate the present study. First, a methodological gap: the great majority of published quality-improvement and VBHC evaluations rely on descriptive run-chart trends alone, without formal inferential statistical testing to distinguish genuine, sustained improvement from common-cause (random) variation [2]. Second, a sectoral and geographic gap: documented, quantified VBHC evidence specific to cardiac catheterization laboratory services — as distinct from the more extensively studied joint-replacement and oncology literature [11,12,14] — remains limited, and this scarcity is compounded in the Gulf region and wider Kingdom of Saudi Arabia, where few of the reviewed international studies originate outside the United States, Europe, and a small number of other high-income countries [1,8]. Third, an implementation-detail gap: hospitals frequently adopt individual VBHC components in isolation rather than an integrated model, and few published reports document the specific, formally approved operational criteria (for example, risk-based day-case eligibility policies) that translate the VBHC framework into replicable clinical practice [2].

This paper addresses these gaps by reporting a statistically rigorous, single-center evaluation of a structured value management framework implemented in the CCL of a Saudi tertiary cardiac referral center, explicitly documenting its operational mechanisms and applying formal inferential statistics — rather than descriptive trends alone — to routinely collected quality-improvement data, in order to determine whether, and to what extent, the framework produced genuine, sustained gains in efficiency, safety, staff capacity, patient and staff experience, and cost.

2. Methodology

2.1 Design

A retrospective and concurrent, quasi-experimental, single-group, before-and-after (pre–post) evaluation design was adopted, comparing baseline performance against performance following sequential Plan-Do-Study-Act (PDSA) improvement cycles, consistent with the Institute for Healthcare Improvement's Breakthrough Series Collaborative model [16]. No parallel control group was used. Reporting follows the SQUIRE 2.0 guideline for quality-improvement research [17], with the retrospective observational elements additionally reported in accordance with the STROBE guideline [18]. The study drew entirely on data generated through the routine operation and monitoring of an existing improvement project; no new primary data-collection instruments were introduced specifically for this research.

2.2 Setting and context

The study was conducted in the Cardiac Catheterization Laboratory (CCL) and associated Day Patient Unit (DPU) of Madinah Cardiac Center (MCC), a specialized cardiac referral center within the Madinah Health Cluster, Kingdom of Saudi Arabia. MCC participated in the Center for National Health Insurance's (CNHI) "Efficiency Improvements at the Point of Care" Learning and Improvement Collaborative, part of the Kingdom's Health Sector Transformation Program under Vision 2030, which supports provider teams in applying structured improvement methods with an explicit focus on cost reduction, ecosystem sustainability, shared learning, and frontline improvement capacity.

2.3 Study period and population

The study spans January 2022 to December 2024, comprising a baseline phase (January–December 2022) and an intervention/monitoring phase (January 2023–December 2024) during which sequential PDSA cycles were implemented and outcomes tracked monthly. The study population comprised all patients scheduled for, or undergoing, cardiac catheterization at the MCC CCL during this period: 7,284 procedures in 2023 (6,964 adult; 320 pediatric; 4,266 unique patients) and 8,237 procedures in 2024 (7,900 adult; 337 pediatric; 4,814 unique patients), a 13.1% year-on-year increase in activity.

2.4 The intervention: value management framework

A multidisciplinary improvement team — comprising a project sponsor, the medical director, cardiology and CCL leadership, patient relations, nursing, a quality-improvement coach, and a data lead — constructed current- and future-state process maps of the CCL patient pathway and performed Pareto root-cause analysis of cancellations and crossovers. The leading identified causes of cancellation were rescheduling/postponement and the need for further pre-procedure investigation; the leading causes of crossover were the need for further clinical management and late procedure timing.

Building on these findings, the team developed and formally approved a risk-based Day Patient Unit admission policy (Document No. DPU-1.1-1E, effective 1 April 2023), operationalized through (a) documented medical (e.g., heart failure, impaired renal function, complex percutaneous coronary intervention) and social (e.g., no reliable post-procedure caregiver or home facilities) contraindications to day-case management, screened for every patient before booking, and (b) an approved list of case types eligible for day-case management across adult catheterization, electrophysiology, congenital heart disease, and adult cardiac surgery services. Eligible patients followed a standardized pathway comprising pre-procedure investigations, anesthesia clearance, documented consent within 30 days, and designation of a responsible post-procedure caregiver. Improvement work was structured and tracked across five domains — Quality, Safety, Experience, Capacity, and Cost — on a Visual Management Board, later digitized as a Digital Value Management Board, with progress monitored via run charts against calculated medians, consistent with statistical process control convention.

2.5 Outcome measures

Table 1 summarizes the five outcome domains, their stated aims, measures, and data sources, as operationalized on the project's Value Management Board.

Table 1. Outcome Domains, Aims, Measures, and Data Sources

Domain	Aim	Measure	Data source	Frequency
Quality	Decrease CCL cancellation rate by 25% by December 2024	Overall cancellation rate (%), elective and day case	Pre- and post-cath list, CCL	Daily
Safety	Monitor/ reduce crossover rate against 2% benchmark; increase non-invasive investigations	Crossover rate (%, DPU→inpatient); SPECT case volume	CCL database; complication-reporting form	Weekly / Monthly
Experience	Improve patient and staff satisfaction	Patient satisfaction (%); employee satisfaction (%)	Patient and employee surveys	Weekly / Quarterly
Capacity	Normalize staff time between direct and indirect care	% time in direct, indirect, and free time	Manual time-motion log	Weekly
Cost	Reduce cost of managing eligible cardiac cases	Cost saved (SAR) via day-case conversion, prevented cancellations, non-invasive diagnostics	Quality and Patient Safety Dept. calculation	Weekly

2.6 Data sources

All data were collected prospectively as part of routine improvement-project monitoring and compiled retrospectively for this study. Sources comprised daily pre- and post-procedure cath lists (cancellation tracking); the CCL electronic database (crossover rate, case volumes); monthly quality-indicator profile reports, cross-validated against Digital Value Management Board records and benchmarked against the Australian Day Surgery Council standard of 2% for crossover in the absence of a validated national benchmark [19]; manual time-motion logs for sampled shifts; patient- and employee-experience survey instruments; cost calculations based on fixed per-case savings assumptions (SAR 3,600 per avoided admission day-pair; SAR 4,150 per case diagnosed non-invasively via SPECT rather than angiography); and weekly and monthly Digital Value Management Board (Box Score) records spanning 31 consecutive weeks (1 March–27 September 2024) and 32–33 consecutive months (January 2022–August/September 2024) respectively.

2.7 Data analysis

Quantitative data were analyzed descriptively using run charts with calculated median centerlines. Pareto analysis ranked root causes of cancellation and crossover. Cost savings were calculated cumulatively using the fixed per-case assumptions above. Inferential statistical testing determined whether observed changes were statistically significant rather than attributable to chance, using two complementary methods: (1) a chi-square test of independence [20] comparing proportions of cancelled/crossed-over cases between earlier and later halves of the available monitoring window, supplemented by a Cochran–Armitage trend test [21] for linear trend across the full sequence; and (2) a statistical process control p-chart, with center line set at the overall mean proportion and upper/lower control limits at ±3 standard deviations for each period's sample size, following standard p-chart methodology [22]. Points falling outside control limits were classified as special-cause signals.

2.8 Ethical considerations

The study was approved by the Institutional Review Board, Madinah Cardiac Center (National Registration Number NCBE–KACST, KSA: H-03-M-143; approval reference IRB log no. MCC-143-2501; approved 10 February 2025, expedited review category). All data were de-identified and aggregated prior to analysis; no individual patient-identifiable information was used.

3. Results and Discussion

3.1 Study population and activity volume

Procedure volume increased 13.1% year-on-year, from 7,284 (2023) to 8,237 (2024) completed cardiac catheterizations, indicating that the efficiency, safety, and cost gains reported below were achieved concurrently with — not at the expense of — increased clinical activity.

3.2 Quality: cancellation rate

A baseline (January–September 2021) Pareto analysis identified case rescheduling/postponement and the need for further pre-procedure investigation as the two leading, and largely predictable, contributors to cancellation, together accounting for the majority of recorded cases; causes were classified as predictable (18%) or unpredictable (82%), a distinction that shaped the design of the pre-admission preparation and booking-verification steps.

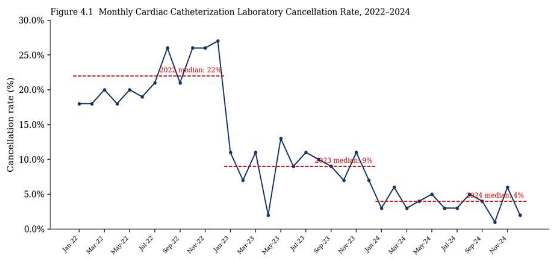

Figure 1. Monthly Cardiac Catheterization Laboratory Cancellation Rate, 2022–2024

The overall CCL cancellation rate fell from a 2022 median of 22% (range 18–27%) to a 2023 median of 9% (2–13%) and a 2024 median of 4% (1–6%) (Figure 1) — an approximate 82% relative reduction, substantially exceeding the project's 25% target. Disaggregated by case type, the elective cancellation rate fell from 36.8% (1,387/3,772) at 2022 baseline to 8.2% (598/7,337) during the 2023–2024 intervention period, a highly significant reduction ($\chi^2(1) = 1{,}388.56$, $p < .001$), with a significant declining trend across 32 available months (Cochran–Armitage $Z = -32.39$, $p < .001$) (Table 2). The day-case cancellation rate, starting from a substantially lower baseline (6.7%), did not change significantly ($\chi^2(1) = 0.10$, $p = .753$), consistent with a ceiling effect in an already well-controlled sub-process.

Table 2. Baseline (2022) versus Intervention (2023–2024) Comparison of the Cancellation Rate

Indicator	Baseline 2022 (n)	Intervention 2023–2024 (n)	Test statistic	p-value
Elective (cardiac catheterization) cancellation rate	36.8% (1,387/3,772)	8.2% (598/7,337)	$\chi^2(1) = 1388.56$	< .001
Elective cancellation rate — trend across 32 months	—	—	$Z = -32.39$ (Cochran–Armitage)	< .001
Day-case cancellation rate	6.7% (38/569)	6.2% (89/1,441)	$\chi^2(1) = 0.10$	.753
Day-case cancellation rate — trend across 33 months	—	—	$Z = -1.58$ (Cochran–Armitage)	.115

The phase-segmented p-chart (Figure 2) shows a clear, sustained step-change at the start of the intervention phase rather than a temporary fluctuation, and weekly case-level analysis found no significant difference in the elective cancellation rate between the earlier and later halves of a 31-week 2024 monitoring window ($\chi^2(1) = 0.19$, $p = .664$) — indicating that the bulk of improvement had already been consolidated by 2023. This early-consolidation pattern mirrors the experience reported from Dutch heart centers implementing value-based cardiac care, where sustained gains followed an initial period of concentrated redesign rather than continuous incremental change [15], a directly relevant

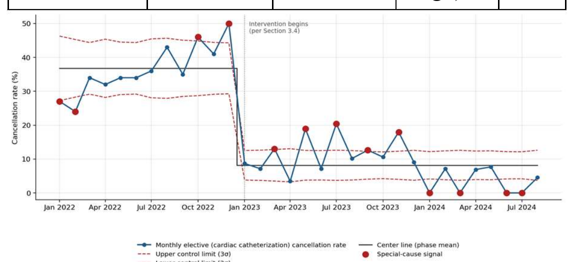

Figure 2. Statistical Process Control (p-chart) for the Monthly Elective Cancellation Rate, with Separate Baseline and Intervention Control Limits

comparator given both settings involve cardiac procedural services restructured around VBHC principles. The magnitude of the reduction — considerably larger than the 18% baseline "predictable-cause" classification alone would predict — suggests that the risk-based categorization policy and standardized pre-admission pathway also addressed causes nominally classified as unpredictable (for example, incomplete pre-admission preparation), consistent with the broader implementation-science literature finding that translating VBHC principles into practice depends on structured, locally adapted models rather than adoption of the framework in name alone [23].

3.3 Safety: crossover rate and non-invasive investigations

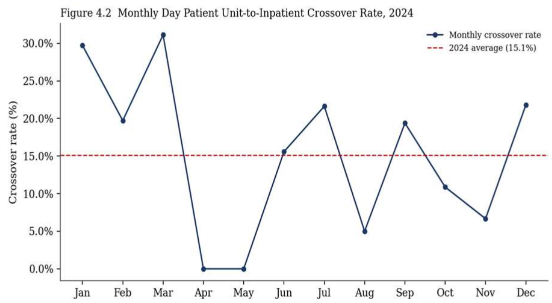

Figure 3. Monthly Day Patient Unit-to-Inpatient Crossover Rate, 2024

The 2024 monthly crossover rate fluctuated between 0.0% (April, May) and 31.1% (March), averaging approximately 15.0% (Figure 3) — above the 2% Australian Day Surgery Council external benchmark [19]. However, case-level weekly analysis found a significant reduction between the earlier and later halves of the 31-week monitoring window, from 25.13% (199 cases) to 12.55% (239 cases) ($\chi^2(1) = 10.67$, $p = .0011$), with a significant declining trend across all 31 weeks (Cochran–Armitage $Z = -3.38$, $p = .0007$) (Table 3), indicating genuine improvement in day-case patient selection consistent with the intent of the categorization policy. As this benchmark reflects a different health system, case-mix, and eligibility framework, the more locally meaningful comparison is the within-service before-and-after trend, consistent with Møberg's [7] observation that public-hospital VBHC initiatives are typically guided by locally defined indicators rather than externally imposed benchmarks.

Table 3. Weekly Case-Level Statistical Test Results, 1 March–27 September 2024

Indicator	Period A (n)	Period B (n)	Test statistic	p-value
Elective cancellation rate	12.68% (497)	13.75% (611)	$\chi^2(1) = 0.19$	0.664
Day-case cancellation rate	3.73% (161)	4.55% (220)	$\chi^2(1) = 0.02$	0.893
Crossover rate (DPU→inpatient)	25.13% (199)	12.55% (239)	$\chi^2(1) = 10.67$	0.0011
Crossover rate — trend across 31 weeks	—	—	$Z = -3.38$ (Cochran–Armitage)	0.0007

Pareto analysis of documented crossover causes identified the need for further clinical management as the dominant contributor (≈72.5% of analyzed cases), followed by late procedure timing, emergency referral, and post-procedure complications — suggesting the residual crossover rate substantially reflects appropriate clinical caution rather than a remaining process failure of the kind addressed by the cancellation-focused cycles. Further reduction toward the external benchmark may therefore require clinical-pathway changes rather than further scheduling refinement, and should be weighed against patient-safety risk. Concurrently, non-invasive (SPECT) diagnostic volume expanded to 398 cases in 2024 (monthly range 14–58, with two months of reduced volume attributable to a documented nuclear-medicine supply shortage), consistent with the cost-transparency rationale underlying time-driven activity-based costing, which links a shift toward lower-cost, lower-risk diagnostic pathways to more accurate visibility of the true cost of alternative care processes [10].

3.4 Capacity: staff time-utilization

Following the improvement work, the proportion of shift time spent on direct patient care decreased slightly from 75% to 70%, indirect patient care decreased from 25% to 18%, and previously unaccounted free time increased from 0% to 12%. Considered alongside the concurrent 13.1% increase in procedure volume, one plausible interpretation is that reduced cancellation- and crossover-related rework freed capacity previously absorbed by non-value-adding activity, consistent with evidence that granular time-motion measurement itself tends to engage clinical staff in identifying and redesigning low-value activity [24]. An alternative, less favorable interpretation — under-utilization or measurement artifact in manual time-motion sampling — cannot be fully excluded from the available data, and this finding is accordingly reported as directionally, rather than statistically, supported.

3.5 Experience: patient and staff satisfaction

In-patient satisfaction rose from 92% (Q1 2024) to a sustained 100% (Q2–Q4 2024; annual average 98%), and CCL employee satisfaction rose from 62% (Q1–Q2 2024) to 87% (Q3–Q4 2024). These directionally favorable trends are consistent with Porter and Lee's [25] argument that integrating outcome and cost management into a single, coherent delivery system — rather than pursuing efficiency and experience as separate initiatives — tends to improve both simultaneously, since fewer cancellations and crossovers translate into fewer disrupted expectations for patients and less administrative and emotional burden for staff. Both measures are self-reported and were not benchmarked against an external or pre-2024 baseline; the low starting point for employee satisfaction may partly reflect a general upward trend in engagement following the visible early success of the Quality and Safety interventions rather than a direct causal effect of any single Experience-domain action, and these results should be read as corroborating rather than independently establishing the framework's overall value.

3.6 Cost: economic impact

Applying the fixed per-case savings assumptions cumulatively across the study period yielded an estimated total cost saving of approximately SAR 10.5 million between November 2021 and December 2024, rising from a monthly saving of SAR 68,753 at initiative start to SAR 615,066 in December 2024, with three visible step-changes corresponding to sequential introduction of the DPU pathway, the cancellation-focused PDSA cycles, and expanded non-invasive investigation capacity.

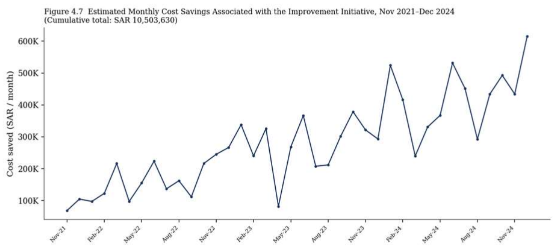

Figure 4. Estimated Monthly Cost Savings Associated with the Improvement Initiative, November 2021–December 2024

This figure is substantial in absolute terms but rests on fixed per-case assumptions rather than activity-based costing drawn from the hospital's financial system — a limitation acknowledged by the improvement team itself, which reported no access to cost-center or fixed-cost data when the methodology was developed. The estimate is therefore best interpreted as a defensible, transparent indication of the direction and approximate scale of economic benefit rather than an audited financial saving, mirroring a recurring theme in the TDABC literature that such per-unit costing estimates should be treated as directional pending further methodological standardization [26].

3.7 Summary of findings against stated aims

Table 4. Summary of Results Against Stated Aims, by Value Management Board Domain

Domain	Aim	Result	Statistically tested?
Quality	Decrease overall cancellation rate by 25% by Dec 2024	22% → 4% median (≈82% relative reduction); elective rate reduction highly significant	Yes (elective)
Safety	Reduce crossover rate; increase non-invasive (SPECT) investigations	Weekly crossover rate 25.1% → 12.6%, significant; SPECT volume 398 cases in 2024	Yes
Capacity	Normalize direct/indirect staff time distribution	Direct care 75%→70%; indirect 25%→18%; free time 0%→12%	No (descriptive)
Experience	Improve patient and staff satisfaction	In-patient satisfaction 92%→100%; employee satisfaction 62%→87%	No (descriptive)
Cost	Reduce cost of managing eligible cardiac cases	~SAR 10.5 million cumulative estimated savings, Nov 2021–Dec 2024	No (deterministic estimate)

All five domains improved over the study period; the Quality and Safety domains were additionally supported by formal inferential statistical testing, while Capacity, Experience, and Cost are reported descriptively (Table 4). Considered together, the findings present a coherent narrative consistent with the value-based healthcare and IHI Breakthrough Series framework underpinning the intervention: coordinated improvement across multiple quality dimensions, rather than optimization of a single indicator in isolation, was associated with the most durable gains.

3.8 Practical implications and limitations

For practice, the specific mechanisms employed — the formally documented risk-based day-case eligibility criteria and the Digital Value Management Board's structured aim–measure–data-collection template — constitute a transferable model for other cardiac catheterization services within the CNHI Learning and

Improvement Collaborative and the wider Saudi healthcare system, achieved using routinely collected operational data rather than resource-intensive new data collection. This directly extends the small existing body of cardiac-specific VBHC implementation evidence [15] to a new geographic and health-system context, partially addressing the sectoral and geographic gap identified in Section 1.

Several limitations qualify these findings. The single-center, pre–post design without a concurrent control group cannot fully exclude secular trends, including the broader CNHI/HSTP transformation program of which this initiative formed a part, particularly for the Capacity and Experience domains, which were not subjected to inferential testing. Manual time-motion sampling may introduce measurement variability. The crossover-rate inferential tests remain restricted to the available 31-week case-level window; the corresponding statistical process control chart could not be regenerated for this analysis pending the underlying dataset. The Australian benchmark used for the crossover rate [19] reflects a different health system and case-mix and should be interpreted as an approximate external reference rather than a directly comparable target. The cost-saving estimate rests on fixed, non-audited assumptions. These limitations temper, but do not negate, the statistically supported core findings for the Quality and Safety domains.

4. Conclusion

This study evaluated a structured value management framework applied to cardiac catheterization laboratory services at a Saudi tertiary referral center, using a retrospective and concurrent, single-group, before-and-after design applied to routinely collected operational data (November 2021–December 2024). The framework was associated with a statistically significant reduction in the elective cancellation rate (36.8%→8.2%; $\chi^2(1) = 1{,}388.56$, $p < .001$), an overall 82% relative reduction in cancellation exceeding the project's 25% target, a statistically significant reduction in the Day Patient Unit-to-inpatient crossover rate across the available monitoring window ($\chi^2(1) = 10.67$, $p = .0011$), expanded non-invasive diagnostic capacity, and directionally favorable improvements in staff capacity utilization, patient and staff satisfaction, and an estimated SAR 10.5 million in cumulative cost savings — achieved concurrently with a 13.1% increase in clinical activity.

This paper contributes to the literature in three respects. First, it provides a documented, multi-year, single-center case study of a value management framework applied specifically to cardiac catheterization services within a Saudi CNHI Learning and Improvement Collaborative, extending the small existing body of cardiac-specific VBHC implementation evidence [15] to a new geographic context and directly addressing the geographic and sectoral evidence gap identified in Section 1. Second, it demonstrates and reports, in full, the application of inferential statistical methods — chi-square tests [20], Cochran–Armitage trend tests [21], and statistical process control p-charts [22] — to quality-improvement data more commonly reported using descriptive run charts alone, offering a template for more statistically rigorous reporting consistent with SQUIRE 2.0 [17] and STROBE [18] standards, and addressing the methodological gap identified in Section 1. Third, it documents, in replicable detail, the specific risk-based day-case categorization criteria and Digital Value Management Board structure that underpinned the observed improvements, providing a transferable operational model for other procedural units and addressing the implementation-detail gap identified in Section 1.

For practice, we recommend that (a) similar cardiac catheterization services formalize risk-based day-case eligibility criteria and structured, multi-domain digital improvement boards as a transferable model; (b) the crossover-rate indicator be benchmarked against a locally or nationally derived standard once available, rather than relying indefinitely on an international reference point; and (c) cost-saving methodologies migrate from fixed per-case assumptions toward activity-based costing to strengthen auditability. For future research, we recommend (a) incorporating a concurrent comparison site or longer pre-intervention baseline to better isolate the framework's effect from concurrent system-level trends; (b) completing the case-level statistical process control analysis for the crossover-rate indicator; (c) examining whether the observed shift in staff time-utilization reflects genuine capacity release or measurement artifact, using continuous electronic time-tracking; and (d) assessing the durability of these gains beyond the study period and their extension to comparable procedural units.

Within the limitations described, this study provides statistically supported evidence that a structured, multidisciplinary value management framework can produce substantial, sustained improvements in the efficiency and safety of cardiac catheterization services, achieved concurrently with increased clinical activity. These findings support the continued application and wider dissemination of value management methods within cardiac catheterization services in the Saudi healthcare system and comparable settings, while underscoring the continued need for more rigorous, audited data collection to support the Capacity, Experience, and Cost domains of future improvement work.

Conflicts of interest: The authors declare no conflicts of interest.

Funding: All study was conducted by staff in a governmental organization

Data availability: Data underlying this study were collected as part of routine quality-improvement monitoring at Madinah Cardiac Center and are not publicly available due to institutional data governance restrictions; de-identified aggregate data may be available from the corresponding author upon reasonable request and with institutional permission.

Ethics approval: Approved by the Institutional Review Board, Madinah Cardiac Center (IRB log no. MCC-143-2501; approved 10 February 2025).

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