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Temporal trends in hospital technical quality under unified clinical governance: a nationwide multicenter longitudinal study in Brazil

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Abstract

Background Large private hospital networks operating under unified clinical governance are increasingly prevalent, yet evidence of sustained improvements in technical quality remains limited, particularly in middle-income countries. We assessed network-wide temporal trends in technical quality indicators, including hospital-acquired infections, falls, pressure injuries, and selected process measures, and examined their association with financial performance.

Methods We conducted a nationwide multicentre longitudinal study of a private hospital network in Brazil from 2016 to 2024. Hospitals entered the cohort at different time points, yielding an unbalanced panel (25–57 hospitals). Network-level trends were estimated using volume-weighted linear regressions of annual means. Hospital-level analyses used mixed-effects models to estimate annual adjusted changes (modelled slopes), with adjustment for changes in earnings before interest, taxes, depreciation, and amortisation (EBITDA), net margin, annual surgical volume, intensive care unit beds, and staffed beds. Trajectories were compared according to hospital type at network entry (network-built versus acquired).

Results Network-level analyses showed statistically significant annual declines in central line-associated bloodstream infection (−0·18 per 1,000 central line-days), catheter-associated urinary tract infection (−0·15 per 1,000 catheter-days), pressure injury incidence density (−0·05 per 1,000 patient-days), and overall inpatient fall incidence density (−0·015 per 1,000 patient-days). Antibiotic administration within 1 h of sepsis or septic shock recognition increased by 0·78% per year (95% CI: 0·37 to 1·19), and door-to-wire time for primary percutaneous coronary intervention decreased by 4·0 min per year (95% CI: −6·66 to −1·28). Most indicators improved or remained stable over time, with non-linear temporal patterns, including transient increases during the COVID-19 period. Trajectories were consistent across hospital entry types. Changes in EBITDA were not associated with annual changes in quality indicators, and net margin showed no association with most indicators but was inversely associated with fall-with-harm and pressure injury incidence.

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Conclusions In this nationwide hospital network, improvements in technical quality were observed over time without a consistent association with financial performance, although inverse associations were identified for selected indicators. These findings suggest that quality improvement and financial stability can coexist within large hospital networks operating under unified clinical governance.

Keywords Quality of health care, Patient safety, Hospital-acquired infection, Quality assurance

Background

The incidence and severity of medical errors during hospital care constitute a global public concern. In response, health system leaders are adopting rigorous approaches to improve and sustain care quality [1]. Durable gains in patient safety and technical quality require disciplined measurements, focused management, and system-wide implementation of evidence-based practices [1]. Hospitals increasingly rely on standardized indicators, including device-associated infections, pressure injuries, falls, perioperative outcomes, and time-critical processes, to reduce unwarranted variations and prevent avoidable harm [2]. However, beyond single-site or short-term evaluations, multicenter longitudinal evidence from middle-income countries such as Brazil remains limited, particularly regarding long-term indicator trajectories, the organizational features associated with improvement, and the resilience of gains during exogenous shocks such as the COVID-19 pandemic [3, 4].

A central question concerns the link between technical quality and financial performance [5]. As W. Edwards Deming [6] argued, "Profits are the result of attention to quality and customer satisfaction, while the reverse is rarely true." This principle suggests that better processes reduce defects, stabilize throughput, and build trust. Services research by Rust et al. conceptualized how quality improvements can increase revenue, reduce costs, expand market share, and enhance profitability through multiple pathways, including fewer complications, shorter lengths of stay, and reduced rework [7]. At the ecological level, longitudinal evidence from high-income countries indicates that health system reforms involving increased private sector participation in publicly funded systems have frequently been associated with worse health outcomes, largely attributed to organizational fragmentation and weak system-level governance rather than ownership status itself [8]. Although many analyses in high-income contexts favor public management, counterexamples indicate that management models alone do not determine outcomes when context and risk are appropriately considered [8–10]. These observations highlight that ownership, financing, and organizational governance represent distinct dimensions of health system design, each with potentially independent effects on quality and performance.

Brazil provides a pertinent context. The country has a mixed public–private healthcare system, in which the Unified Health System (Sistema Único de Saúde, SUS) provides universal coverage to the majority of the population, while a substantial private sector delivers care to individuals covered by supplementary health insurance or through out-of-pocket payments [11]. Private hospital networks represent an important segment of healthcare delivery, particularly in the provision of specialised and high-complexity services. Chronic underfunding in the public sector coexists with comparatively greater infrastructure in segments of the private sector [4]. Large private networks operating under unified clinical governance may facilitate process standardization, cross-site learning, and benchmarking at scale, potentially accelerating improvement [12]. In this study, the focus is on organizational governance and management structure within a unified network, rather than on ownership or payer mix, as these dimensions may exert distinct and independent influences on quality and performance. Whether these organizational features are associated with superior technical quality trajectories, and how such trajectories relate to hospital financial health, measured by operating performance and net margins, remains insufficiently explored. Evidence from U.S. affiliation networks indicates that branded, franchise-like membership is associated with improved operating margins for affiliates without measurable gains in clinical quality, underscoring that network governance alone does not guarantee quality improvement and encouraging longitudinal evaluations within large health systems [13].

Our a priori hypothesis was that sustained improvement in technical quality would not be associated with higher costs or deterioration in financial performance, and that, under unified network governance, temporal trends would be directionally consistent across hospital entry types (network-built versus acquired). Accordingly, this study aimed to characterise temporal trends in hospital technical quality indicators within a large private network in Brazil and to examine the association between within-hospital changes in quality and financial performance, measured by EBITDA and net margin. We further sought to assess whether these trajectories were consistent across hospital types defined by mode of network entry and to explore their robustness during the COVID-19 period.

Methods

We conducted a retrospective, multicentre, observational cohort study of tertiary hospitals within a private hospital network in Brazil, using internal administrative and clinical datasets from 2016 to 2024. A total of 57 hospitals were included, contributing data over the study period, with the number of active hospitals ranging from 25 to 57 per year due to staggered entry into the network. The study population comprised general medical–surgical hospitals; facilities built or acquired during the observation window were included from the onset of data reporting.

The study population comprised general medical–surgical hospitals. Analytical variables included audited hospital financial statements and harmonized inpatient quality indicators collected according to network technical specifications. Secondary, primary, and long-term care facilities were excluded. Prespecified analyses examined adjusted associations between within-hospital changes in quality indicators and financial performance (EBITDA and net margin), with adjustment for hospital capacity and activity (annual surgical volume, intensive care unit beds, and staffed beds). Sensitivity analyses accounted for the COVID-19 period and compared temporal trends across hospital mode-of-entry groups.

Quality of care indicators and financial health

This study assessed several healthcare quality indicators as part of the annual quality audits performed by the Quality Department. Ten quality indicators (Q) were included in the final analysis. The average values of all quality indicators in adult patients were calculated. Inpatient quality indicators included: Q01, surgical mortality rate (%); Q02, surgical site infection rate (%); Q03, central line-associated bloodstream infection (CLABSI) in the adult intensive care unit (ICU) (rates per 1,000 central line-days); Q04, catheter-associated urinary tract infection in the adult ICU (CAUTI) (rates per 1,000 urinary catheter-days); Q05, ventilator-associated pneumonia (VAP) (rates per 1,000 ventilator-days); Q06, fall incidence density (rates per 1,000 patient-days); Q07, fall-with-harm incidence density (rates per 1,000 patient-days); Q08, pressure–injury incidence density (rates per 1,000 patient-days); Q09, adherence to antibiotic administration within 1 h of sepsis or septic shock recognition (%); and Q10, Time from hospital arrival to guidewire crossing during primary percutaneous coronary intervention in acute myocardial infarction (time variables in minutes). Upon inclusion, all hospitals adhered to a unified technical specification and data dictionary for indicator definitions, data collection, and analysis, ensuring standardized and harmonized measurements across sites. All indicators were reviewed monthly and validated by the local quality department to confirm accuracy, completeness, and adherence to standardized specifications before system-level reporting. The indicators were measured in different calendar years: Q02 (2018), Q07 (2019), and Q09 and Q10 (2017). Analyses for each indicator used all available years. The quality indicators were selected a priori based on their widespread use in Brazil and alignment with national hospital benchmarking initiatives, accreditation standards, and quality assessment frameworks adopted by major hospital associations and health systems. These indicators capture core domains of technical quality and patient safety, including healthcare-associated infections, inpatient harm events, surgical outcomes, and time-sensitive processes of care, and are routinely monitored for external comparisons and internal performance management. All indicators were defined according to standardized network technical specifications, supported by a unified data dictionary applied consistently across hospitals. Definitions and surveillance protocols remained stable throughout the study period, with only minor operational refinements introduced as part of routine quality improvement processes. Detailed technical specifications for all indicators, including definitions, denominators, and data collection procedures, are provided in the Supplementary Materials (Description of Methods for Technical Quality Indicators). As a sensitivity analysis, we repeated the primary analyses in a restricted cohort of hospitals with continuous participation over the study period ($n = 25$) to assess the potential impact of compositional changes arising from the unbalanced panel.

Assessing changes in quality indicators is essential to characterise system performance under conditions of stress, such as the COVID-19 pandemic. Analyses were stratified a priori into three periods: pre-COVID-19 (2016–2019), COVID-19 (2020–2022), and recovery (2023–2024). These definitions were selected to capture broad phases of system disruption and subsequent stabilisation, with the COVID-19 period anchored to the onset of the pandemic in Brazil in 2020 and the recovery phase aligned with the transition from the global public health emergency, as defined by the World Health Organization in May 2023.

Two financial outcomes were analysed. First, the net margin was measured monthly at the hospital level and aligned monthly with each technical quality indicator, allowing a direct comparison of financial performance and quality results within the same month. Second, EBITDA captured financial dynamics over time through a monthly change in EBITDA.

We used EBITDA because it removes jurisdiction-dependent taxes, financing choices, and non-cash charges, thereby approximating operating cash generation and hospital operating performance. In the healthcare sector, EBITDA is widely used to gauge the capacity for asset renewal, shock resilience, and overall operational efficiency [14]. To focus on core clinical operations and avoid distortion from non-operating items, a revised definition restricted to medical operating profits plus depreciation and amortization was used, excluding non-medical revenues and other non-operating income. EBITDA captured financial dynamics over time as the annual change in EBITDA (ΔEBITDA), defined as EBITDA in year t minus EBITDA in year t − 1; this quantity was modelled as a continuous outcome. The definition of EBITDA was applied consistently and corresponded to the standard metric used for the company's official financial statements, which are subject to external independent audits.

The monthly net margin was calculated at the hospital level as 100 × net income divided by net revenue, expressed in percentage points. Net revenue was gross patient service revenue minus contractual deductions, discounts, revenue taxes, and denials; net income was the bottom line after operating expenses, financial income and expenses, depreciation and amortization, taxes, and non-controlling interests under accrual accounting.

Over the study period, some hospitals were newly built and operated by the network ("network-built"), whereas others were acquired as preexisting facilities; all acquired hospitals were privately owned and had previously operated outside hospital networks. Data for each hospital were only included from the calendar year in which they entered the network, yielding an unbalanced panel that expanded from 25 hospitals in 2016 to 57 hospitals in 2024. For like-for-like comparisons between the mode-of-entry groups, trajectories were aligned in the hospital's first measurement year and contrasted over subsequent years.

Organizational model and quality management framework

During the 9-year cohort period (2016–2024), all hospitals in the network operated under a standardized Manual of Clinical Practices designed to harmonize quality and safety procedures. Once incorporated into the network, hospitals were managed under a uniform governance and operating model with centralized policies, oversight, and performance management to ensure consistent implementation across sites. The network conducted regular audits, delivered continuous feedback on performance, and strengthened Patient Safety Units. System-wide educational and motivational campaigns promoted greater standardization of care processes and operational optimization to improve clinical workflow efficiency. Monthly cross-hospital meetings on clinical practice encouraged benchmarking and continuous learning across units. All indicators and their critical appraisals were reviewed with an explicit improvement focus. Additional initiatives included issuing guidance to strengthen the Professional Development Program, implementing checklists and standardized protocols for high-risk procedures, and conducting leadership rounds to recognize best practices and address emerging concerns. Collectively, these strategies were intended to maximize staff engagement, enhance communication, and foster an organizational environment prioritizing patient safety and improving outcomes.

This study was conducted in accordance with the principles of the Declaration of Helsinki and followed the STROBE Reporting Guidelines [15]. Only anonymized aggregated data from publicly available official sources were included. Ethical approval was obtained from Hospital São Luiz & Rede D´or and the Affiliated Teaching Hospitals Research Ethics Board (protocol # 90767125.3.0000.0087, assent CEP 7.745.616), which waived the need for informed consent. This study complied with Resolution 466/2012 of the Brazilian National Health Council.

Patient and public involvement statement

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination plans of our research.

Statistical analysis

For each indicator and calendar year, we first computed hospital-level annual values (such as rates per 1,000 patient-days or device-days, proportions, or minutes) using the appropriate exposure/denominator at each hospital (patient-days, device-days, eligible cases, or procedures). Subsequently, the network-level annual estimate was obtained as the volume-weighted mean of hospital values (denominator-weighted), with weights equal to the hospital-year exposure used to construct the indicator. Dispersion was summarized as the standard deviation around the weighted mean. This approach reflects system-level performance by accounting for differences in hospital volume and exposure, providing an estimate analogous to a pooled rate across the network, consistent with established surveillance methodologies in which rates are derived from aggregated numerators and denominators across reporting units [16].

We modelled the calendar year as a continuous predictor and reported annual change as the primary effect measure. This approach was selected to provide a parsimonious and interpretable summary of the average temporal trend across the study period. For the primary analyses, each indicator was evaluated on its native clinical scale, preserving its natural direction. For harm and time measures (surgical mortality, CLABSI, CAUTI, VAP, inpatient falls, injurious falls, and pressure–injury incidence), lower values indicate better performance; therefore, negative annual changes denote improvement. For adherence (antibiotic administration within 1 h of sepsis or septic shock recognition), higher values indicate better performance, and positive annual changes denote improvement.

Consistent with the construction of network-level estimates, regression analyses incorporated the corresponding denominators to account for differences in exposure and measurement precision across hospitals and over time. For network-level analysis, volume-weighted linear regressions were fitted to annual network means, with weights equal to the underlying exposure (e.g., patient-days, device-days, or eligible cases). The inference used heteroskedasticity and autocorrelation-robust standard errors for the yearly series. Indicators that began later (including injurious falls from 2019) were analyzed over their available windows, acknowledging reduced precision; no imputation across unmeasured years was performed.

To account for the nested longitudinal structure (repeated annual observations within hospitals), staggered cohort entry, between-hospital heterogeneity at baseline, and temporal trend, each indicator was analyzed using multivariate linear mixed-effects models on hospital-year data. Calendar year was specified as a continuous predictor; hospital-level random intercepts accounted for within-hospital correlations. Fixed effects included ΔEBITDA, net margin (percentage points), annual surgical volume (procedures per year), ICU beds, and staffed beds (time-varying covariates capturing capacity, activity, and operational complexity). Effects are reported as β estimates (absolute annual change on the native clinical scale) with 95% confidence intervals (CIs) and two-sided p values. All outcomes were modelled on their native continuous scales (no binomial or count links). Model adequacy was evaluated through residual diagnostics, inspection of random-effects variance components, and marginal and conditional R^2, including assessment of residuals versus fitted values to examine linearity, Q–Q plots to evaluate approximate normality, scale–location plots to assess homoscedasticity, and Cook's distance to identify influential observations. The inference used cluster-robust standard errors at the hospital level.

Given that analyses were conducted on hospital-year aggregated outcomes at the network level, the distribution of rates and proportions was sufficiently symmetric to support linear modelling. The use of volume-weighted estimation and robust standard errors further mitigated potential heteroscedasticity related to differences in denominators across hospitals.

To examine whether temporal trends differed by the mode of entry, the models additionally included hospital type (network-built versus acquired) and year × hospital type interaction as fixed effects. (Network-built hospitals were newly constructed and operated by the network; acquired hospitals were preexisting facilities incorporated into the network). Although some indicators represent proportions or event rates, analyses were conducted at the hospital-year aggregate level, where linear mixed-effects models are commonly used to estimate longitudinal trends with adequate robustness and interpretability. The primary focus of the analysis was longitudinal directional changes rather than individual-level risk estimation.

To explore potential non-linear temporal patterns, restricted cubic spline models with low degrees of freedom (df = 3) were fitted as sensitivity analyses. These models were used to assess whether deviations from linearity, including potential transient deteriorations and subsequent recovery, materially influenced the interpretation of temporal trends.

To assess the potential impact of the COVID-19 pandemic on quality trajectories, we conducted prespecified sensitivity analyses based on three calendar periods: 2016–2019 (pre-pandemic), 2020–2022 (pandemic), and 2023–2024 (post-pandemic). First, we compared the period means for each indicator using analysis of variance, with two-sided post-hoc pairwise tests and multiplicity controls, as appropriate (Tukey's Honest Significant Difference test).

Analyses were conducted using R version 4.3.1 (R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria), with statistical significance set at $p < 0{\cdot}05$.

Results

Hospital characteristics and trajectory of quality indicators

The analytical cohort comprised tertiary hospitals distributed across five Brazilian regions. Hospital participation increased from 25 sites in 2016 to 57 in 2024 as additional hospitals were progressively integrated into the network (Suppl. Fig. S1). The characteristics of the participating hospitals (geographic region, accreditation status, and hospital type by mode of network inclusion (acquired versus network-built facilities) across study years are shown in the Supplementary Material (Suppl. Tables S1–S3; Suppl. Fig. S2). Temporal distributions of ICU capacity, hospital size (staffed beds), and annual surgical volume are presented in Suppl. Table S4.

We report the annual change (β estimate) as the average difference in the indicator per calendar year. Figure 1 illustrates observed values and spline-based fitted trends, whereas linear models were used for primary inference. Surgical mortality (Q01) decreased significantly over the study period (β estimate – 0·014 [95% CI: −0·02 to – 0·01]; $p < 0{\cdot}001$). No evidence of a sustained downward trajectory was observed for surgical site infections (Q02) (β: −0·014 [95% CI: −0·02 to 0·04]; $p = 0{\cdot}54$), with non-linear temporal variation and no consistent directional pattern.

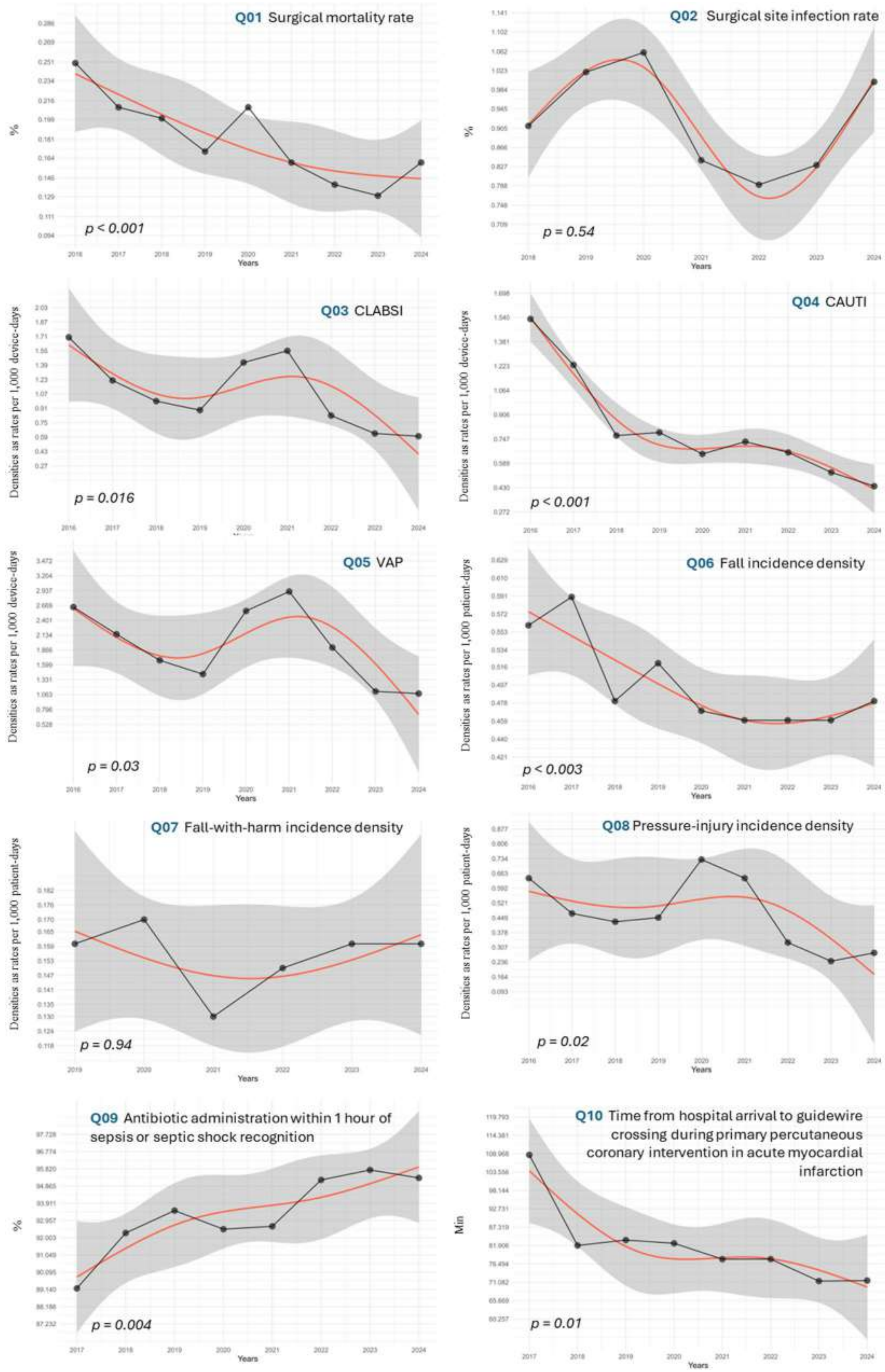

Fig. 1 Each panel displays the annual trajectory of a hospital quality indicator (Q01–Q10). The black line represents observed annual mean values, and the red line represents the fitted non-linear trend estimated using spline-based regression models. The shaded grey area indicates the 95% confidence interval around the fitted curve. Series initiated in different years: Q02 from 2018; Q07 from 2019; Q09 and Q10 from 2017. Abbreviations: CLABSI = Central Line–Associated Bloodstream Infection; CAUTI = Catheter-Associated Urinary Tract Infection; VAP = Ventilator-Associated Pneumonia

CLABSI (Q03) rates in adult ICUs significantly declined (β: −0·183 [95% CI: −0·32 to − 0·04]; $p = 0·016$). Spline-based analyses indicated a non-linear trajectory, with an initial decline followed by a transient increase during 2020–2021 and subsequent improvement, consistent with the overall downward linear trend.

We observed a marked reduction in CAUTI (Q04), averaging 0·148 (95% CI: −0·21 to − 0·09) fewer events per 1,000 catheter-days each year ($p < 0·001$). After steep early gains, rates stabilized briefly and then continued to fall to near-series lows by 2024. VAP (Q05) significantly declined, with an average annual change of − 0·196 per 1,000 ventilator-days (95% CI: −0·37 to − 0·02) ($p = 0·03$). Spline-based analyses suggested a non-linear pattern, with early reductions, a transient increase during 2020–2021, and subsequent decline, without altering the overall downward linear trend.

Fall incidence density (Q06) showed a consistent network-wide decrease (β estimate − 0·015 per 1,000 patient-days (95% CI: −0·02 to − 0·01; $p = 0·003$), marked by early improvements, stabilization through 2021–2023, and a small late-series rise that did not alter the net decline. Conversely, injurious fall incidence density (Q07), measured from 2019 onward, displayed no detectable linear trend ($p = 0·94$), reflecting year-to-year volatility rather than sustained change. We observed a net decrease in pressure-injury rates (Q08) (β: −0·050 per 1,000 patient-days per year (95% CI: −0·09 to − 0·01; $p = 0·022$). Temporal smoothing suggested a non-monotonic pattern, with an increase during 2020–2021 followed by a subsequent decline.

Adherence to antibiotic administration within 1 h of sepsis or septic shock recognition (Q09) increased by 0·78% annually (95% CI: 0·37 to 1·19; $p = 0·004$), consistent with strengthened implementation of the institutional sepsis protocol. Time from hospital arrival to guidewire crossing during primary percutaneous coronary intervention for acute myocardial infarction decreased by approximately 4 min annually (Q10) (β: −4·0 min per year; 95% CI: −6·66 to − 1·28; $p = 0·01$), indicating sustained improvement in timeliness with an initial steep decline followed by smaller annual reductions.

Residual diagnostics are presented in Supplementary Fig. S3, annual descriptive statistics for the technical quality indicators (Q01–Q10) are presented in Table 1, and comparisons of linear and spline-based models are shown in Supplementary Table S7. In sensitivity analyses restricted to hospitals with continuous participation over the study period ($n = 25$), results were consistent with the primary analyses. The direction of effects was preserved

Table 1 Annual descriptive statistics for hospital technical quality indicators (Q01–Q10), 2016–2024

Quality indicator	Year; Mean (SD)									Absolute difference from baseline to 2024 (95% CI)
	2016	2017	2018	2019	2020	2021	2022	2023	2024	
Q01 - Surgical mortality	0·25 (0.16)	0·23 (0·17)	0·2 (0·16)	0·18 (0·14)	0·22 (0·14)	0·17 (0·2)	0·15 (0·15)	0·13 (0·1)	0·16 (0·21)	−0·09 (− 0·17 to − 0·01)
Q02 - Surgical site infection	NA	NA	0·91 (1·01)	1·02 (1·19)	1·06 (1·19)	0·84 (0·85)	0·79 (0·62)	0·83 (0·75)	1·00 (0·67)	0·09 (− 0·33 to 0·51)
Q03 - Central line–associated bloodstream infection rate in adult ICUs	1·62 (1·3)	1·16 (0·83)	1·47 (2·2)	0·87 (0·62)	1·57 (1·74)	1·71 (1·46)	1·13 (1·44)	0·71 (0·58)	0·75 (0·84)	−0·87 (− 1·42 to − 0·32)
Q04 - Catheter-associated urinary tract infection in adult ICUs [2]	1·29 (0·81)	1·22 (0·89)	0·92 (0·77)	0·75 (0·83)	0·66 (1·01)	0·91 (1·03)	0·68 (0·96)	0·65 (0·81)	0·52 (1·2)	−0·77 (− 1·21 to − 0·33)
Q05 - Ventilator-associated pneumonia	2·6 (1·86)	1·96 (1·16)	1·48 (1·15)	1·27 (1·75)	2·93 (3·02)	3·31 (4·79)	1·53 (1·72)	1·11 (1·3)	1·14 (1·4)	−1·46 (− 2·28 to − 0·65)
Q06 - Fall incidence density	0·56 (0·27)	0·62 (0·27)	0·49 (0·17)	0·55 (0·25)	0·47 (0·29)	0·51 (0·52)	0·48 (0·27)	0·4 (0·2)	0·47 (0·22)	−0·09 (− 0·14 to 0·03)
Q07 - Fall-with-harm incidence density	NA	NA	NA	0·16 (0·11)	0·17 (0·11)	0·13 (0·11)	0·15 (0·11)	0·16 (0·11)	0·16 (0·12)	0·00 (− 0·05 to 0·05)
Q08 -Pressure-injury incidence density	0·61 (0·43)	0·51 (0·44)	0·42 (0·25)	0·45 (0·33)	0·71 (0·5)	0·68 (0·65)	0·4 (0·47)	0·25 (0·23)	0·28 (0·21)	−0·33 (− 0·51 to − 0·15)
Q09 - Adherence to antibiotic administration within 1 h of sepsis or septic shock recognition	NA	88·9 (7·84)	92·63 (6·59)	92·12 (9·74)	91·97 (11·24)	90·28 (15·68)	95·3 (4·42)	94·92 (9·72)	95·27 (6·27)	6·37 (2·89 to 9·85)
Q10 - Time from hospital arrival to guidewire crossing during primary percutaneous coronary intervention in acute myocardial infarction (min)	NA	114·87 (27·75)	82·92 (17·06)	83·52 (18·86)	86·12 (30·4)	76·05 (24·54)	76·95 (17·26)	76·84 (21·52)	74·25 (26·38)	−40·62 (− 53·47 to 27·77)

Absolute difference from baseline to 2024 reports. For each indicator, rates were calculated using appropriate denominators, including per 1,000 patient-days for falls and pressure injuries, per 1,000 device-days (central line, urinary catheter, and ventilator-days) for healthcare-associated infections, and proportions or percentages where applicable. NA – not applicable

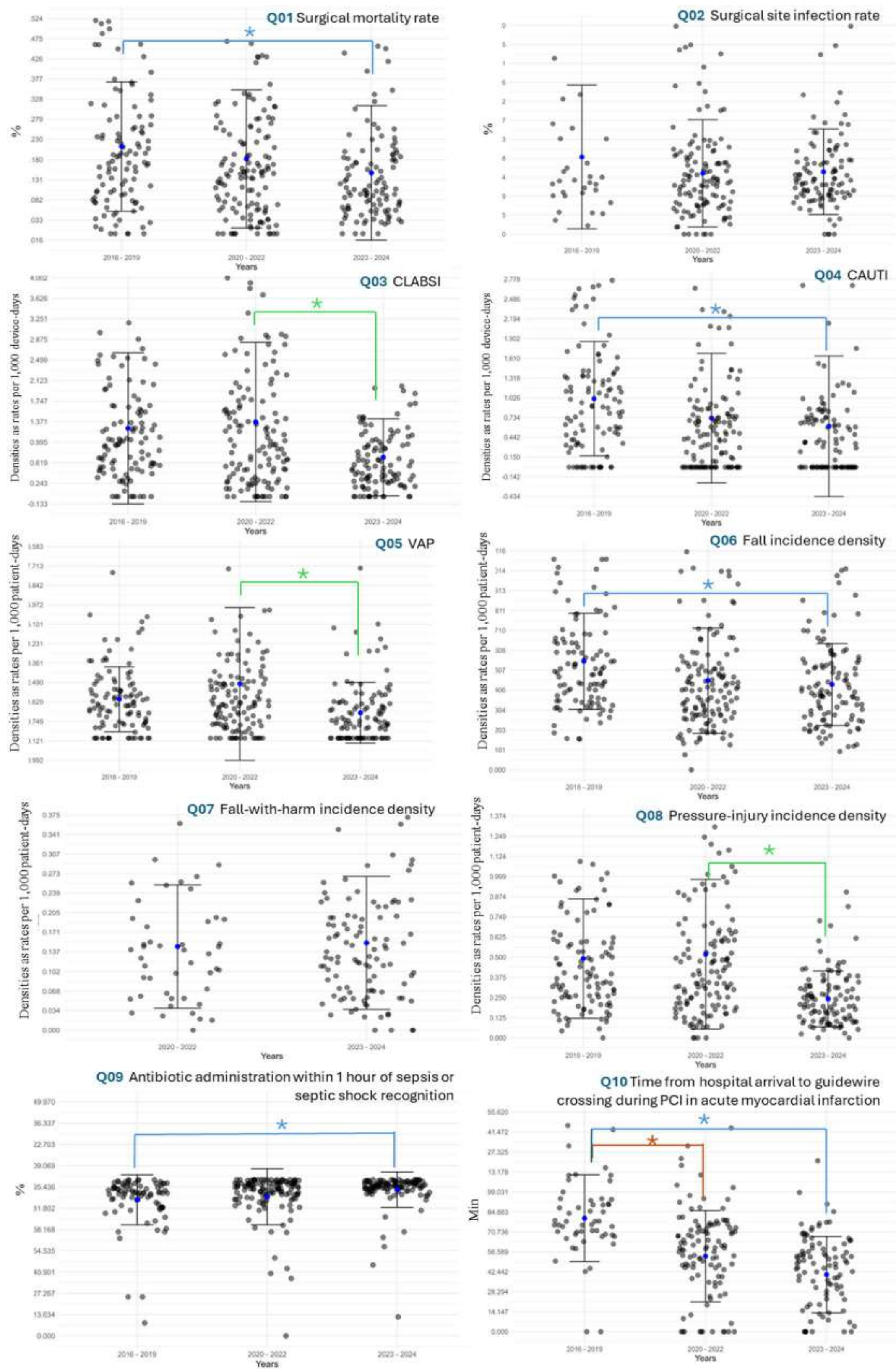

Fig. 2 (See legend on next page.)

(See figure on previous page.)

Fig. 2 Comparative Analysis of Hospital Quality Indicators Across Three Time Periods (Pre-pandemic, Pandemic, and Post-pandemic), 2016–2024. Each panel displays the mean (SD) for each hospital quality indicator (Q01–Q10) across three distinct time periods: 2016–2019 (pre-pandemic), 2020–2022 (pandemic), and 2023–2024 (post-pandemic). Blue dots represent period means, and vertical bars denote SD. Horizontal colored lines represent statistically significant post-hoc pairwise comparisons between periods (green = 2016–2019 vs. 2023–2024; blue = 2016–2019 vs. 2020–2022; red = 2020–2022 vs. 2023–2024), with asterisks (*) indicating $p < 0.05$. Series initiated in different years: Q02 from 2018; Q07 from 2019; Q09 and Q10 from 2017. Abbreviations: CLABSI = Central Line–Associated Bloodstream Infection; CAUTI = Catheter-Associated Urinary Tract Infection; VAP = Ventilator-Associated Pneumonia; PCI = Percutaneous coronary intervention

across all indicators, with similar magnitudes of change (Suppl. Table S8; Suppl. Fig. S4), suggesting that the observed trends were not primarily driven by compositional changes due to network expansion.

Sensitivity analyses of indicator trajectories in the context of the COVID-19 outbreak

Stratification into three periods—pre-COVID-19 outbreak (2016–2019), COVID-19 outbreak (2020–2022), and recovery (2023–2024)–confirmed these segmented patterns. Surgical mortality decreased from 0·21% to 0·15% ($p = 0·01$; pre-COVID-19 outbreak vs. recovery $p = 0·005$), whereas surgical site infection remained unchanged ($p = 0·32$). CLABSI increased from 1·26 to 1·45 and then decreased to 0·73 per 1,000 catheter-days (overall $p < 0·001$; pre-COVID-19 outbreak vs. recovery, $p = 0·005$; COVID-19 outbreak vs. recovery, $p < 0·001$). CAUTI decreased from 1·02 to 0·59 ($p = 0·003$; pre-COVID-19 outbreak vs. recovery, $p = 0·002$). VAP increased from 1·79 to 2·51 and then decreased to 1·13 per 1,000 ventilator-days (overall, $p < 0·001$; COVID-19 outbreak vs. recovery, $p < 0·001$).

Fall incidence density decreased from 0·55 to 0·43 per 1,000 patient-days ($p < 0·001$; pre-COVID-19 outbreak vs. recovery, $p = 0·007$). Fall with harm incidence density was stable between the COVID-19 outbreak and recovery periods (0·15 vs. 0·16 per 1,000 patient-days; $p = 0·58$). Pressure–injury incidence density increased from 0·49 to 0·58 and then decreased to 0·26 per 1,000 patient-days (overall $p < 0·001$; pre-COVID-19 outbreak vs. recovery, $p = 0·002$; COVID-19 outbreak vs. recovery, $p < 0·001$). Adherence to antibiotic administration within 1 h of sepsis or septic shock recognition increased from 91·33% to 95·09% ($p = 0·008$; pre-COVID-19 outbreak vs. recovery, $p = 0·01$). Time from hospital arrival to guidewire crossing during primary percutaneous coronary intervention in acute myocardial infarction decreased from 88·72 to 75·52 min ($p < 0·001$; pre-COVID-19 outbreak vs. COVID-19 outbreak, $p = 0·04$; pre-COVID-19 outbreak vs. recovery, $p = 0·004$) (Fig. 2; Suppl. Table S5).

Temporal trends by hospital type (network-built vs. acquired)

Using indicator-specific linear mixed-effects models with hospital-level random intercepts and slopes for the calendar year, we estimated the within-hospital annual changes overall and by hospital type (network-built vs. acquired) (Table 2). Surgical mortality declined over time in both groups ($p < 0·05$), whereas surgical site infection showed no significant change. CLABSI incidence decreased over time ($p < 0·05$). VAP, CAUTI, and overall inpatient fall incidence declined in both groups ($P < 0·05$), whereas fall-with-harm incidence did not change significantly. Pressure–injury incidence decreased, adherence to antibiotic administration within 1 h of sepsis or septic shock recognition increased, and door-to-wire time shortened over time in both groups (all $p < 0·05$). Supplementary Figs. S5–S7 and Supplementary Table S6 present hospital-level trajectories from network entry stratified by hospital type.

Analysis of net margin and year-over-year EBITDA

Weighted linear regression with year as a continuous predictor, with weights equal to the number of hospitals contributing to each year, found no evidence of temporal change in net margin (β: 0·008, 95% CI: −0·012 to 0·028; $p = 0·31$) or year-over-year ΔEBITDA (β: −0·019, 95% CI: −0·536 to 0·499; $p = 0·91$) (Suppl Fig. S8).

In multivariate mixed effects models adjusted for net margin, change in EBITDA, annual surgical volume, intensive care unit beds, and staffed beds, the annual trend indicated consistent improvements in several indicators. CLABSI decreased by 0·07 per 1,000 central line-days per year (95% CI: −0·13 to − 0·01; $p = 0·03$), CAUTI by 0·07 per 1,000 catheter-days (95% CI: −0·13 to − 0·01; $p = 0·01$), pressure–injury incidence density by 0·04 per 1,000 patient-days (95% CI – 0·06 to – 0·02; $p < 0·001$), and fall incidence density by 0·01 per 1,000 patient-days (95% CI – 0·03 to – 0·00; $p = 0·02$). The proportion of patients with sepsis or septic shock receiving antibiotic administration within 1 h of sepsis or septic shock recognition increased by 1·67% per year (95% CI: 1·10 to 2·23; $p < 0·001$). Time from hospital arrival to guidewire crossing during primary percutaneous coronary intervention in acute myocardial infarction decreased by 6·76 min per year (95% CI: −8·45 to – 5·07; $p < 0·001$). Trends for surgical mortality (β: −0·01, 95% CI: −0·02 to 0·00; $p = 0·08$) and VAP (β: −0·07, 95% CI: −0·18 to 0·04; $p = 0·20$) were not significant, and surgical site infection showed no change (β: −0·0005, 95% CI: −0·0012 to 0·0002; $p = 0·15$) (Table 3). Across indicator-specific mixed-effects models, most indicators showed favourable or stable annual trends, while some exhibited non-significant or transient worsening during the COVID-19 period. ΔEBITDA

Table 2 Indicator-specific linear mixed-effects estimates of baseline level and annual trend by hospital type (network-built vs. acquired), 2016–2024

Quality indicator	Acquired Hospital		Network-built Hospital	
	β estimate (95% CI)	*P*-Value	β estimate (95% CI)	*P*-Value
Q01 - Surgical mortality[1]				
Intercept	0·24 (0·19 to 0·29)	< 0·001	0·21 (0·14 to 0·27)	< 0·001
Year (annual trend)	-0·01 (-0·02 to -0·01)	**< 0·001**	-0·01 (-0·02 to -0·01)	**0·001**
Q02 - Surgical site infection[1]				
Intercept	0·012 (0·009 to 0·014)	< 0 ·001	0·0141 (0·01 to 0·0185)	< 0·001
Year (annual trend)	-0·0005 (-0·001 to 0·0002)	0·18	-0·0008 (-0·002 to 0·0003)	0·16
Q03 - Central line–associated bloodstream infection rate in adult ICUs [2]				
Intercept	1·73 (1·42 to 2·05)	< 0 ·001	1·22 (0·87 to 1·57)	< 0,001
Year (annual trend)	-0·13 (-0·19 to -0·07)	**< 0·001**	-0·10 (-0·15 to -0·04)	**< 0·001**
Q04 - Catheter-associated urinary tract infection in adult ICUs [2]				
Intercept	1·31 (1·09 to 1·53)	< 0·001	1·38 (1·19 – 2·95)	0·02
Year (annual trend)	-0·12 (-0·16 to -0·08)	**< 0·001**	-0·06 (-0·10 to -0·02)	**0·002**
Q05 - Ventilator-associated pneumonia [2]				
Intercept	2·89 (2·26 to 3·52)	< 0·001	2·54 (1·79 to 3·30)	< 0·001
Year (annual trend)	-0·26 (-0·38 to -0·14)	**< 0·001**	-0·17 (-0·30 to -0·03)	**0·02**
Q06 - Fall incidence density [2]				
Intercept	0·58 (0·52 to 0·65)	< 0·001	0·56 (0·45 to 0·67)	< 0·001
Year (annual trend)	-0·02 (-0·03 to -0·01)	**< 0·001**	-0·03 (-0·05 to -0·02)	**< 0·001**
Q07 - Fall-with-harm incidence density [2]				
Intercept	0·16 (0·12 to 0·20)	< 0·001	0·14 (0·04 to 0·24)	0·01
Year (annual trend)	0·003 (-0·02 to 0·01)	0·68	-0·003 (-0·04 to 0·03)	0·85
Q08 -Pressure-injury incidence density[2]				
Intercept	0·62 (0·54 to 0·71)	< 0·001	0·76 (0·55 to 0·96)	< 0·001
Year (annual trend)	-0·05 (-0·07 to -0·03)	**< 0·001**	-0·08 (-0·11 to -0·05)	**< 0·001**
Q09 - Adherence to antibiotic administration within 1 hour of sepsis or septic shock recognition [1]				
Intercept	82·32 (77·71 to 86·93)	< 0·001	85·78 (82·28 to 89·28)	< 0,001
Year (annual trend)	2·00 (1·32 to 2·69)	**< 0·001**	1·58 (0·88 to 2·27)	**< 0·001**
Q10 - Time from hospital arrival to guidewire crossing during primary percutaneous coronary intervention in acute myocardial infarction [3]				
Intercept	61·11 (51·07 to 71·15)	< 0,001	85·7 (62·98 to 108·41)	< 0·001
Year (annual trend)	-4·98 (-6·60 to -3·36)	**< 0·001**	-7·75 (-10·3 to -5·20)	**< 0·001**

Series initiated in different years: Q02 from 2018; Q07 from 2019; Q09 and Q10 from 2017. [1] Proportions are reported as percentages (%). [2] Rates were calculated using appropriate denominators, including per 1,000 patient-days for falls and pressure injuries and per 1,000 device-days (central line-days, urinary catheter-days, and ventilator-days) for healthcare-associated infections. [3] Time variables are reported in minutes. For like-for-like comparisons between mode-of-entry groups, trajectories were aligned at each hospital's first year of measurement and compared over subsequent years. CI, confidence interval

(Suppl. Fig. S9) was not associated with annual changes in the quality indicators (Q01–Q10). Net margin (Fig. 3) showed no association with most indicators; however, higher net margin was significantly associated with lower incidence of fall with harm (Q07) (β – 0·0012, 95% CI – 0·0020 to – 0·0005; $p = 0·002$) and pressure injury (Q08) (β – 0·0023, 95% CI – 0·0038 to – 0·0009; $p = 0·002$).

Discussion

This study adds to the literature on system-level quality improvement by examining longitudinal changes in technical quality indicators and financial performance within a nationwide private hospital network operating under unified clinical governance. Over 9 years, we assessed a broad set of quality-of-care measures, aligned trajectories to each hospital's first measurement year, and contrasted trends between newly network-built hospitals and acquired facilities. Using hospital-year mixed-effects models, complementary network-level analyses, and sensitivity analyses accounting for the COVID-19 period, we evaluated the magnitude and direction of temporal change and the extent to which quality improvement coincided with stable operating performance.

In multivariate mixed effects models adjusted for net margin, change in EBITDA, annual surgical volume, intensive care unit beds, and staffed beds, we observed sustained downward trajectories in CLABSI (Q03), CAUTI (Q04), fall incidence density (Q06), and

Table 3 Mixed-effects linear models for annual trends in hospital quality indicators, adjusted for hospital characteristics and financial performance

	Fixed effects	**β estimate (95% CI)**	***P*-value**
Q01 - Surgical mortality[1]			
	Intercept	0·20 (0·11 to 0·29)	< 0.001
	ΔEBITDA	-0·000010 (-0·000047 to 0·000027)	0·61
	Net margin (%)	-0·000021 (-0·000751 to 0·000710)	0·96
	Surgical procedures (n)	-0·000008 (-0·000015 to -0·000001)	0·03
	Intensive Care Unit beds (n)	-0·0003 (-0·0012 to 0·0007)	0·57
	Staffed beds (n)	0·0006 (0·00001 to 0·0011)	0·05
	Year (annual trend)	-0·01 (-0·02 to 0·001)	0·08
Q02 - Surgical site infection[1]			
	Intercept	0·01 (0·01 to 0·02)	< 0.001
	ΔEBITDA	0·000001 (-0·000001 to 0·000003)	0·52
	Net margin (%)	0·000023 (-0·000021 to 0·000067)	0·30
	Surgical procedures (n)	0·000000 (0·000000 to 0·000000)	0·52
	Intensive Care Unit beds (n)	-0·000026 (-0·000082 to 0·000029)	0·35
	Staffed beds (n)	0·000007 (-0·000022 to 0·000037)	0·62
	Year (annual trend)	-0·0005 (-0·0012 to 0·0002)	0·15
Q03 - Central line–associated bloodstream infection rate in adult ICUs[2]			
	Intercept	1·53 (1·02 to 2·03)	< 0.001
	ΔEBITDA	0·0001 (-0·0002 to 0·0004)	0·45
	Net margin (%)	-0·0004 (-0·0054 to 0·0047)	0·89
	Surgical procedures (n)	0·000003 (-0·000041 to 0·000047)	0·89
	Intensive Care Unit beds (n)	-0·008 (-0·015 to -0·001)	0·02
	Staffed beds (n)	0·002 (-0·001 to 0·006)	0·23
	Year (annual trend)	-0·07 (-0·13 to -0·01)	0·03
Q04 - Catheter-associated urinary tract infection in adult ICUs[2]			
	Intercept	1·44 (0·72 to 2·15)	< 0.001
	ΔEBITDA	0·0001 (-0·0001 to 0·0004)	0·39
	Net margin (%)	0·0014 (-0·0038 to 0·0066)	0·60
	Surgical procedures (n)	-0·00003 (-0·00008 to 0·00002)	0·23
	Intensive Care Unit beds (n)	-0·0023 (-0·0090 to 0·0045)	0·51
	Staffed beds (n)	0·0009 (-0·0031 to 0·0050)	0·66
	Year (annual trend)	-0·07 (-0·13 to -0·01)	0·01
Q05 - Ventilator-associated pneumonia[2]			
	Intercept	2·39 (1·57 to 3·21)	< 0.001
	ΔEBITDA	0·0000 (-0·0004 to 0·0005)	0·84
	Net margin (%)	0·0025 (-0·0061 to 0·0112)	0·56
	Surgical procedures (n)	-0·00002 (-0·00009 to 0·00005)	0·55
	Intensive Care Unit beds (n)	-0·0052 (-0·0167 to 0·0062)	0·37
	Staffed beds (n)	0·0002 (-0·0055 to 0·0060)	0·93
	Year (annual trend)	-0·07 (-0·18 to 0·04)	0·20
Q06 - Fall incidence density[2]			
	Intercept	0·58 (0·44 to 0·71)	< 0.001
	ΔEBITDA	0·00001 (-0·00004 to 0·00007)	0·58
	Net margin (%)	-0·00059 (-0·00160 to 0·00043)	0·25
	Surgical procedures (n)	-0·00001 (-0·00002 to 0·00000)	0·21
	Intensive Care Unit beds (n)	-0·00031 (-0·00163 to 0·00101)	0·65
	Staffed beds (n)	0·00032 (-0·00047 to 0·00112)	0·42
	Year (annual trend)	-0·01 (-0·03 to 0·00)	0·02
Q07 - Fall-with-harm incidence density[2]			
	Intercept	0·19 (0·10 to 0·27)	< 0,001
	ΔEBITDA	-0·00001 (-0·00004 to 0·00001)	0·37

Table 3 (continued)

	Fixed effects	β estimate (95% CI)	*P*-value
	Net margin (%)	-0·0012 (-0·0020 to -0·0005)	0·002
	Surgical procedures (n)	-0·000003 (-0·000011 to 0·000004)	0·37
	Intensive Care Unit beds (n)	-0·000029 (-0·000788 to 0·000731)	0·94
	Staffed beds (n)	0·0001 (-0·0004 to 0·0007)	0·62
	Year (annual trend)	0·01 (-0·01 to 0·02)	0·47
Q08 -Pressure-injury incidence density[2]			
	Intercept	0·73 (0·59 to 0·87)	< 0.001
	ΔEBITDA	-0·000001 (-0·00008 to 0·00007)	0·98
	Net margin (%)	-0·0023 (-0·0038 to -0·0009)	0·002
	Surgical procedures (n)	0·0000 (0·0000 to 0·0000)	0·92
	Intensive Care Unit beds (n)	-0·0001 (-0·0020 to 0·0018)	0·95
	Staffed beds (n)	-0·0006 (-0·0016 to 0·0004)	0·22
	Year (annual trend)	-0·04 (-0·06 to -0·02)	< 0,001
Q09 - Adherence to antibiotic administration within 1 h of sepsis or septic shock recognition[1]			
	Intercept	79·81 (73·50 to 86·13)	< 0.001
	ΔEBITDA	0·0006 (-0·002 to 0·003)	0·64
	Net margin (%)	0·03 (-0·02 to 0·08)	0·28
	Surgical procedures (n)	0·000 (-0·001 to 0·000)	0·76
	Intensive Care Unit beds (n)	-0·02 (-0·08 to 0·05)	0·61
	Staffed beds (n)	0·03 (-0·01 to 0·07)	0·10
	Year (annual trend)	1·67 (1·10 to 2·23)	< 0.001
Q10 - Time from hospital arrival to guidewire crossing during primary percutaneous coronary intervention in acute myocardial infarction[3]			
	Intercept	67·22 (50·12 to 84·32)	< 0.001
	ΔEBITDA	-0·005 (-0·011 to 0·002)	0·16
	Net margin (%)	0·037 (-0·107 to 0·182)	0·61
	Surgical procedures (n)	0·001 (-0·001 to 0·002)	0·23
	Intensive Care Unit beds (n)	-0·027 (-0·202 to 0·148)	0·76
	Staffed beds (n)	0·060 (-0·044 to 0·164)	0·26
	Year (annual trend)	-6·76 (-8·45 to -5·07)	< 0.001

Each model was estimated separately for each quality indicator, with hospital-level random intercepts and slopes for the calendar year. Fixed effects included ΔEBITDA, net margin (%), number of surgical procedures, number of intensive care unit beds, and staffed beds, which were incorporated to account for secular changes in hospital size, complexity, and financial performance. β estimates represent annual changes in each indicator after adjustment. Significant p-values (< 0·05) are shown in bold. Series initiated in different years: Q02 from 2018; Q07 from 2019; Q09 and Q10 from 2017. Series initiated in different years: Q02 from 2018; Q07 from 2019; Q09 and Q10 from 2017. [1] Proportions are reported as percentages (%). [2] Rates were calculated using appropriate denominators, including per 1,000 patient-days for falls and pressure injuries and per 1,000 device-days (central line-days, urinary catheter-days, and ventilator-days) for healthcare-associated infections. [3] Time variables are reported in minutes. ΔEBITDA denotes the year-over-year change in Earnings Before Interest, Taxes, Depreciation, and Amortization, used as a proxy for hospital operating performance

pressure–injury incidence density (Q08), together with favourable movement in process and timeliness metrics, namely higher adherence to antibiotic administration within 1 h of sepsis or septic shock recognition (Q09) and shorter time from hospital arrival to guidewire crossing during primary percutaneous coronary intervention in acute myocardial infarction (Q10). Conversely, the annual trends for surgical mortality (Q01) and VAP (Q05) were not significant after adjustment, surgical site infection (Q02) showed no clear temporal change, and injurious falls (Q07) exhibited marked year-to-year variability without a consistent trend. These patterns are broadly concordant with the national findings from the AHRQ Hospital Acquired Conditions Scorecard [17], which reported an overall 13% decline in hospital-acquired conditions (HACs) from 2014 to 2017, with heterogeneity across components.

Beyond these temporal trends, we also identified statistically significant inverse associations between financial performance and selected patient safety indicators. Specifically, higher net margin was associated with lower incidence of fall with harm (Q07) and pressure injury (Q08). Although the magnitude of these associations was modest, the directionality suggests a potential alignment between technical quality and financial performance within a unified governance framework. This pattern should be interpreted with caution. The observational design precludes causal inference, and residual

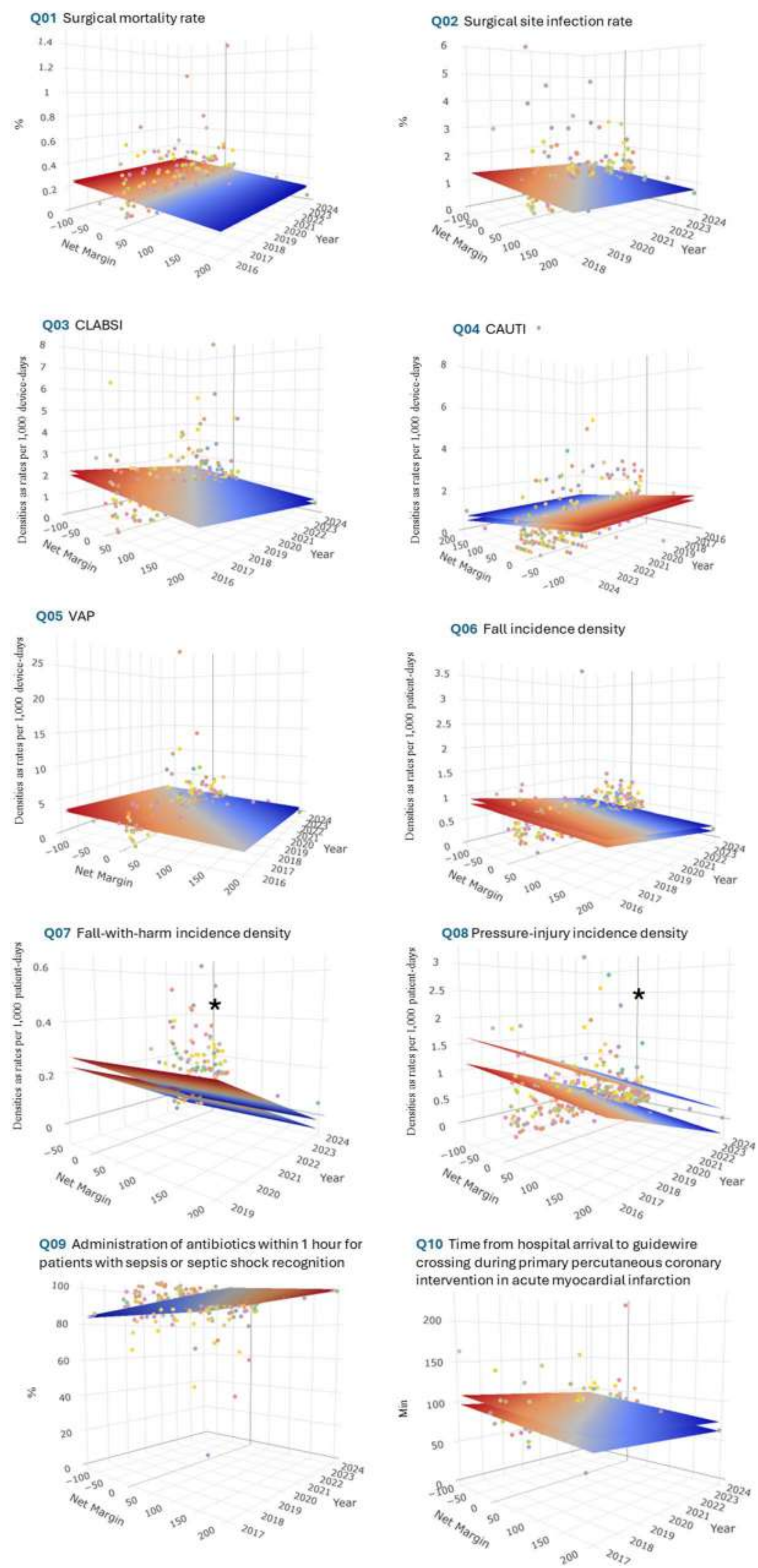

Fig. 3 (See legend on next page.)

(See figure on previous page.)

Fig. 3 Three-dimensional scatter plot with mixed model plan - Hospital quality indicators by calendar year and net margin (Q01–Q10), 2016–2024. Each panel displays hospital-year observations (dots) for a given indicator with Net margin (%) on the x-axis, Calendar year on the y-axis, and the indicator value on the z-axis (units as shown: %, rates per 1,000 patient-days/device-days, as appropriate, or minutes). The colored surface represents the fitted plane from a linear mixed-effects model including calendar year and net margin as fixed effects and hospital-level random effects. The blue-to-red gradient denotes increasing predicted values. Abbreviations: CLABSI = Central Line–Associated Bloodstream Infection; CAUTI = Catheter-Associated Urinary Tract Infection; VAP = Ventilator-Associated Pneumonia. * P-value < 0.05

confounding cannot be excluded. One possible explanation is that safer care processes reduce complications and associated resource utilisation, thereby contributing to improved financial performance [7]. Alternatively, hospitals with stronger financial margins may have greater capacity to invest in staffing, training, and safety infrastructure. These bidirectional mechanisms highlight the complex interplay between quality and financial outcomes.

Data reported in 2016 estimated that, during 2011–2014, reductions in HACs totalled 2·1 million, corresponding to approximately $19·9 billion in cost savings and about 87,000 fewer HAC-related in-hospital deaths. Compared with those shorter, pre-pandemic aggregates, our network shows indicator-specific improvement sustained from 2016 to 2024, including recovery from COVID-19 related disruptions, consistent with a maturing safety program under unified clinical governance. Another potential contributing factor is the implementation and subsequent renewal of accreditation in approximately 90% of hospitals, reaching 100% by 2024. However, this temporal association does not establish causality, and the observed improvements cannot be attributed solely to accreditation without a study design capable of causal inference and adequate control for concurrent system-wide initiatives.

A clear post-pandemic improvement was evident in all three indicators. CLABSIs (Q03) declined from the pandemic period to 2023–2024, with lower means in the recovery period compared with 2020–2022. VAP (Q05) also improved during the recovery period, thereby reversing the pandemic. Pressure injury incidence density (Q08) decreased further after the pandemic, with recovery period values that were significantly lower than those observed from 2020 to 2022. Similar reductions have also been reported in several countries [3, 18]. A national analysis from the U.S. National Healthcare Safety Network reported a higher healthcare-associated infection incidence in 2020 than in 2019, with the largest increase in CLABSI and significant increases in ventilator-associated events; CAUTI also increased at the national level [19]. Different patterns were observed in our network. After adjusting for hospital capacity and activity, CAUTI infection did not worsen; rather, it followed an approximately linear downward trajectory across all years, including the pandemic and recovery periods, consistent with sustained improvement and no pandemic-related step change. Our observed hospital mortality during the COVID-19 period was 7·8%, as reported in our previous study, significantly lower than rates previously reported in Brazil [4]. This difference may reflect multiple organisational factors within the network, including standardized care pathways, continuous audits with feedback, and the restoration of routine prevention practices, which together may have attenuated the impact of the pandemic on clinical outcomes.

The COVID-19 period placed exceptional pressure on emergency services with variable impacts across systems. Several studies have reported a deterioration in time-sensitive care during the COVID-19 period, including lower compliance with primary percutaneous coronary intervention within 90 min for ST-segment elevation myocardial infarction and delays in early antibiotic therapy for sepsis [20–23]. Conversely, in our cohort, the time from hospital arrival to guidewire crossing during primary percutaneous coronary intervention for acute myocardial infarction improved steadily from 2016 to 2024, with shorter times and sustained adherence to the 90 min benchmark across the pandemic and recovery periods. Contrary to the prevailing signal of delay, our network maintained a year-on-year improvement without a pandemic-related step change.

An important objective of this study was to examine how trajectories of technical quality indicators evolve once hospitals are integrated under a unified network of clinical governance. Prior U.S.A. work using a quasi-experimental design reported that joining an affiliation network was not associated with better clinical quality or financial performance for affiliates of networks sponsored by multispecialty hospitals, with heterogeneous financial effects and no change in clinical quality or patient experience [13]. Proposed explanations included limited uptake of sponsor resources, access frictions, and reluctance to change practices. In contrast, within our network, indicator-specific linear mixed-effects models showed consistent year-over-year improvements across multiple technical domains, with directionally similar trends in both network-built and acquired hospitals. Notably, whereas that study focused on thirty-day readmission and condition-specific 30-day mortality for selected diagnoses, our indicator set spanned safety, device-related infections, inpatient harm, and time-sensitive care processes across services. These measures are proximal to bedside practice and governance standardization, which may increase the sensitivity to detect system-level improvement and provide earlier signals than the downstream thirty-day outcomes influenced by post-discharge factors. Collectively, the pattern observed here is compatible with an integration model that extends beyond affiliation by coupling unified governance with standardized pathways, benchmarking at scale, and active performance management.

Structural differences between health systems likely help explain the contrast between our findings and those of prior U.S.A. studies [13]. In Brazil, hospitals are typically smaller, operate with constrained access to capital, and have tighter operating margins. In such settings, integration into a large network can generate meaningful gains through a shared administrative infrastructure, centralized quality management, standardized clinical pathways, and pooled investment in improvement capabilities, enabling a single governance and support structure to serve multiple hospitals. Conversely, hospitals in the United States tend to be larger, more technologically intensive, and operate at higher baseline costs, often retaining substantial operational autonomy even after joining affiliation networks. These characteristics may attenuate the incremental impact of network integration on frontline clinical practice. Collectively, these contrasts suggest that the effects of network integration on technical quality are context dependent and may be more pronounced in health systems, where scale constraints and fragmentation create a greater scope for system-level coordination. These interpretations should be considered within the scope of the present study, which does not include a public-sector comparison group and therefore does not assess differences in performance between private and public healthcare systems.

During the study period, multiple measures were implemented across the participating hospitals to strengthen patient safety culture. Interventions included the introduction of a standardized Manual of Clinical Practices in all hospitals to unify quality and safety procedures, routine audits with continuous feedback on performance, and reinforcement of Patient Safety Units while fostering a culture that encourages open reporting of adverse events and near misses. The consistent strengthening of safety culture over time throughout the network, as described in other studies [12, 24], is temporally aligned with the improvements observed in technical quality indicators in this cohort.

Consistent with prior U.S. evidence from the 1990s suggesting that safety net activity had, at most, small effects on hospital profitability, our mixed-effects estimates indicate that sustained improvement in technical quality was not associated with deterioration in financial performance [25]. In other words, investment in quality improvement is not associated with a deterioration in financial performance. Although the settings and methods differ, both results are compatible with a scenario in which organizational missions and system-level quality initiatives need not erode net margins.

Historically, hospital leaders have been reluctant to fund quality improvement and safety programs, and literature directly linking technical quality to financial performance remains limited [5]. Prior studies have argued for the closer integration of quality and financial management, noting that separating these functions may miss operational interdependencies [26, 27]. Beauvais et al. reported positive associations between Leapfrog patient safety scores and several financial metrics, including net operating margins per discharge, suggesting that stronger safety performance can align with stronger profitability [27, 28]. In a later analysis, Beauvais et al. (2019) found that higher patient safety performance is positively associated with hospital financial performance [28]. Our results complemented these findings. Using a long-horizon panel in a large private network in Brazil and mixed-effects models that adjust for hospital capacity and activity, we observed sustained improvement in multiple technical indicators without evidence of financial deterioration, as measured by EBITDA and net margin. Although these metrics do not capture capital investment cycles or long-term strategic returns, they provide a pragmatic and comparable measure of short- to medium-term financial performance across hospitals and years. Our findings are consistent with the premise that disciplined quality management can coexist with financial sustainability when quality and finance are managed as connected components of the same operating system.

Although one might expect sustained improvements in technical quality to translate into higher margins [29], our models do not show a positive association between hospital improvement and financial performance. While inverse associations were observed for selected patient safety indicators (fall-with-harm and pressure-injury incidence), these were modest in magnitude and not consistent across all measures. This result is consistent with the level of analysis and the nature of the financial outcomes [30]. Net margins and EBITDA are aggregate measures that pool many revenue and cost streams. Savings from fewer complications, shorter length of stay, and greater process reliability are real at the episode level, but can be diluted by concurrent forces such as case mix shifts, investment cycles, pricing and payer mix, and accounting policies. The absence of a positive association at the margin level does not undermine the business quality. Instead, our findings are consistent with financial neutrality at the network level alongside meaningful clinical gains, supporting health system sustainability and aligning with the principles of value-based care. In practical terms, reductions in adverse events are likely to have decreased the direct costs associated with preventable harm, even if these savings were not reflected in the aggregate financial indicators over the study period. Importantly, the lack of an inverse association between quality improvement and financial performance indicates that sustained investments in clinical governance can coexist with economic viability, although causal inferences cannot be made.

Our findings suggest that a strategic focus on quality may be compatible with maintaining financial stability, while supporting improvements in technical quality. This study extends the literature that links structural and operational characteristics to hospital financial distress [31, 32]. Beyond the previously cited drivers, such as occupancy and case mix, we suggest that hospital managers may consider measurable quality as a modifiable domain when seeking to improve operating performance and reduce the risk of financial distress. Financial decline carries consequences that can be difficult to reverse, including weaker credit ratings, higher borrowing costs, and profit margin compression [31].

Study strengths and limitations

This study has several strengths alongside important limitations. Strengths include the nationwide multicentre longitudinal design with up to nine years of follow-up, the use of harmonised technical quality indicators defined a priori under a unified data dictionary, and the integration of audited financial data with clinical quality measures within the same analytical framework. The analytical strategy accounted for staggered hospital entry, repeated measurements, and time-varying hospital capacity and activity using mixed-effects models, thereby improving internal consistency and robustness of the estimated trends. This study also has limitations. First, the observational, unbalanced hospital-year design with staggered entry and late indicator start may have left residual confounding factors despite adjustment. Second, the analyses were based on administratively defined quality indicators, which are susceptible to measurement error, variation in surveillance intensity, and changes in operational definitions. The potential “measurement maturation” of these indicators, including improvements in detection and reporting, may have partially influenced the observed temporal changes and should be considered when interpreting longitudinal trends. Third, important determinants of clinical and financial variation were not measured, including service mix, patient demographics, range of services offered, and clinical staff composition; interaction terms among covariates were not explored and could account for additional variation. Fourth, nonlinear patterns and inflection points may not be fully captured outside period-based sensitivities. In addition, the use of mixed-effects models for rate and proportion outcomes, although supported by aggregation at the hospital-year level and diagnostic evaluation, may be less appropriate for bounded or potentially skewed variables. Alternative modelling approaches using generalized linear mixed models with appropriate link functions could be considered. Fifth, the financial variables are aggregate accounting measures that can dilute episode-level savings and do not constitute a formal test of cost neutrality. As the analyses were associational rather than causal, we cannot infer that unified governance caused the observed improvements. Sixth, hospital accreditation status and the intensity of improvement cycles may have contributed to performance gains; however, these factors were not incorporated, which limits interpretation. Seventh, the period-based stratification of the COVID-19 analysis simplifies a complex and time-varying phenomenon. The use of broad categories (pre-COVID-19, COVID-19, and recovery) may obscure within-period variability and does not fully capture the heterogeneous and dynamic impact of the pandemic across hospitals. These analyses should therefore be interpreted as descriptive sensitivity analyses rather than formal comparisons of causal effects across periods. Eighth, the analyses did not include patient-level case-mix or severity adjustment. Although models incorporated hospital-level characteristics such as ICU capacity, surgical volume, and bed availability as proxies of case complexity, these measures do not fully capture variation in patient severity over time. Changes in case-mix, particularly during the COVID-19 period, may have influenced the observed trends in quality indicators and cannot be excluded. Finally, the findings are most applicable to large private hospital networks operating under unified clinical governance and may not be generalizable to publicly financed health systems in different socioeconomic contexts. Despite these constraints, the inclusion of multiple hospitals and local market characteristics supported the internal validity of the estimated trends.

Conclusions

In this nationwide private hospital network in Brazil, technical quality improved over 9 years, with similar directional trends in hospitals built by the network and those acquired from the private sector after alignment with network entry. Improvements persisted throughout the COVID-19 period in descriptive sensitivity analyses that accounted for pandemic-related pressures and hospital capacity and activity. Most quality indicators showed improvement or remained stable over time, with some transient worsening observed in specific indicators during the COVID-19 period. No consistent association was observed between changes in technical quality indicators and financial performance, although inverse associations were identified between net margin and selected indicators (fall with harm and pressure injury). These findings describe sustained improvements in technical quality alongside overall stable financial performance within a large hospital network operating under unified clinical governance. Further research should assess generalizability to other organisational contexts, examine the relationship between technical indicators and patient-centred outcomes, and incorporate more granular economic measures to better characterise the pathways through which quality improvement interacts with hospital finances.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12913-026-14729-2.

Supplementary Material 1

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Author contributions
Conceptualization: HOL, LRT, RGC, and LMS. Methodology: HOL, LMS, and LRT. Data collection: HOL, LMS, DVR, LRT, ACLFA, VMST, and DS. Data analysis: HOL, LMS, and GBM. Project administration and supervision: HOL, DVR, LMS, and DS. Literature search: HOL, LMS, and GBM. Writing of the original draft: HOL, LMS, and LRT. Critical review, editing, and approval of final manuscript: All authors (HOL, LMS, LRT, ACLFA, VMST, and DS). All authors had full access to all data, participated in data interpretation, revised the manuscript, and approved the final version of the manuscript for publication. LMS is the guarantor in the Contributor ship Statement.

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Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Ethical approval was obtained from the Hospital São Luiz & Rede D´or and Affiliated Teaching Hospitals Research Ethics Board for the publication of this report (protocol # 90767125.3.0000.0087, assent CEP 7.745.616). This study complied with Resolution 466/2012 of the Brazilian National Health Council.

Consent for publication
Not applicable.

Use of AI and AI-assisted technologies in scientific writing
Not applicable.

Competing interests
The authors declare no competing interests.

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