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Neonatal Inborn-Outborn Mortality Concordance in Pediatric Surgery: Gastroschisis and Neonatal Bowel Emergencies Drive Hospital-Level Correlation

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Analysis and interpretation of data: Mehl, Lohmann, Bose, King, Fernandes
Drafting of manuscript: Mehl, Lohmann, Fernandes
Critical revision: Mehl, Lohmann, Bose, King, Fernandes
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Abstract

Background: It is unknown if there is hospital variation in postoperative mortality when stratifying infants by inborn versus outborn status.

Methods: The Pediatric Health Information System® database (2012–2020) was used to identify infants who underwent one of 38 operations. For inborn and outborn infants, reliability-adjusted postoperative mortality rates were generated for each hospital. Sensitivity analyses were performed for gastroschisis and neonatal bowel emergencies.

Results: Overall, 65,217 infants were identified across 47 academic, pediatric hospitals (inborn: 35,046; outborn: 30,171). Adjusted hospital mortality rates for inborn and outborn infants were 1.4% [0.9–2.0] to 2.6% [1.6–3.7] and 6.1% [4.2–8.1] to 13.5% [11.4–15.5] respectively. A significant correlation between inborn and outborn mortality was identified for gastroschisis ($r=0.47$, $p<0.01$) and neonatal bowel emergencies ($r=0.37$, $p=0.01$).

Conclusions: Outborn infants have higher mortality and considerable variation exists between hospitals. When evaluating gastroschisis and neonatal bowel emergencies, there is a significant correlation between outborn and infant adjusted mortality.

Level of Evidence: Level II, Retrospective cohort study
Keywords: Hospital variation, Inborn, Outborn, Mortality

Abbreviation (in order of appearance)	**Definition**
NICU	Neonatal Intensive Care Unit
NEC	Necrotizing Enterocolitis
CDH	Congenital Diaphragmatic Hernia
TEF	Tracheoesophageal Fistula
PHIS	Pediatric Health Information System®
NSQIP – P	National Surgical Quality Improvement Program – Pediatrics
TPN	Total Parenteral Nutrition
ECMO	Extracorporeal Membrane Oxygenation
ICD	International Classification of Diseases

INTRODUCTION

Postoperative mortality, a critical indicator of pediatric surgical quality, has been shown to vary considerably among institutions and high-risk neonatal surgical conditions, with reported mortality rates ranging from 4.0% to 16.3% across institutions. (1) These post-surgical mortality differences are more significant when investigating the variation in outcomes of preterm infants, especially at lower gestational ages. (2) A key determinant of outcome in this vulnerable population is birth location. Infants born at facilities with neonatal intensive care and pediatric surgical capabilities show better survival than those requiring postnatal transfer to such centers. This survival disadvantage for outborn infants persists even after adjustment for gestational age, illness severity, and other perinatal risk factors. (3, 4) Previous studies reported that prenatal transfers and transfer to perinatal centers with high volumes and advanced neonatal intensive care units (NICU) improved the outcomes of extremely premature infants. (5, 6)

For surgical neonates specifically, evidence is mixed regarding the impact of postnatal transfer. For example, outborn infants transferred to freestanding pediatric hospitals had worse outcomes than those transferred to perinatal centers. (7) However, a study evaluating very low birth weight infants with surgical necrotizing enterocolitis (NEC) found that transfer between birth and surgery and a higher level of surgical resources at the operative center were associated with lower mortality. (8) Furthermore, a recent systematic review, with data from high-income countries, indicates that transfer for surgery does not inherently increase risk-adjusted mortality or disability compared with centers with co-located care for conditions such as congenital diaphragmatic hernia (CDH), esophageal atresia and tracheoesophageal fistula (TEF), and gastroschisis. (9)

The extent to which surgical performance for high-risk conditions differs for inborn versus outborn infants has not been well characterized. It remains unclear whether hospitals that demonstrate favorable outcomes for inborn infants perform similarly for transferred infants. Thus, the present study examines hospital-level variation in adjusted mortality for high-risk neonatal surgical conditions, stratified by inborn versus outborn status, using contemporary multicenter data. We hypothesized that outborn neonates would exhibit higher and more variable mortality rates, independent of case mix and volume, with implications for regionalized care and quality improvement efforts.

METHODS

Data Source and Study Population

The Pediatric Health Information System (PHIS) inpatient database was used to conduct a national cohort study of infants (<365 days old at time of surgery) who had 1 of 38 surgical procedures from 2012 to 2020 **(Supplemental Table 1)**. These specific procedures have been evaluated in previous publications evaluating hospital variation in outcomes for children. (10-12). In the initial publication, 57 surgical procedures were identified which included all surgical procedures with at least 2 mortality events in the National Surgical Quality Improvement Program–Pediatric (NSQIP–P) database from 2012–2016. (13, 14). In the current study, procedures with significant overlap were condensed into a single procedure (e.g., enterectomy, ileostomy, colectomy, colostomy were previously separated; now included under enterectomy and/or colectomy +/- ostomy), which condensed the list of procedures from 57 to 38 procedures. The PHIS database was used for this analysis instead of NSQIP–P because it has hospital identifiers and allows for hospital level analysis. The study population was divided into infants born within the hospital system (i.e., inborn) versus infants born outside of the hospital system with subsequent transfer to the treating hospital (i.e., outborn). This was determined based on the "Source of Admission" variable within PHIS. One hospital was excluded because it did not report this variable (n=4,746). For patients who had more than 1 admission during the study period, only the initial admission was analyzed. This study was deemed not human subjects research and exempt from review by the Baylor College of Medicine Institutional Review Board.

Variables

PHIS includes information about race, sex, health insurance, total parenteral nutrition (TPN), mechanical ventilation, and extracorporeal membrane oxygenation (ECMO). Age at time of surgery (in days) was calculated using a combination of date of birth, age at admission, and preoperative length of stay. International Classification of Diseases (ICD) versions 9 and 10 codes were used to determine gestational age (**Supplemental Table 2**). A combination of ICD-9/-10 procedure codes, ICD-9/-10 clinical modification codes, and CPT codes were used to identify patients with high-risk diagnoses (specifically gastroschisis, volvulus/malrotation, NEC, intestinal atresia, meconium peritonitis, TEF, CDH, and perinatal intestinal perforation; **Supplemental Table 3**). These specific diagnoses were identified to control for case mix in the multivariate model due to high associations with morbidity and mortality. (1, 20) The presence of complex chronic conditions were identified using the ICD-9/-10 codes described by Feudtner and colleagues. (15, 16) The Feudtner complex chronic conditions are defined as any medical condition that can be reasonably expected to last at least 12 months (unless

death intervenes) and to involve either several different organ system or 1 organ system severely enough to require specialty pediatric care. (15-17) Over the study period, all hospitals treated patients in either level III or IV NICU. Postoperative mortality was defined using the PHIS “Discharge Mortality Flag.”

Statistical Analysis

The primary outcome was hospital-level, risk and reliability adjusted mortality. Adjusted hospital mortality rates were generated for inborn and outborn infants. Reliability-adjustment is an empirical Bayesian approach that shrinks each hospital’s mortality rate toward the population mean to a degree inversely proportional to its surgical volume. (18, 19) To calculate each hospital’s reliability adjusted mortality rate, a multivariable logistic regression model was created evaluating mortality as the outcome while adjusting for sex, race, insurance status (public, private, other/unknown), age at time of surgery (in days), mechanical ventilation, TPN use, ECMO use, gestational age, each of the Feudtner complex chronic conditions, and case mix (controlling for gastroschisis, volvulus/malrotation, NEC, intestinal atresia, meconium peritonitis, TEF, CDH, and perinatal intestinal perforation). Model covariates were selected a priori in a non-parsimonious fashion. Because the inborn and outborn populations represent distinct patient cohorts, separate models were fit for each. Multicollinearity between model covariates was assessed with variance inflation factor and generation of a correlation matrix of coefficients. The maximum variance inflation factor was 2.30 for inborn and 1.77 for outborn, and all covariates had correlations <0.47. The C-statistic for the model was 0.95 for inborn and 0.86 for outborn. The log(odds) of mortality from the multivariable logistic regression was then obtained using post-estimation prediction. Hierarchical regression (patients clustered within hospitals), including a random effect for the hospital, was then utilized to derive the shrinkage factor, which was applied to create the hospital-level, reliability-adjusted postoperative mortality rates. Specifically, a mixed-effects logistic regression (melogit) was specified with the log-odds of predicted mortality constrained to a coefficient of 1, isolating the hospital-level random effect as the empirical Bayes shrinkage estimate. The hospital-level best linear unbiased predictor was added to the log-odds of the population mean mortality and back-transformed via the inverse logit function to produce the final reliability-adjusted rate. Separately, Pearson correlation coefficient was used to quantify the correlation between the inborn and outborn reliability-adjusted mortality rates. Sensitivity analyses were repeated for the following patient populations: (1) gastroschisis and (2) neonatal bowel emergencies (i.e., NEC, meconium

peritonitis, perinatal intestinal perforation, malrotation with volvulus). Correlation analyses for TEF and CDH could not be performed because reliability adjustment produced negligible between-hospital variance for inborn rates in these subgroups, with all hospitals converging to the population mean. All analyses were performed using Stata version 16.0 (StataCorp, College Station, TX). Significance was determined with p-value <0.05.

RESULTS

Overall, 65,217 infants were identified across 47 academic, pediatric hospitals (inborn, n=35,046; outborn, n=30,171). The most common general surgical procedures for inborn infants were pyloromyotomy (25.6%), enterectomy and/or colectomy with/without stoma creation (17.0%), gastrostomy tube (15.3%), and repair of gastroschisis (6.9%). (**Supplemental Table 1**). The most common general surgical procedures for outborn infants were enterectomy and/or colectomy with/without stoma creation (32.3%), gastrostomy tube (25.3%), repair of gastroschisis (15.4%), and esophagogastric fundoplasty with/without hiatal hernia repair (11.1%). **Table 1** displays demographics, clinical characteristics, and admission characteristics by inborn and outborn status. The proportion of African American patients and patients with public health insurance was higher for outborn infants. There was a higher proportion of patients with at least one of the high-risk diagnoses and at least one of the complex chronic conditions in the outborn cohort. There was an increased incidence of prematurity for outborn infants. Outborn infants were more likely to require mechanical ventilation, TPN, and ECMO.

Table 2 displays demographics, clinical characteristics, and admission characteristics when stratifying inborn and outborn cohorts by mortality tertiles. The mortality rate for all inborn infants was 2.1% [95% confidence interval 2.0–2.3]. Adjusted hospital mortality rates for inborn infants ranged from 1.4% [0.9–2.0] to 2.6% [1.6–3.7] (**Figure 1**). For inborn infants, there was one hospital with significantly lower adjusted mortality rates (**Figure 1, green square)** and zero hospitals with significantly higher adjusted mortality rate when compared to the population mean.

The mortality rate for all outborn infants was 8.2% [7.9–8.5]. Adjusted hospital mortality rates for outborn infants ranged from 6.1% [4.2–8.1] to 13.5% [11.4–15.5] (**Figure 2**). For outborn infants, there was one hospital with significantly lower adjusted mortality rates (**Figure 2, green square)** and three hospitals with significantly higher adjusted mortality rates (**Figure 2, red diamond)** when compared to the population mean.

Figure 3 displays a scatter plot for inborn versus outborn adjusted mortality rates with the size of each point estimate representing hospital volume. Hospitals in the left lower quadrant (n=19) had low adjusted mortality rates for both inborn and outborn infants relative to the population means. In contrast, hospitals in the right upper quadrant (n=8) had high adjusted mortality rates for both inborn and outborn infants relative to the population means**.** There were five hospitals that were identified as inborn mortality T3 and outborn mortality T1 (i.e., left upper quadrant in Figure 3). Conversely, there were two hospitals that were identified as Inborn mortality T1 and outborn mortality T3 (i.e., right lower quadrant). The correlation coefficient for inborn versus outborn mortality for all patients (r=0.21, p=0.15) was not significant. However, there was a significant correlation when limiting the analysis to gastroschisis (r=0.47, p<0.01) and neonatal bowel emergencies (r=0.37, p=0.01) (**Figure 4**).

DISCUSSION

This multicenter analysis of high-risk neonatal surgical conditions using the Pediatric Health Information System (PHIS) database shows significant hospital-level variation in adjusted postoperative mortality, with higher mortality rates for outborn infants as compared to their inborn counterparts. Adjusted mortality also ranged more widely among outborn infants (approximately 6–14%) compared with inborn infants (1–3%), underscoring greater outcome variability in the transferred population. Prior studies report on advantages for inborns in preterm and surgical neonates (1, 3, 21), but our study highlights novel heterogeneity: hospital performance for inborn infants (generally considered a more stable cohort) does not reliably predict equivalent performance for outborn infants (a higher-risk group often requiring complex pre-transfer stabilization and transport), except for infants with gastroschisis and neonatal bowel emergencies.

Several meaningful insights emerge. Inborn infants, who may present with potentially higher initial illness severity due to early detection and coordinated delivery at tertiary centers, exhibited lower overall mortality and less variability across institutions. This observation is consistent with prior evidence that inborn status confers advantages through rapid access to level IV NICU and pediatric surgical expertise, minimizing delays in diagnostics and intervention (3, 22, 23). In contrast, outborn infants demonstrated higher mortality and greater performance variation across hospitals. These disparities may reflect pre-transfer factors such as physiologic instability during transport, heterogeneity in stabilization at referring facilities, and transport-related complications as well as differences in post-arrival

management. We speculate that birth location and referral protocols exert effects beyond patient illness severity.

Another notable finding is the discordance in hospital performance between cohorts. Some centers excelled with outborn high-risk infants but underperformed with inborn ones, while other centers exhibited the opposite pattern. This suggests that distinct aspects of care may be influencing outcomes for each group. For outborn infants, favorable results may depend on robust retrieval systems, rapid triage and prompt management of complications—factors that mitigate transport-related risks and are consistent with failure to rescue (FTR) as a driver of variation in high-risk neonatal surgeries (1). In contrast, for inborn infants, optimal outcomes may rely more on coordinated perinatal management and cohesive obstetric, neonatal and surgical teams (22). The existence of these "discordant" performers indicates that institutional expertise varies, and tailored quality improvements efforts could effectively target vulnerabilities unique to each patient cohort.

The moderate correlation observed between inborn and outborn mortality for gastroschisis ($r=0.47$, $p<0.01$) is a clinically meaningful finding. Unlike many neonatal surgical conditions, gastroschisis frequently presents as an outborn transfer due to late or absent prenatal diagnosis. The correlation we observed suggests that shared institutional quality factors — surgical technique for abdominal wall closure, infection control protocols, parenteral nutrition management, and early feeding protocols — exert a similar influence on outcomes for both birth cohorts. Hospitals proficient in managing inborn gastroschisis patients appear to similarly excel with outborn transfers. These findings complement prior single-center data demonstrating that inborn delivery at tertiary centers is associated with shorter TPN duration and hospital length of stay (25, 26).

The correlation between inborn and outborn mortality for neonatal bowel emergencies — encompassing NEC, spontaneous intestinal perforation, meconium peritonitis, and volvulus — is perhaps the most clinically compelling finding in this analysis. As previously demonstrated by our group, these conditions collectively represent the dominant driver of neonatal surgical mortality (reference 20), making them a high-impact target for quality improvement. For inborn infants, outcomes are strongly dependent on early clinical recognition of bowel compromise, timely surgical consultation, and prompt operative intervention, consistent with evidence that delayed intervention in surgically indicated NEC

is associated with worsened outcomes. For outborn infants, the correlated performance likely reflects the quality of pre-transfer stabilization at referring centers (hemodynamic optimization, broad-spectrum antibiotics, bowel decompression) and efficiency of the regional transport process coupled with early surgical intervention after arrival. Hospitals that perform well for inborn bowel emergency patients appear to have developed systems of early recognition and operative decision-making that translate to better management of transferred patients as well. This suggests that neonatal bowel emergency outcomes may be particularly amenable to cross-institutional quality benchmarking, and that quality improvement efforts targeting early surgical recognition, standardized perioperative care pathways, and postoperative nutritional support may benefit both inborn and outborn patients at a given center (20, 27, 28, 29).

In contrast, sensitivity analyses for TEF and CDH could not be meaningfully performed because reliability adjustment produced negligible between-hospital variance for inborn and outborn rates in these high risk conditions, with all hospitals converging to the population mean. This finding may reflect that management of TEF and CDH — both congenital structural anomalies identified prenatally and managed according to standardized surgical protocols specific — is more protocolized across institutions, leaving less room for center-specific quality variation. This stands in contrast to NEC and other bowel emergencies, which require real-time clinical recognition and individualized surgical decision-making, potentially explaining the greater between-hospital variation observed for those conditions.
In our analysis eighteen out of forty-seven hospitals (almost 40%) revealed lower than average mortality for both outborn and inborn neonates whereas seven hospitals (15%) demonstrated higher than average for both outborns and inborns. It would be informative to explore the practices employed by the highest-performing centers. Notably, these patterns did not appear to demonstrate an association with institutional case volume, in contrast to what has been previously reported (6, 7, 24).

Our study has several limitations. First, the study utilized an administrative database which utilizes ICD-9 and ICD-10 codes to identify pathologies. With this identification process, the severity of diagnoses could be underappreciated. For example, infants with mild and severe CDH would not be differentiated. Similarly, different hospitals that contribute to PHIS will experience different volumes of infant pathologies (e.g., high volume CDH center compared

to a low volume CDH center). We included case mix into our logistic model to attempt to control for these limitations. In addition, we chose diagnoses that are associated with high morbidity and mortality to account for centers that care for high volumes of infants with these specific diagnoses. By including case mix and other clinical characteristics (e.g. utilization of ECMO, TPN, and mechanical ventilation), the C-statistic for the models were >0.85. Also, the current study's index-admission framework may undercount mortality occurring on a subsequent encounter not captured in PHIS. And finally, PHIS lacks granular clinical risk variables (e.g., preoperative sepsis, ASA classification) available in clinical registries, which may limit the validity of cross-institutional mortality comparisons.

CONCLUSIONS

By stratifying infants by inborn versus outborn status, we identified disparities in hospital performance that are not apparent when examining overall mortality alone. Outborn infants consistently show higher mortality and considerable variation exists between hospitals. Hospital performance for inborn infants does not reliably reflect outcomes for outborn infants, except in the setting of gastroschisis and neonatal bowel emergencies. This would suggest that hospital-level quality improvement initiatives might need to be tailored separately to inborn and outborn infant cohorts. However, the quality improvement efforts specific to gastroschisis and neonatal bowel emergencies might be relevant for both inborn and outborn transfers.

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Figure Legends

Figure 1. Caterpillar plot of risk adjusted *inborn* mortality rates for each hospital with 95% confidence interval. Gray box represents 95% confidence interval for population mean mortality rate (2.1%). Square – mortality tertile 1, circle – mortality tertile 2, diamond – mortality tertile 3.

Figure 2. Caterpillar plot of risk adjusted *outborn* mortality rates for each hospital with 95% confidence interval. Gray box represents 95% confidence interval for population mean mortality rate (8.2%). Square – mortality tertile 1, circle – mortality tertile 2, diamond – mortality tertile 3.

Figure 3. Green symbols (n=19) represent hospitals that had lower adjusted mortality for both inborn and outborn than average mortality for both inborn and outborn. Red symbols (n=8) represent hospitals that were worse than average mortality for both inborn and outborn.

Figure 4. Outborn versus inborn adjusted mortality rates for (a) all patients, (b) gastroschisis, (c) neonatal bowel emergencies

Figure 1

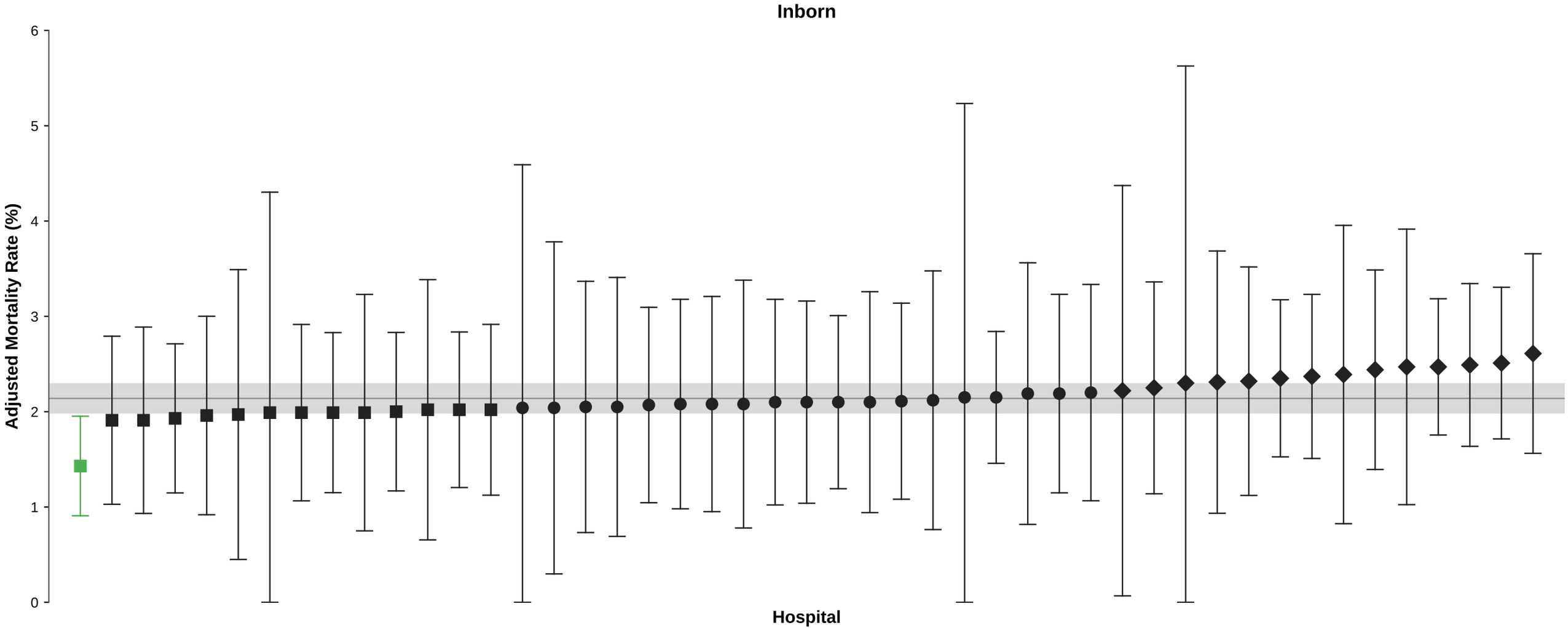


Figure 2

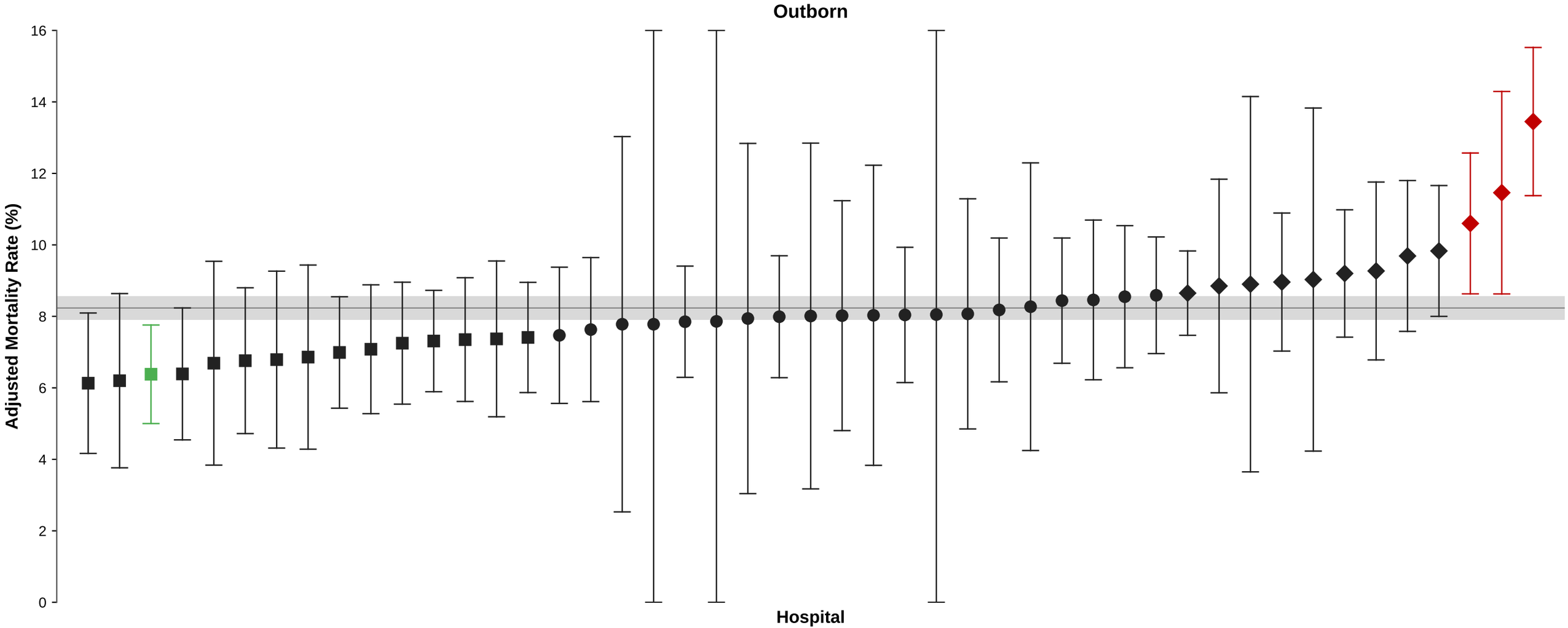


Figure 3

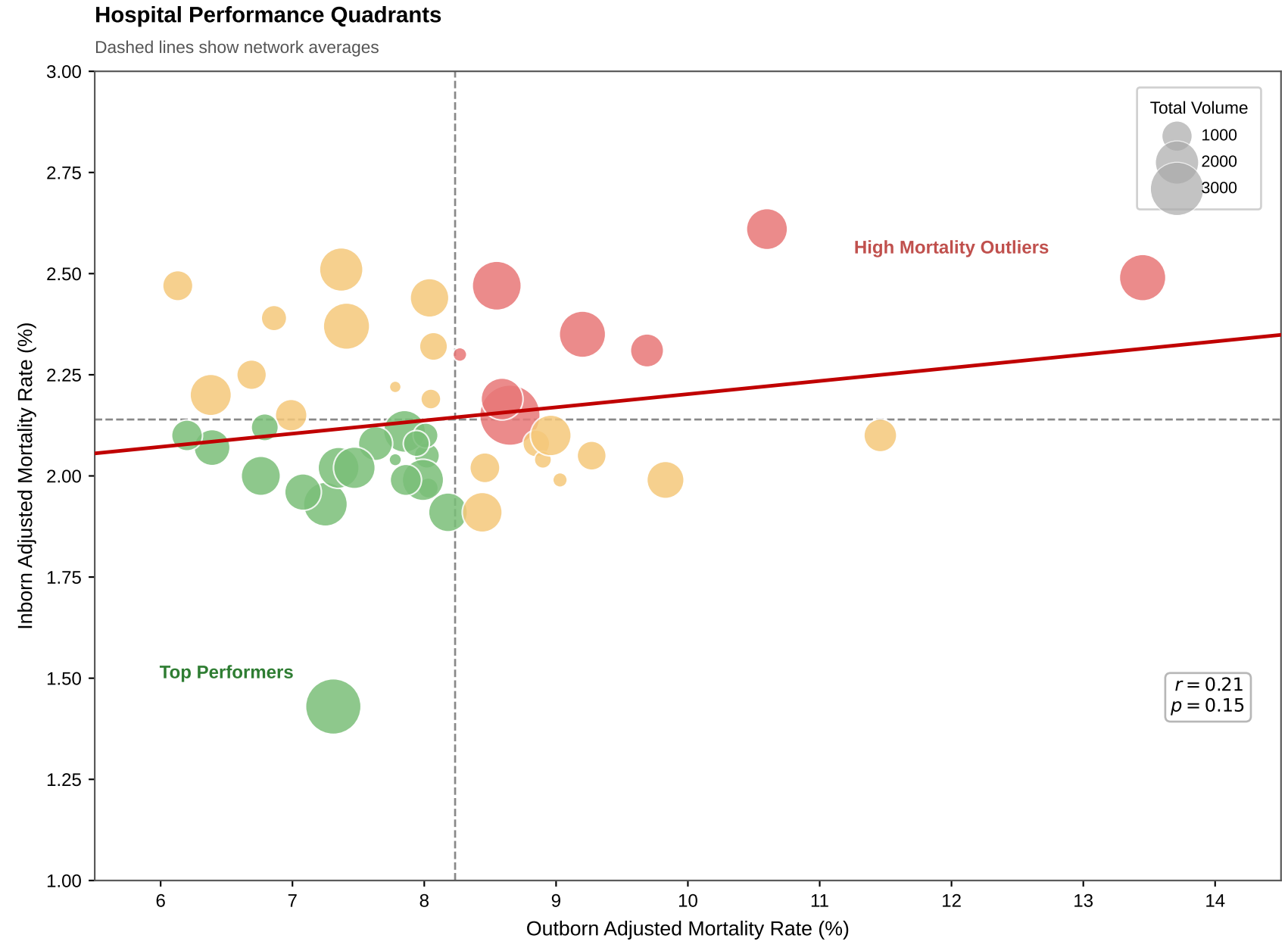
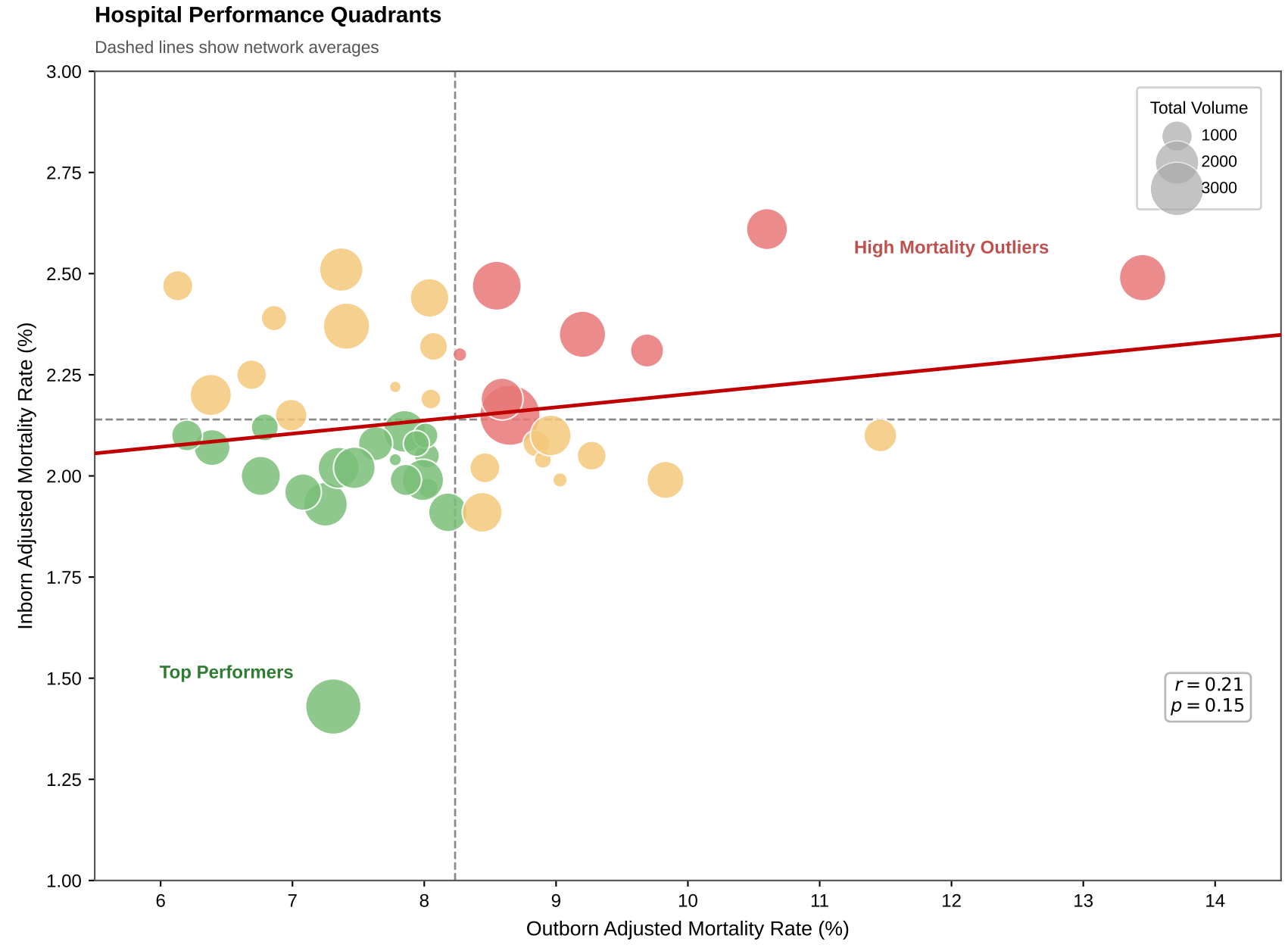

Hospital Performance Quadrants
Dashed lines show network averages
Total Volume
1000
2000
3000
High Mortality Outliers
Top Performers
r = 0.21
p = 0.15
Inborn Adjusted Mortality Rate (%)
Outborn Adjusted Mortality Rate (%)
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
6
7
8
9
10
11
12
13
14

Figure 3


Hospital Performance Quadrants
Dashed lines show network averages
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