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Evaluation of a Quality Improvement Intervention for Anesthetic Management of
Acute Ischemic Stroke Patients Undergoing Endovascular Therapy

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Abstract

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BACKGROUNDS: For acute ischemic stroke (AIS) cases receiving endovascular therapy (EVT), the use of general anesthesia (GA), physiological perturbations, and delays in the institution of EVT adversely impact the outcomes. In 2012, a quality improvement (QI) intervention utilizing PDSA (Plan-Do-Study-Act) model was implemented at Harborview Medical Center (HMC) aiming at minimizing delays for EVT, encouraging the use of monitored anesthesia care (as opposed to the routine use of general anesthesia) and avoiding physiologic perturbations under anesthesia, to improve neurological outcomes of the patients. The objective of this project is to evaluate the effectiveness of the QI intervention quantitatively.

METHODS: This is a retrospective pre-post interventional study. The study period was separated into pre-intervention period (Jan 2008 to May 2012), QI intervention roll-out period (Jun 2012 to Nov 2012, the first six months of implementation), and post-intervention period (Dec 2012 to Aug 15th, 2015.) Patient characteristics, choice of anesthetic technique (general anesthesia or monitored anesthesia care), arterial line placement rate, timeliness indicators, intra-procedural physiological parameters, and clinical outcomes were collected and compared between pre-intervention and post-intervention phases. Multi-level generalized estimating equation models were used to estimate the clinical impacts.

RESULTS: Data from 78 patients from pre-intervention phase and 43 patients from post-intervention phase were compared. The use of general anesthesia decreased from 97.4% to 72.1% ($p < 0.0005$). The use of arterial catheter decreased from 75.6% to 39.5% ($p < 0.0005$). The median anesthesia-ready time decreased from 14 to 12 minutes ($p = 0.007$). The median door-to-puncture time decreased from 111 to 82 minutes ($p = 0.02$). The prevalence of intra-procedural relative hypotension (non-invasive SBP below the recommended 140mmHg) decreased from 100% to 90.7% ($p = 0.006$). No significant decreases in respiratory parameters were identified ($\text{EtCO}_2 > 40$ mmHg, $\text{EtCO}_2 < 30$ mmHg, $\text{SpO}_2 < 92\%$). The subjects in post-intervention phase had lower in-hospital all-cause mortality, (adjusted OR 0.67 [0.55-0.80]; $p < 0.0005$), higher likelihood of favorable neurologic outcome ($\text{mRS} \leq 2$, adjusted OR 1.27 [0.42-3.8]; $p = 0.67$) and favorable discharge disposition (adjusted OR 1.57 [0.88-2.8]; $p = 0.13$), shorter hospital stay (adjusted IRR 0.79 [0.51-1.19]; $p = 0.25$) and ICU stay (adjusted IRR 0.61 [0.51-1.19]; $p = 0.25$).

DISCUSSION: The QI intervention utilizing interdisciplinary “PDSA” model effectively changed physician decision-making for anesthesia technique choice and was significantly associated with less delay to treatment, less relative hypotension, and better survival.

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DEDICATION

To my family, friends, teachers and professors inspiring me along the way.
And to Yu Lwo, my wife, my best friend, and the one who is always there for me.

Chapter 1. INTRODUCTION

1.1 RESEARCH BACKGROUND

Stroke, also referred to as cerebrovascular accident (CVA), is a combination of disease entities that involve disruption of blood flow supplying the central nerve system and cause the cell death of the brain, spinal cord, or retina. [1] Stroke is notoriously one of the leading causes of disability and death on a national and global scale, [2] and presents itself as a significant public health problem. According to the statistics of World Health Organization, stroke solely accounts for 6.11% of deaths and 3.17% of disability-adjusted life year lost (DALYs) in the United States, [3] which undoubtedly puts a heavy burden on the U.S. health care system.

Of all stroke cases, about 87% are ischemic strokes, which are associated with blockade of blood flow to the central nervous system. [4] Traditionally, access to specialized institutes, expeditious evaluation, aggressive medical treatment, and intravenous fibrinolytic agents (drugs that dissolve blood clots) for eligible patients form the mainstay of the acute ischemic stroke (AIS) management. [5, 6] However, with the introduction of new medical instruments such as stent retrievers, endovascular therapy (EVT) has been shown to be an effective treatment for select AIS patients. [7,8]

The EVT for AIS involves puncture of an artery, introduction of guide wires and therapeutic catheter into the vascular system, injection of fibrinolytic agents, and/or mechanically extraction of the blood clots that block the blood vessels of the brain. A successful and timely EVT can reestablish the blood supply to the lesion and improve the clinical outcome. In a recent meta-analysis of randomized controlled trials, EVT combined with medical treatment was associated with better functional outcome in 90 days, especially for patients with large

vessel occlusion or treated with the newer stent retriever device. [8] The EVT (specifically mechanical thrombectomy, the direct extraction of the blood clots) is rapidly changing the landscape of AIS management and is claimed to be the promisingly new gold standard for AIS by some experts. [9]

The anesthesiologists are involved in the EVT for AIS to provide general anesthesia (GA) or monitored anesthesia care (MAC) and close vital sign monitoring. The anesthetic management affects the quality of the care as well as patient level outcomes. [10] For example, GA was commonly used for EVT of AIS largely due to the interventionalist's preference. However, an increasing body of evidence started to show a detrimental effect of GA over MAC in AIS management, which changed the consensus of the professional community to prefer MAC in suitable patients. [11-13] Besides the anesthetic technique, delay to treatment and physiological perturbations, defined as blood pressure and respiratory parameter deviation from clinical guidelines, have been found to be associated with worse outcomes. [5, 14-17] Because of the emergent nature of the procedure, the patients undergoing EVT for AIS are often taken care of by on-duty anesthetic providers who may not be specialized in neuroanesthesiology and may not have up-to-date knowledge of EVT guidelines for informed decision-making. As a result, it is reasonably suspected that this potential knowledge gap could contribute to a higher likelihood of GA use, delay to treatment, and physiological perturbations. The recognition of the need for quality improvement (QI) in this area led to a comprehensive intervention by the division of Neuroanesthesiology & Perioperative Neurosciences at the University of Washington.

1.2 HARBORVIEW QUALITY IMPROVEMENT INTERVENTION

In medicine, QI is a constant need requiring endless efforts for building a better service delivery system. In the recent decade, numerous QI practitioners were inspired by and borrowed

the improvement models from business and industry, trying to adapt them to their institutes and practice. For example, in the field of AIS care, Toyota's lean manufacturing principles and value stream had been used to reduce door-to-needle (DTN) times. [18] Another example was the use of Six-Sigma-based “pit-crew” model to improve DTN (this could mean door-to-puncture or door-to-groin times in the same context) for EVT. [19]

The PDSA (Plan-Do-Study-Act) quality improvement model has been widely used in medicine. A growing body of literature documents that PDSA is being used in several critical faucets of AIS care, such as enhancing the adherence to the evidence-based guidelines, [20, 21] decreasing waiting times to the carotid ultrasound for acute stroke patient, [22] and integrating self-management support into AIS service. [23] However, the evidence of using PDSA model to improve the quality of anesthesia care by incorporating evidence-based best practices in AIS patients undergoing EVT is lacking. Two poster abstracts accepted by neurology-specialized journals had utilized the PDSA model to address timeliness indicators (process metrics) in AIS care without exploring the potential clinical impacts. [24, 25] Another poster abstract used PDSA cycle model to improve the timeliness indicator of AIS care and also tried to link functional outcome (modified Rankin Score, mRS). [26] However, the sample size was too small (20 vs. 5 patients) to reach any statistically meaningful conclusion.

To enhance the quality of AIS care, a QI intervention using the PDSA model was implemented for AIS patients undergoing EVT at Harborview Medical Center (HMC). We compared the data collected before and after the QI intervention to examine the effectiveness of the QI intervention. HMC is a Joint Commission certified Comprehensive Stroke Center in Seattle and affiliated with University of Washington School of Medicine. HMC is also recognized with the American Stroke Association’s “Get with the Guidelines” Awards due to consistent

institutional adherence to clinical guidelines and dedication to close monitoring of the quality of stroke care. The aim of this interdisciplinary QI intervention utilizing the PDSA model implemented at HMC in 2012 was to minimize delays in EVT, reduce unwarranted GA use and physiological perturbation, and thereby improve AIS patient outcomes.

Firstly, in the “Plan (P)” phase, the target population and aim are specified, followed by extensive evaluation of the system, identification of contributors and barriers to the aim, and development of the corresponding intervention plans. In our intervention, the target population was AIS patients planned to receive EVT. The aims were to minimize Anesthesia-Ready Time (ART, defined as the time between “anesthesia start” and “anesthesia ready”), to keep the door-to-puncture time (DTP, defined as the time between “patient arrival at the emergency department or hospital” and “radiologist performs the groin puncture on patient”) under the 90-minute institutional benchmark (National benchmark proposed by Brain Attack Coalition is 120 minutes [27]), and to optimize hemodynamic and respiratory parameters under anesthesia. Information for potential improvement points was collected through the neuroanesthesiology faculty meetings, discussion with individual anesthesia providers, and interdisciplinary meetings involving Neuroradiology, Neurology, Neurosurgery, and Neurocritical Care departments. Several QI issues were identified within the process, which included prolonged or multiple attempts to secure arterial lines, mental preparedness and knowledge gaps, limited experience and exposure to EVT-related anesthesia, and use of GA in almost all patients. Based on this information, the stakeholders reached consensus and developed an evidence-based protocol for anesthetic management of AIS, which was demonstrated in **Figure 1.1**. The protocol was tailored for AIS patients planned to receive EVT and anesthetic care. Several targets were emphasized:

- (1) Coordinate workflow between specialties to meet the institutional timeliness indicators (DTP time within 90 minutes and CTA-to-groin puncture within 60 minutes)
- (2) Provide the guidance for selecting GA or MAC as the preferred anesthesia technique.
- (3) Delineate the major anesthetic goals to optimize the quality of care, including the desired level of blood pressure control, respiratory parameters, blood glucose monitoring, and other specific anesthetic techniques.

In the “Do (D)” phase of the PDSA cycle, the plan is operationalized while also obtaining stakeholder buy-in. For our QI intervention, we provided staff education through presentation at morning conference with question and answer session and disseminated the protocol through the electronic medical record system and posters in the angiography suites as cognitive assistance and guidance for every provider (**Figure 1.1**). The relevant data collection was started simultaneously in this phase. The process and outcome metrics were collected, with emphasis on treatment timeliness indicators and physiological parameters.

Thirdly, in the “Study (S)” phase, the collected data are analyzed to determine if the pre-specified process and outcome targets are being reached, and if there are any unintended consequences. In the HMC QI intervention, the data from all AIS cases were analyzed monthly by the Neuroanesthesiology faculty to evaluate the progress of the intervention and the performance of the care team in the aggregate. The institutional QI database maintained the data for system level performance and patient level outcomes.

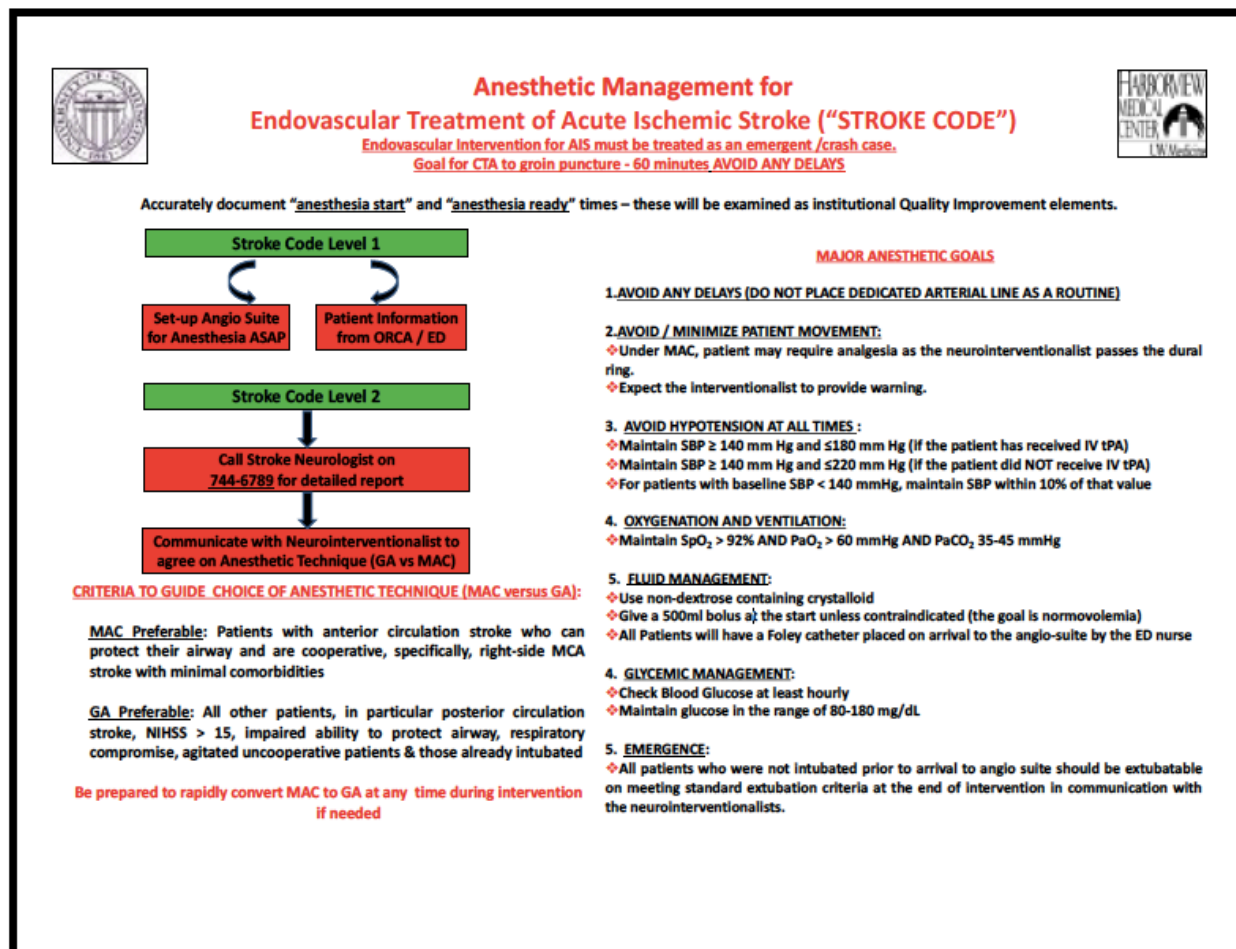


Figure 1.1 Poster for QI Protocol Dissemination in Angiography Suites

Finally, for the “Act (A)” phase of the PDSA cycle, the processes and the results from the previous phases are rigorously reviewed to give timely feedback to the providers and stakeholders, to refine the PDSA process itself, and to develop the future strategy for the next round of PDSA cycle. The process continues until the system reaches an improved, satisfactory, and sustainable status. For our QI intervention, the results of all case-reviews were shared with providers. Care performance data were presented monthly at QI meetings, to provide staff education regularly.

1.3 CONCEPTUAL MODEL

Figure 1.2 presents the conceptual model for the Anesthesiology Quality Improvement Intervention for patients with AIS, which consists of five parts: predisposing factors, QI intervention, target process metrics, clinical outcomes, and EVT team-related time-varying factors.

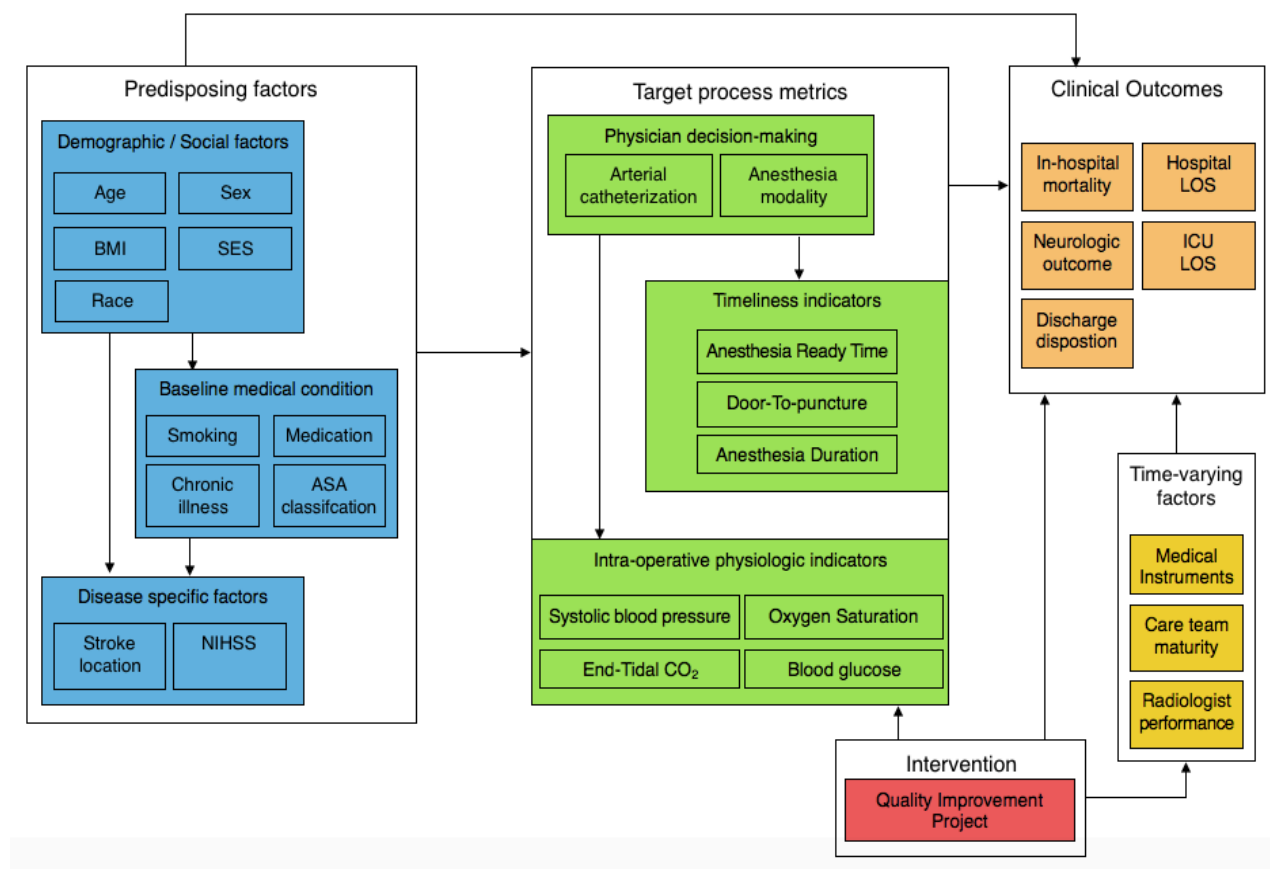


Figure 1.2 Conceptual Model of the Anesthesiology Quality Improvement Intervention

The first part consists of predisposing factors, which are further separated into three subgroups:

- (1) Demographic / social factors: age, sex, body mass index (BMI), race, and socioeconomic status (SES). These factors are known to be associated with stroke outcomes and also affect provider's clinical decision-making on the anesthesia technique. [28-31]
- (2) Baseline medical condition: Chronic illness / diagnosis, medication use, smoking, and American Society of Anesthesiologists (ASA) physical status classification are well-established outcome predictors for stroke. [32]
- (3) Disease specific factors: For AIS patients, National Institute of Health Stroke Scale/Score (NIHSS) would be given at the presentation to the emergency room to evaluate the eligibility for fibrinolytic agent and also serves as a comprehensive indicator of stroke severity. NIHSS is one of the most reliable predictors for stroke outcomes. [33] Stroke location (divided into anterior or posterior circulation stroke) is also categorized in this group. Stroke location directly affects disease presentation and corresponding anesthetic management. [34] Duration of stroke symptoms and radiographic features such as proximal arterial occlusion are well-recognized factors impacting the outcomes of AIS.

The predisposing factors, as a whole, make up the patient clinical profile, which may directly affect a provider's decision-making and change the target process metrics.

The second part is the implementation of the QI intervention. The QI intervention is designed to improve the providers' decision-making, practice quality, and team coordination. Therefore, it is expected to change the target process metrics, which, in turn, may affect clinical outcomes. Another potential pathway that QI could affect clinical outcome is through some time-varying factors specified in the model. The QI protocol

emphasizes the coordination of the teamwork; communication between radiologist and anesthesiologist is particularly valued. The team maturity and the anesthesia provider performance are expected to be enhanced by the QI intervention in the long run and bring positive impacts on clinical outcomes. Finally, the mental preparedness and the mindset for constant pursuit of quality stimulated by the QI project might have direct and beneficial spillover effects on clinical outcomes.

The third group is the target process metrics and is also our main pathway of interest. As aforementioned, the routine use of general anesthesia, time delay to EVT, and physiological perturbation all has consequences on outcomes. Specifically, the unwarranted routine use of GA and arterial catheterization may directly cause longer ART and worse timeliness indicators. Similarly, the use of GA may be related to lower systolic blood pressure (SBP) than MAC, and contribute to worse outcomes.

The fourth part is the clinical outcomes, which include all-cause in-hospital mortality, favorable neurological outcome at hospital discharge defined as modified Rankin Score (mRS) ≤ 2 , favorable discharge disposition defined as discharge home or transfer to rehabilitation facility. The length of stay (LOS) of hospital and ICU are also of interest, because they capture not only the effect of disease progression and severity after EVT, but also some of the QI project's effects, such as less invasiveness and encouragement of early extubation.

Lastly, the fifth part is composed of time-varying factors of the health care organization. Health care organizations and systems are not static but rather change constantly. The QI might improve the anesthetic care and some part of team coordination, but radiologists' experience and skill, other hospital-wide improvement efforts, team

maturity, and even the medical instruments (specifically the therapeutic catheter and retriever system) could all vary over the life of the QI intervention. These factors might contribute significantly to patient outcomes but are usually difficult to quantify in QI studies.

1.4 RESEARCH QUESTIONS

Based on the conceptual model, the purpose of this study is to address the following question: Among patients with AIS receiving EVT at Harborview Medical Center, is the Anesthesiology Quality Improvement Intervention associated with better timeliness indicators, less physiological perturbations, and better clinical outcomes?

1.4.1 *Hypothesis testing*

To answer the research question, the following three hypotheses were tested:

- (1) The QI intervention led to improved timeliness indicators, such as ART and DTP time.
- (2) The QI intervention is associated with less physiological perturbations, defined as less likelihood of any episodes of non-invasive SBP < 140 mmHg, EtCO₂ > 40 mmHg, EtCO₂ < 30 mmHg, SpO₂ < 92%. (EtCO₂ only compared in GA cases for measurability.)
- (3) The QI intervention is associated with lower in-hospital, all-cause mortality, higher likelihood of favorable neurologic outcome (mRS ≤ 2) or disposition (discharge home or transfer to rehabilitation facility) at hospital discharge, and shorter hospital or ICU LOS.

Chapter 2. METHODS

2.1 STUDY DESIGN

The study design was a retrospective pretest-posttest interventional study. [35] The total study period was from January 1, 2008 to August 15th 2015. The QI intervention was started in June 2012. In the study design, the period between January 1, 2008, and May 2012 was the “pre-intervention phase.” Because the QI intervention required time to reach and educate most trainees and frontline providers, the first six months of QI implementation were defined as the “roll-out phase” (i.e., June 2012 to November 2012.) Last, the study period after the roll-out phase was defined as “post-intervention phase” (i.e., December 2012 to August 15th, 2015.) The study was reviewed and approved by the University of Washington Institutional Review Board.

2.2 SELECTION OF STUDY SUBJECTS

2.2.1 *Source*

The data sources for identifying eligible study patients were institutional stroke registry and the anesthesiology database, which were cross-checked with each other to identify the patients who received EVT for AIS during the study period.

2.2.2 *Eligibility criteria for inclusion/exclusion of cases*

The eligibility criteria were defined as all adult patients (≥ 18 years of age) with AIS undergoing EVT at HMC with verifiable EMR records in the study period defined previously. The exclusion criteria included age < 18 years, patients with data recorded before the

introduction of the electronic anesthetic record, and patients without extractable electronic records due to technical issues.

2.2.3 Process of study subject selection

Figure 2.1 documents the selection of study patients with AIS. A total of 156 patients were identified, with 96 patients before the QI month (June 2012) and 60 patients in and after the QI month. After manual crosscheck with EMR system, 5 patients were excluded due to mismatched data and 16 patients were excluded due to lack of electronic anesthetic records and thus inconsistent data quality.

135 patients were included for final data extraction and analysis, with 78 patients from pre-intervention phase, 14 patients from the roll-out phase, and 43 patients from the post-intervention phase.

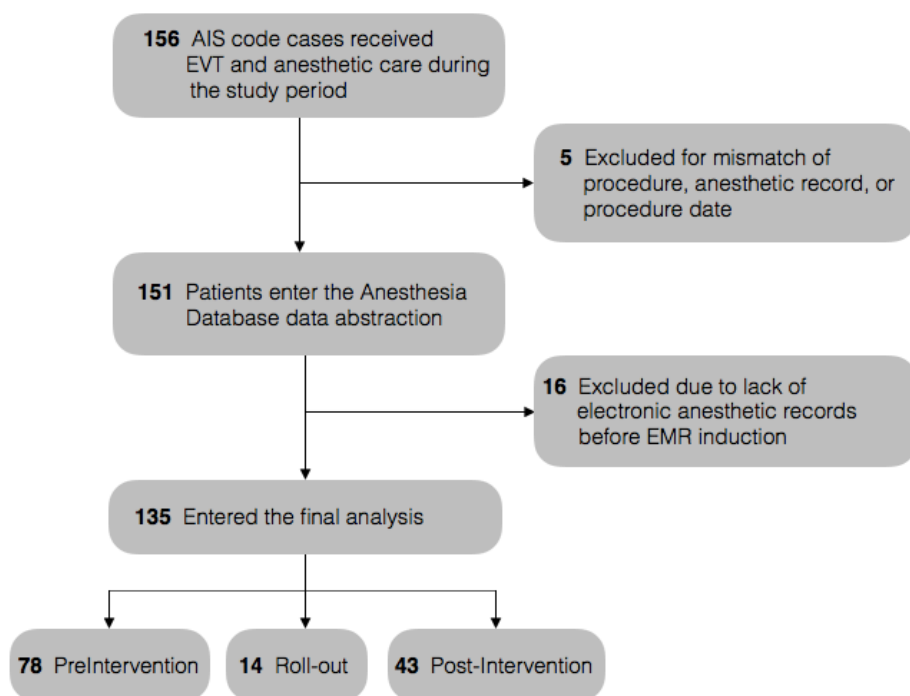


Figure 2.1 Selection of Study Subjects

2.3 DATA SOURCES AND MEASURES

There were three major sources of data. One data source was the timeliness indicators from the HMC Stroke Code QI Committee, another was the intra-procedural hemodynamic, respiratory, and anesthetic parameters from the Anesthesia database of the University of Washington School of Medicine, and the last one was the clinical outcome data, which were extracted manually from HMC electronic medical records to create the following measures:

(1) For timeliness indicators:

Anesthesia-Ready Time was defined as the time between “anesthesia start” and “anesthesia ready.” Total anesthesia duration was defined as the time between “anesthesia start” and “anesthesia end.” Door-to-Puncture is defined as the time between “patient arrival at the emergency department or hospital” and “radiologist performs the groin puncture on patient.”

(2) For physiological parameters:

Blood pressure was measured by systolic blood pressure (SBP), and non-invasive SBP (NSBP) was measured by non-invasive blood pressure gauge (as opposed to ASBP, arterial SBP, which is measured invasively through arterial catheter). EtCO₂ means end-tidal carbon dioxide, which is the concentration of CO₂ in the exhaled gas. EtCO₂ is also an important Indicator for appropriateness of intra-operative ventilation. SpO₂ stands for peripheral capillary oxygen saturation, an estimate of the amount of oxygen in the blood.

(3) For the clinical outcomes:

Five clinical outcomes were measured. The first one was the all-cause in-hospital mortality within the hospitalization following EVT for AIS, which was documented in the medical

record. The second was the favorable neurologic outcome at discharge, which was measured according to the physical therapy note and defined as $mRS \leq 2$. The third one was favorable discharge disposition defined as discharge home or transfer to rehabilitation facility. The last two ones were hospital and ICU length of stay (LOS). One midnight bed-occupancy day was counted as one day, which was the closest proxy for exact length of stay counted in hours.

[36]

After integrating the three different sources of data into a single patient data file, de-identification of the patient data was performed before the data analysis.

2.4 ANALYSIS PLAN

2.4.1 *Sample size/power consideration*

Due to the nature of the retrospective study, in which the sample size was predetermined by the HMC QI project, we performed a power calculation based on the existing sample size to evaluate the effect size that our study was able to detect, with 78 patients in the pre-intervention and 43 patients in the post-intervention group (not counting the roll-out phase). The calculation was based on presumed 80% power and $\alpha=0.05$ for a two-tailed test.

For the physiological parameters:

- (1) Any relative hypotension during anesthesia: The institutional baseline data was 100% (99.76% was used to approximate the 100% ratio in the calculation) and our study was powered to detect 12.5% difference.
- (2) Any hypercapnia or hypocapnia during anesthesia: The institutional baseline data were 72% and 91%, respectively. Our study was powered to detect 24.2% and 19.8%

differences, respectively.

For the clinical outcomes:

- (1) Post-EVT favorable neurologic outcome ($mRS \leq 2$) at discharge: According to the literature review from a single-centered, single-arm descriptive study of EVT for AIS patients [37], 28% of the patients receiving EVT had $mRS \leq 2$ at discharge. Our study was powered to detect a 24.9% difference.
- (2) Mortality of all causes: The same study reported 8% of mortality rate before discharge was associated with EVT patient population. Our study was powered to detect a 16.6% difference.

2.4.2 *Statistical Methods*

To compare the patient predisposing factors and target process metrics between the pre-intervention and post-intervention phases, student t-test and chi-square test were used for continuous and proportional variables, respectively.

Timeliness indicators (e.g., door-to-puncture time) were generally not normally distributed. Consequently, median, inter-quartile range (IQR), and range were computed for descriptive statistics, and the pre-intervention and post-intervention measures were compared by Mann-Whitney U test. The scatterplots of timeliness indicators over time (in quarters) were used to analyze the temporal trend of the indicators. The data within the pre-intervention, roll-out, and post-intervention phases were analyzed separately using the least square linear regression with calculated slopes.

Multi-level generalized estimating equation (GEE) models clustering on radiologists were used to test hypotheses, adjusting for age, sex, ASA class, NIHSS, and stroke location.

Correlation structure is specified as independent, and estimation was performed with robust standard errors. For modeling binary outcomes, such as in-hospital mortality, favorable neurologic outcomes and disposition at discharge, logit link with binomial family was used; while for modeling count data, such as hospital and ICU LOS, log link with negative binomial regression family was used. The clinical outcomes of the post-intervention group were compared to the pre-intervention group. The intervention effects were presented as adjusted odds ratios (OR) and adjusted incidence rate ratios (IRR), depending on the characteristics of the outcome metrics. The roll-out group was not included in the statistical analysis.

All p values were 2-sided and statistical significance was defined as a p value of less than 0.05. All statistical analyses were performed with STATA 13.1 (Stata Corp LP).

Chapter 3. RESULTS

3.1 STUDY SUBJECT CHARACTERISTICS

The demographic and clinical characteristics of the study subjects at the time of EVT are set out in **Table 3.1**. There were no significant difference between the pre- and post-intervention groups in mean age, female proportion, mean BMI, ASA class distribution, proportion of anterior circulation stroke, major chronic illness, smoking history, specific medication use (Not shown in Table 3.1, including 13 meds including common antihypertensive, NTG, anti-diabetic medication, statins, anti-platelet agents, p value from chi-square test from 0.12-0.89), mean of first non-invasive SBP, and first invasive SBP. However, mean NIHSS was significantly higher in the post-intervention group compared to the pre-intervention group (mean score \pm SD: 17.5 ± 7.6 v.s. 21.8 ± 9.4 ; $p = 0.02$), indicating that the mean stroke severity was higher for the post-intervention period.

Table 3.1 Demographic and Clinical Characteristics of Study Patients

	PRE-INTERVENTION (N=78)	POST-INTERVENTION (N=43)	<i>p</i> Value
Age (yr)	60.7 ± 17.4	61.6 ± 14.5	0.82
Female sex — no. (%)	29 (37)	16 (40)	0.71
BMI	26.8 ± 5.0	28.5 ± 5.3	0.24
ASA class — no. (%)			0.92
1	3 (4)	3 (5)	
2	9 (12)	6 (14)	
3	31 (40)	20 (28)	
4	35 (45)	28 (53)	
Stroke Location — no. (%)			0.77
Anterior circulation	58 (74)	33 (77)	
Posterior circulation	20 (26)	10 (23)	
NIHSS	17.5 ± 7.6	21.8 ± 9.4	0.02
Medical illness — no. (%)			
Hypertension	48 (62)	27 (63)	0.89
Diabetes	14 (18)	10 (23)	0.53
Cardiovascular disease	48 (63)	21 (49)	0.13
CVA/TIA history	15 (20)	13 (30)	0.20
Smoking	17 (22)	9 (21)	0.86
First non-invasive SBP (mmHg)	139 ± 32	148 ± 24	0.07
First invasive SBP (mmHg)	131 ± 38	145 ± 32	0.08

3.2 ANESTHETIC TECHNIQUE

Figure 3.1 illustrates the pattern of change in providers' decision-making on the anesthetic technique and the use of arterial catheterization. GA use and arterial line replacement rate were 97.4% and 75.6% before in the pre-intervention period, respectively, compared to 72.1% and 39.5% in the post-intervention period. The difference of both rates between the pre- and post intervention periods were statistically significant.

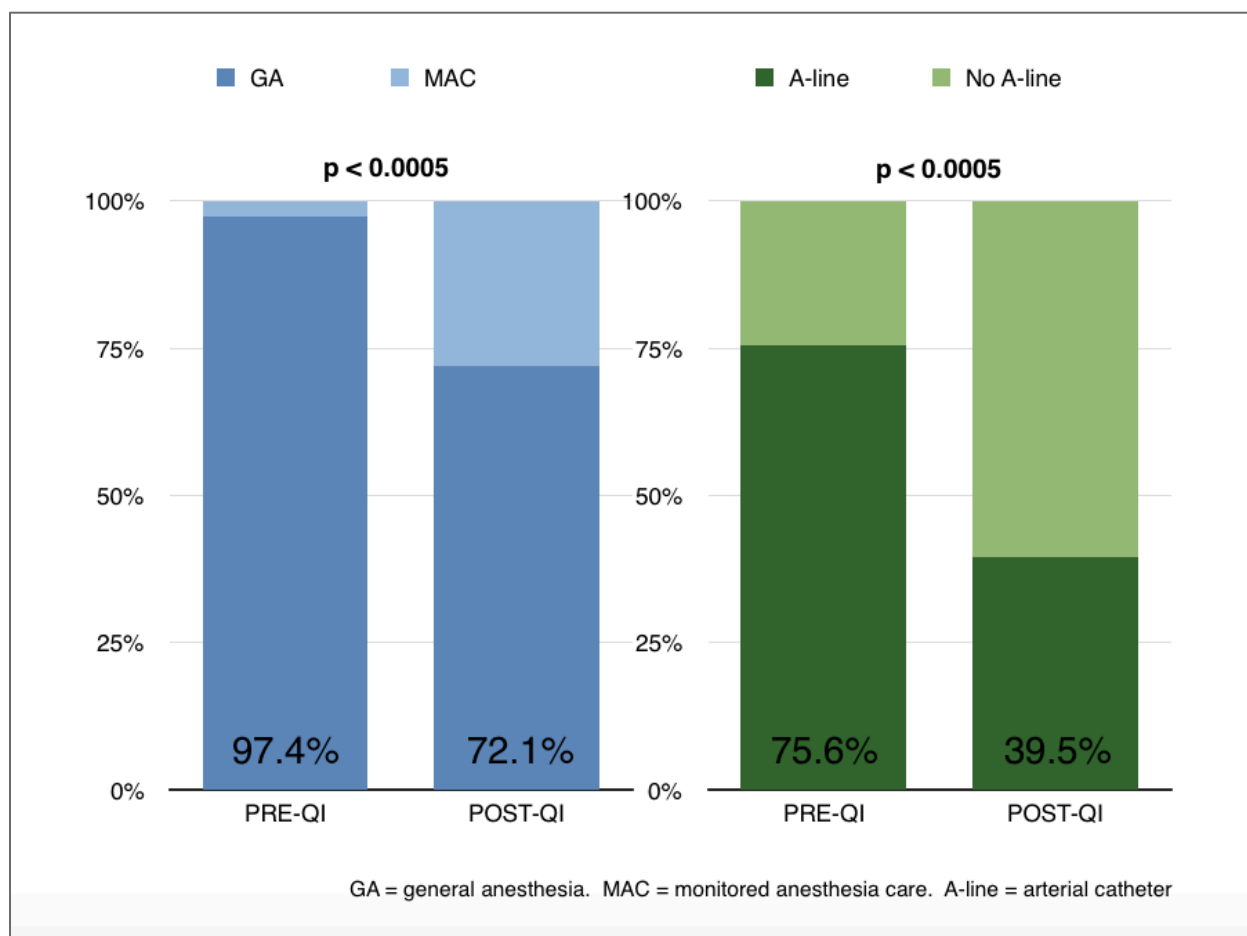


Figure 3.1 Anesthesia Technique Change after QI Intervention

3.3 TIMELINESS INDICATORS

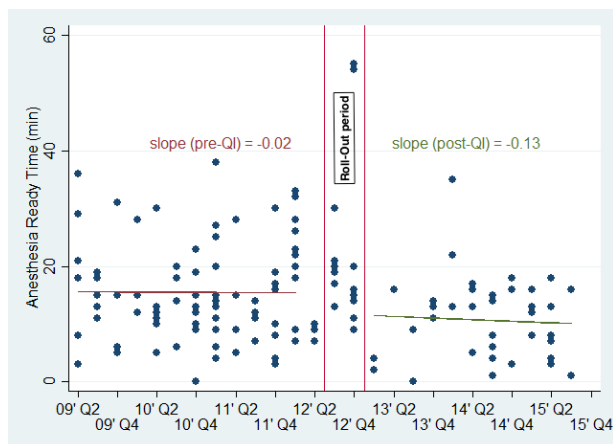
Table 3.2 presents the pre- and post-intervention timeliness indicators of workflow. The median anesthesia-ready time decreased from 14 minutes to 12 minutes, the median total anesthesia duration median decreased from 177 minutes to 159 minutes, and the median door-to-puncture time decreased from 111 minutes to 82 minutes. Although all three indicators showed the direction of change consistent with the primary objective of QI intervention, our findings only demonstrated statistical significance on ART and DTP (Hypothesis 1).

Table 3.2 Timeliness Indicators Involving Anesthesia Team

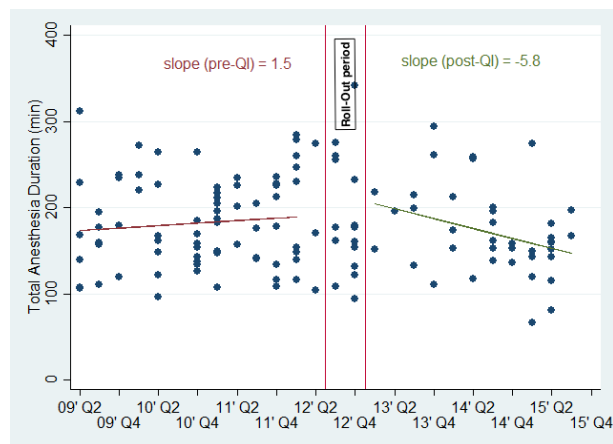
	Pre-Intervention (n=78)	Post-Intervention (n=43)	P value
Anesthesia ready time	14 (9-20, 1-38)	12 (5-16, 1-35)	0.007
Total anesthesia duration	177 (142-228, 96-1260)	159 (136-197, 67-294)	0.14
Door-to-puncture	111 (84-138, 47-480)	82 (62-131, 25-450)	0.02
All values in Median (IQR, Range)			

In addition to comparing the timeliness indicators between pre and post-intervention phases, the detailed temporal distributions of the indicators were also examined. The **Figure 3.2** shows the scatter plots for three timeliness indicators across study periods in quarters. In **Figure 3.2 (a)**, the slope improved only slightly, but there was an obvious drop of the regression line (intercept change) and a different data distribution pattern compatible with the numerical result. In **Figure 3.2 (b)**, although there was no obvious interruption of the regression line, the slope changed from +1.5 to -5.8. This means the DAT was increasing stably each quarter on average in the pre-intervention period, but changed to decreasing by 5.8 minutes each quarter in the post-

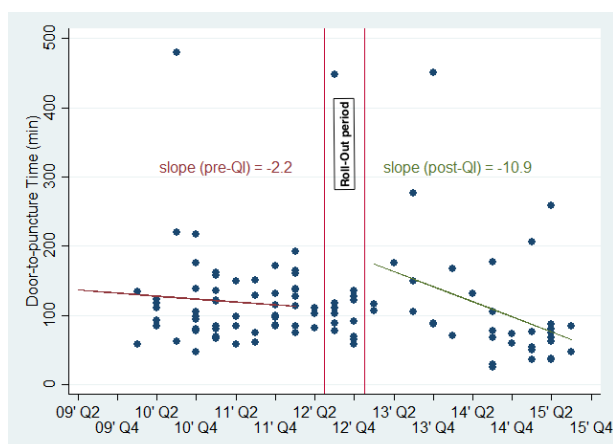
intervention period. In **Figure 3.2 (C)**, it was shown that the DTP was already improving in the pre-intervention period, and there was an upward jump in the start of the post-intervention period but soon went down with an even larger negative slope than the pre-intervention period.



(a) Anesthesia-ready time



(b) Total anesthesia duration



(c) Door-to-puncture time

Figure 3.2 Temporal Trends and Distribution of Timeliness Indicators

3.4 PHYSIOLOGIC PARAMETERS

Another major objective of the AIS QI intervention was to decrease the intra-procedural physiological perturbations. **Figure 3.3** shows the prevalence of the physiological perturbations. The QI intervention was associated with lower prevalence of non-invasive SBP < 140 mmHg (100% v.s. 90.7%; $p=0.006$). A sensitivity test using several different cut-off NSBP values also showed similar improvement patterns that were statistically significant (**Figure 3.4**). However, except for intra-procedural blood pressure control, the QI intervention was not associated with lower prevalence of physiological perturbations in other respiratory parameters (Hypothesis 2).

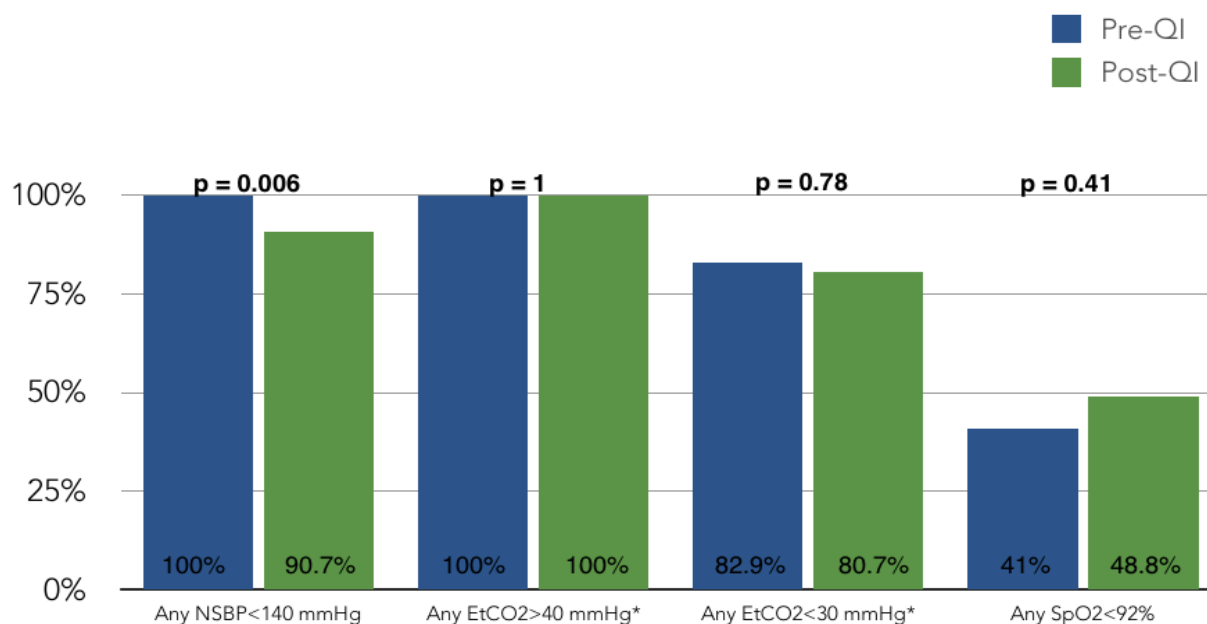


Figure 3.3 Prevalence of Intra-procedural Physiological Perturbations
(EtCO₂ only compared for GA cases)

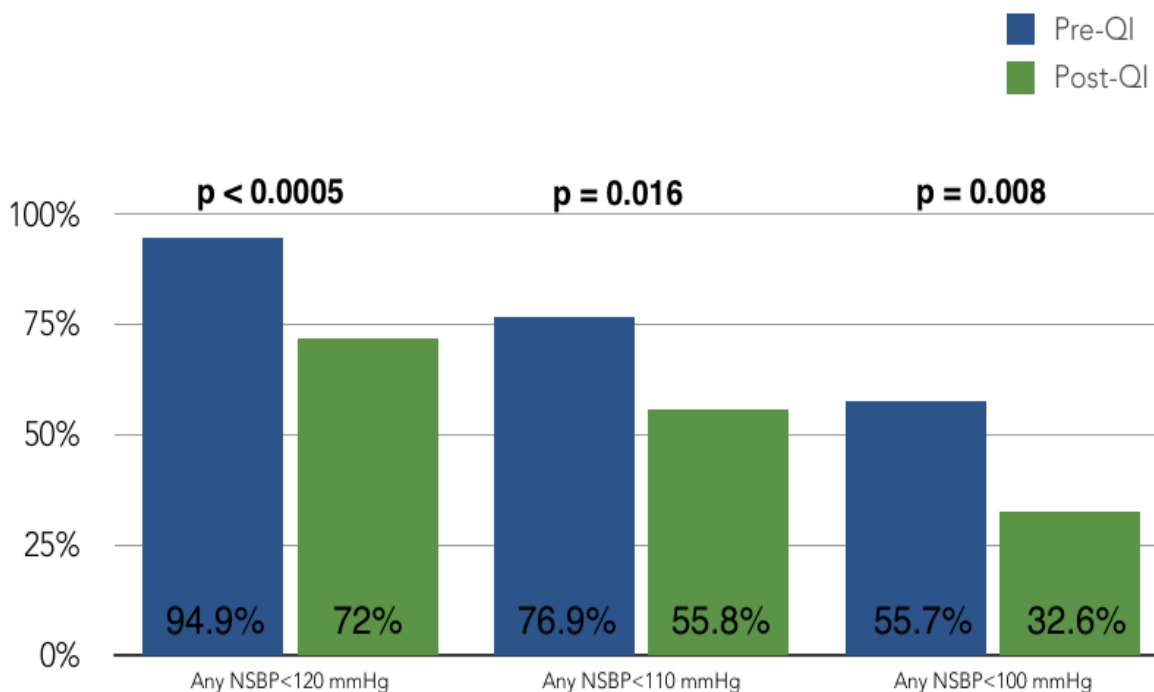


Figure 3.4 Prevalence of Relative Hypotension Using Different NSBP Cut-off Values

3.4 CLINICAL OUTCOMES

Clinical outcome differences between the pre- and post-intervention periods are summarized in **Table 3.3**. Our findings showed that the QI intervention was associated with lower in-hospital all-cause mortality rate (adjusted OR=0.67, 95% CI=0.55-0.8, p<0.0005) and shorter ICU LOS marginally (adjusted IRR=0.61, 95% CI=0.37-1.01, p=0.05). The QI intervention was also associated with higher likelihood of favorable neurologic outcome, favorable discharge disposition, and shorter hospital LOS, but did not reach statistical significance (Hypothesis 3).

Table 3.3 Pre- and Post-intervention Differences in Clinical Outcomes

	Crude rate		Crude OR* (post-QI / pre-QI)	Adjusted OR (post-QI / pre-QI)	95% CI	p value
	Pre-QI	Post-QI				
In-hospital mortality of all causes	14.1%	23.2%	1.85	0.67	0.55-0.81	<0.0005
Favorable neurologic outcome (mRS 0-2)	19.5%	16.3%	0.80	1.27	0.42-3.80	0.67
Favorable discharge disposition	53.3%	53.5%	1.01	1.57	0.88-2.80	0.13
* OR = Odds Ratio, used to compare outcome difference by logistic regression.						

	Median LOS (days)		Crude IRR* (post-QI / pre-QI)	Adjusted IRR (post-QI / pre-QI)	95% CI	p value
	Pre-QI	Post-QI				
Hospital LOS	10	7	0.99	0.79	0.51-1.19	0.25
ICU LOS	3	2	0.85	0.61	0.37-1.01	0.05
* IRR = Incidence Rate Ratio, used to compare outcome difference by Poisson or negative binomial regression. The LOS analysis only included the survivors of the first hospital course.						

Chapter 4. DISCUSSION

4.1 DISCUSSION OF RESEARCH FINDINGS

In the baseline characteristics comparison between pre- and post-intervention study subjects, we found that post-intervention group had higher stroke severity at presentation to the emergency room, in terms of higher mean NIHSS. This imbalance could potentially undermine the internal validity of the study if left unaddressed. According to our protocol, GA is favored in more severe stroke patients, and arterial line placement might be considered more frequently in those patients. Therefore, more GA use, more arterial line placement, longer timeliness indicators, and poorer clinical outcomes may be expected in the post-QI intervention group. However, instead of showing negative results as aforementioned, our findings demonstrated lower use of GA and arterial line and faster timeliness indicators, which demonstrate the potential positive impacts of the QI intervention. In addition, we also addressed this selection issue by adjusting for NIHSS in all our statistical models for clinical outcomes.

All three timeliness indicators that we measured improved in the post-intervention period. To distinguish the QI impacts from other contextual, system-wide effects on these indicators, we used the scatter plots and regression model to capture the changes of the data trend. QI intervention was shown to have impacts on the improvement trends after teasing out other systemic effects.

Besides decreasing the absolute value of the timeliness indicators, the QI project was also expected to decrease the variability of the indicators, as a reasonable proxy for a more stable system. Our findings showed inconsistent and mixed results. By using IQR, range, and variance (not shown in the result section) to evaluate the variability of each indicator, DTP actually showed increased variability, despite decreased median DTP time and decreased median and

variability in two other indicators. One explanation could be the relatively smaller case numbers in the post-QI period, which results in less statistical precision.

Generally speaking, all timeliness indicators improved after implementation of the QI intervention. QI evidently contributed to the improvement by encouraging less use of GA and arterial line by anesthetic providers.

There is no existing literature of PDSA model being used to address intra-procedural or intra-operative physiological perturbations, and our study could contribute to this perspective. Our findings showed that blood pressure control was more sensitive to QI intervention than respiratory parameters. We compared non-invasive SBP due to its robustness against selection bias. Every anesthetic case must have NSBP measurement but not necessarily have ASBP measurement. Arterial line placement could be related to higher disease severity under physician discretion, especially in the post-intervention period when routine arterial line placement is discouraged.

There are fairly limited number of studies using clinical outcomes to measure the effectiveness of PDSA model as a QI tool. Our team acknowledged the methodological challenges and used a more sophisticated statistical tool and conceptual model to guide the analysis.

4.2 STUDY STRENGTHS AND LIMITATIONS

There are strengths to our study. First of all, the scope of metrics evaluated by our study was comprehensive and followed a line of reasoning described by the conceptual model. By collecting and analyzing the relevant data from patient characteristics, workflow-related timeliness indicators, provider decision-making patterns, detailed and accurate intra-procedural

hemodynamic and respiratory parameters, to the patient-level clinical outcomes, we intended to present a holistic view for how QI efforts took effect without significant missing links.

On top of that, the statistical models we used for clinical outcome analysis held some methodological strengths. The utilization of the GEE model lent our study greater statistical sophistication to evaluate the population average response to the QI intervention, and the multi-level model structure provided more efficient adjustment for radiologist performance, compared to using dummy variables.

We also acknowledge a number of limitations to our study. Firstly, due to the relative scarcity of the patients with AIS undergoing EVT and anesthetic care, our sample size did not provide us with enough statistical power to detect meaningful difference in neurologic outcome in terms of mRS. A study result with 10% more patients with favorable neurologic outcome in the post-intervention group could be viewed as clinically meaningful; however, our study was only powered to detect difference larger than 24.9%.

Furthermore, the recruited patient number was not stable over time, which could undermine the reliability of trend analysis. A series of clinical trials published in 2013 did not show the superiority of EVT over traditional medical treatment, in terms of 90-day survival free of disability or functional independence. [38-40] Consequently, the number of patients who underwent EVT at HMC dropped drastically in 2013 but gradually recovered in 2014 and 2015, probably due to new positive evidence coming out. [41, 42]

Data quality could be subject to personal interpretation due to the manual data abstraction process. In our database, there were no pre-specified data points for clinical outcomes, and the functional status at discharge (mRS) was rated according to the physical therapists' reports. In addition, no clinical outcomes in 90 days or 3 months were available in the data infrastructure,

which made trans-research comparison less feasible. A more integrated, standardized, and extended data collection framework is thus recommended, as well as more investment on the data infrastructure.

Another limitation to our study is the generalizability issue. The QI interventions are generally tailored to local needs; while the underlying clinical capacity, operator skill level, and research infrastructure could largely differ between institutes. HMC is a comprehensive stroke center with Stroke Code Quality Improvement Committee actively tracking the institutional performance and quality, and motivating continuous QI efforts both physically and culturally. This solid infrastructure decreased technical obstacles for QI intervention and the corresponding impacts. In addition, Harborview is a safety-net health care organization that cares for low-income patients with and without insurance. Therefore, our findings may or may not be applicable to the facilities without similar infrastructure or patient population.

Finally, although efforts were made to account for measurable confounding factors, the usual caveat that association does not imply causation also applies here, due to the inability to adjust for all potential confounders. The most salient issue was the residual confounding by time-varying, unmeasured variables that could correlate to both the QI intervention and the outcomes. For example, as delineated in the conceptual model, the introduction of innovative medical instruments (e.g., new model of stent retrievers) could happen over time and change the clinical outcomes. [41] The maturity and coordination of the intervention team, hospital wide QI efforts, and radiologists' skill level all shared the same time-varying and confounding characteristics. As a result, while the change of anesthesia patterns and provider decision-making were more robust to this limitation, other clinical outcome findings could overestimate the true effect size.

4.3 IMPLICATIONS OF FINDINGS

The sustainability of change is challenging for every QI intervention, and the institute is obligated for periodical tracking of the change and dissemination of the relevant information to the stakeholders. A mid-to-long term report of this QI intervention could be informative and inspiring for the current and future QI practitioners. The larger sample size and greater statistical power could also strengthen internal validity to improve causal inferences.

Finally, our intervention confirmed the versatility and effectiveness of the PDSA model as a QI tool. Its advantage of improving processes, changing decision-making and practice patterns, and enhancing systemic performance was clearly demonstrated by our study. The PDSA model should continue to be considered and utilized by any frontline provider at “Gemba,” who is trying to make one's system a better one every day.

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