SUPPLEMENTAL MATERIAL

Supplementary Methods

Timeline

The pre-intervention period lasted from Q3/2011 through Q3/2012, while the intervention period lasted from Q4/2012 through Q2/2017. Additional implementation of pneumonia prevention recommendations among 18 of the Michigan Society of Thoracic and Cardiovascular Surgeons Quality Collaborative hospitals occurred between Q1/2016 through Q4/2016.

Facilities

The Society of Thoracic Surgeons (STS) includes nearly 100% of all hospitals performing cardiac surgery in the United States. The Michigan Society of Thoracic and Cardiovascular Surgeons Quality Collaborative (MI-Collaborative) hospitals include:

- Beaumont Hospital – Dearborn (Oakwood) Dearborn, Michigan
- Beaumont Hospital – Royal Oak Royal Oak, Michigan
- Beaumont Hospital – Troy Troy, Michigan
- Borgess Medical Center Kalamazoo, Michigan
- Bronson Methodist Hospital Kalamazoo, Michigan
- Covenant HealthCare Saginaw, Michigan
- Crittenton Hospital Medical Center Rochester, Michigan
- Genesys Regional Medical Center Grand Blanc, Michigan
- Harper University Hospital Detroit, Michigan
- Henry Ford Allegiance Health Jackson, Michigan
- Henry Ford Hospital Detroit, Michigan
- Henry Ford Macomb Hospital Clinton Township, Michigan
- Lakeland Regional Health System St. Joseph, Michigan
- McLaren Bay Region Bay City, Michigan
- McLaren Regional Medical Center Flint, Michigan
- McLaren Greater Lansing Lansing, Michigan
- McLaren Macomb Mount Clemens, Michigan
- McLaren Northern Michigan Petoskey, Michigan
- McLaren Port Huron Port Huron, Michigan
- Mercy Health Partners Muskegon, Michigan
- MidMichigan Medical Center-Midland Midland, Michigan
- Munson Medical Center Traverse City, Michigan
- Providence Hospital and Medical Center Southfield, Michigan
- Sinai Grace Hospital Detroit, Michigan
- Sparrow Health System Lansing, Michigan
- Spectrum Health Grand Rapids, Michigan
- St. John Hospital and Medical Center Detroit, Michigan
- St. John Macomb-Oakland Hospital Warren, Michigan
- St. Joseph Mercy Hospital Ann Arbor, Michigan
- St. Joseph Mercy Oakland Pontiac, Michigan
- St. Mary's of Michigan Saginaw, Michigan
- University of Michigan Hospitals and Health Centers Ann Arbor, Michigan
- UP Health System Marquette Marquette, Michigan

Project Oversight

The MI-Collaborative Pneumonia Prevention Initiative was managed by the MI-Collaborative Data Coordinating Center (Ann Arbor, Michigan). The MI-Collaborative Quality Committee, which is composed of one cardiothoracic surgeon champion from each of the 33 MI-Collaborative centers, provided oversight of the project.

Resources Developed to Support the MI-Collaborative Pneumonia Prevention Initiative (Q4/2012 – Q2/2017)

- Data Analyses:
    - Data analyses concerning pneumonia prevention practices were conducted by staff at the MI-Collaborative Data Coordinating Center. The scope and breadth of these analyses were driven by clinical expertise and experiences, as well as by findings from the peer-reviewed literature. we used data from the Michigan Society of Thoracic and Cardiovascular Surgeons Quality Collaborative (MI-Collaborative) to understand the epidemiology underlying healthcare associated infections (HAIs) after coronary artery bypass grafting (CABG) surgery. We found that HAIs occurred among 5.1% of patients, and isolated pneumonia (3.1%) was the most common HAI.[1] While the observed rate varied 18.2% across the 33 MI-Collaborative centers, the expected rate varied by 2.8%. These findings were substantiated when using the Society of Thoracic Surgeons Adult Cardiac Surgery Database.[2] The MI-Collaborative subsequently identified 17 pre-operative variables that significantly predicted the odds of developing post-operative pneumonia after CABG surgery.[3] In addition, we identified that only 2% of the variability in pneumonia rates across centers was accounted for by traditional risk factors (i.e., pre-, intra- or post-operative).[4] Findings from these data analyses were shared at the MI-Collaborative quarterly meetings, and informed the topics covered during the site visits.
- Structured Literature Reviews:
    - Structured literature reviews concerning pneumonia prevention practices were conducted by staff at the MI-Collaborative Data Coordinating Center. The scope and breadth of the literature reviews were driven by clinical expertise and experiences, as well as by findings from the peer-reviewed literature. Staff from the MI-Collaborative Data Coordinating Center consulted with biomedical librarians at the University of Michigan to assist with the development of the literature reviews. Findings from these reviews were shared at the MI-Collaborative quarterly meetings, and informed the topics covered during the site visits.
- Site Visit Findings:
    - As the foundation for reducing variation in HAIs, the MI-Collaborative undertook a qualitative study to improve our understanding of determinants of hospital-level variation in pneumonia rates. Specifically, the MI-Collaborative studied differences in the clinical use and manner of adoption of pneumonia prevention strategies, and based on these findings, developed pneumonia preventive recommendation practices for CABG surgery based on the literature and on findings emerging from data collected through our qualitative work.[5] A total of 10 site visits were conducted to low and high pneumonia rate hospitals participating in the

MI-Collaborative. Visits included semi-structured interviews with frontline care providers, quality and safety officers and administrators. Findings emerging from initial site visits were shared at quarterly collaborative meetings and served to inform the scope of topics covered at subsequent visits.

- Pneumonia Prevention Recommendations:
    - A draft of the recommendations was shared with clinical representatives and project personnel from MI-Collaborative hospitals. Input was received regarding the literature supporting the recommendations prior to presenting at a MI-Collaborative meeting. The MI-Collaborative Quality Committee reviewed and provided endorsement of the final recommended practices.
- Pneumonia Prevention Webinar:
    - A webinar was developed and subsequently distributed to each MI-Collaborative hospital. The webinar consisted of an evidence-based review supporting each of the pneumonia prevention recommendations based on a presentation of these recommendations at the MI-Collaborative August 2015 Quarterly Meeting.
- Quarterly MI-Collaborative Meetings:
    - Representatives (database managers, perfusionists, surgeons, research personnel) from each MI-Collaborative hospital convened each calendar quarter. Meetings included break-out sessions for the Quality Committee, database managers, perfusionists and surgeons, along with a specific pneumonia-prevention session beginning (February 8, 2014). Attendees signed a confidentiality notice prior to entering the meeting to enable the sharing of unblinded center data.
- STS Quarterly Feedback Reports:
    - Each hospital participating in the STS (in and outside of Michigan) received benchmarking reports from the STS. Reports provide a comprehensive review of each hospital's program, along with comparisons to both comparable hospitals and the entire STS. These reports were distributed electronically to the database manager at each hospital, with the goal of using these reports in their local quality improvement team meetings.
- Quarterly Feedback Reports:
    - Each hospital participating in the MI-Collaborative received benchmarking reports from the MI-Collaborative Data Coordinating Center. Reports provide a detailed, focused review of each hospital's program, along with comparisons to each MI-Collaborative hospital along with a STS benchmark when available. These reports were distributed electronically to the database manager at each hospital, with the goal of using these reports in their local quality improvement team meetings.
- Monthly Pneumonia Prevention Recommendation Reports:
    - Starting in Q1/2016, 18 of the 33 MI-Collaborative hospitals agreed to focus on tracking the use of the pneumonia prevention recommendations, as well as implementing them in their hospitals. To facilitate these activities, the MI-Collaborative's Data Coordinating Center provided monthly benchmark reports detailing each hospital's progress with data collection and implementation. These reports were distributed

electronically to the database manager at each hospital, with the goal of using these reports in their local quality improvement team meetings.

- Follow Up Site Visits:
    - After implementing the pneumonia prevention recommendations, we conducted an additional 5 site visits to high and low pneumonia hospitals to assess barriers and facilitators to implementing these recommendations. Visits included meetings with frontline care providers, and safety officers. Findings from site visits were reported back to hospitals along with supporting recommendations.
- Webinar Focusing on Preventing Post-operative Pneumonia Among Patients with Preexisting Pulmonary Disease:
    - We developed a webinar to provide guidance to frontline clinicians concerning how to make targeted clinical changes through the patient's perioperative course to reduce the risk of developing pneumonia after CABG surgery among patients with pre-existing pulmonary disease. We disseminated the webinar to MI-Collaborative hospitals. The webinar was organizationally divided in 3 sections:
        - Pre-operative Care:
            - Role and importance of patient selection and timing of surgery
            - Pathophysiology of pulmonary disease from a surgeon's perspective.
        - Intra-operative Care:
            - Tailoring anesthetic approaches based on a patient's pulmonary function
        - Post-operative Care:
            - Optimizing handoffs to the intensive care unit
            - Critical areas of information transmission (from an intensive care unit perspective)
            - Optimizing post-operative care to prevent pneumonia

Supplementary Table 1. The Michigan Society of Thoracic and Cardiovascular Surgeons Quality Collaborative's Pneumonia Prevention Practice Recommendations

Setting	Recommendation
Pre-operative	5-meter walk test
	Oral and nasal preparation
	Pulmonary function testing
Intra-operative	Blood conservation
	Lung protective ventilation
Post-operative	Blood conservation
	Detection and management of post-operative pneumonia in the intensive care unit
	Subglottic suctioning
	Daily assessment of oral care
	Daily spontaneous awakening trials
	Daily spontaneous breathing trials
	Pair daily spontaneous breathing trials with spontaneous awakening trials
	Progressive mobility

Supplementary Table 2. Pre-operative Characteristics Across Groups and Time

Characteristics	Pre-Intervention					Intervention				
	Overall	**STSnon MI**	**MI-Collaborative Only**	**MI-Collaborative Plus**	**p-value**	**Overall**	**STSnon MI**	**MI-CollaborativeOnly**	**MI-CollaborativePlus**	**p-value**
N	196,954	189,774	3,410	3,770		714,800	690,605	10,829	13,366	
Demographics										
Age, mean (SD), years	64.9 (10.5)	64.9 (10.5)	65.5 (10.5)	64.9 (10.5)	0.022	65.2 (10.3)	65.2 (10.3)	65.8 (10.2)	65.4 (10.1)	<0.001
Caucasian	85.5	85.4	87.1	90.7	<0.001	84.8	84.6	88.1	91.1	<0.001
Female	26.1	26.1	27.1	26.1	0.42	24.8	24.8	26	24.6	0.019
Laboratory Values										
Last Pre-operative Hematocrit, mean (SD)	38.5 (5.4)	38.6 (5.4)	38.4 (5.2)	38.3 (5.3)	0.0033	39.2 (5.5)	39.2 (5.5)	39.2 (5.4)	39.1 (5.4)	0.12
Last White Blood Cell Count, mean (SD)	8.2 (3.6)	8.2 (3.6)	8.1 (3.9)	8.0 (3.5)	<0.001	8.2 (3.3)	8.2 (3.3)	8.1 (3.0)	8.0 (3.3)	<0.001
Comorbid Disease										
Dyslipidemia	86.2	86.1	89.3	91.8	<0.001	88	87.8	89.9	92.2	<0.001
Peripheral Arterial Disease	14.3	14.2	17.8	16.4	<0.001	14.2	14.2	16.5	15.6	<0.001
Cerebrovascular Disease	14.1	14	16	15.8	<0.001	18.6	18.5	22.1	21.6	<0.001

Diabetes Mellitus	44.5	44.5	45.6	44.5	0.43	47.9	47.9	47.5	45.8	<0.001
Liver Disease	2.2	2.2	2.7	1.7	0.012	3	3	4.1	2.6	<0.001
Pulmonary Function										
Home Oxygen Therapy	1.7	1.7	1.9	1.6	0.6	1.8	1.8	1.8	1.6	0.61
History of Pneumonia					<0.001					<0.001
Recent	2.9	2.9	2.8	3		2.9	3.0	2.7	2.1	
Remote	3.4	3.3	6	4		4.1	4.0	5.8	5.6	
Current Cigarette User	22.8	22.8	24.3	23	0.089	22.7	22.7	23.8	22.7	0.032
History of Chronic Lung Disease					<0.001					<0.001
Unknown Severity[l]						3.9	3.9	3.2	3.8	
Severe	4.3	4.2	8.7	4.4		4.3	4.2	6.4	4.4	
Moderate	6.2	6.1	7.6	5.4		5.3	5.3	7	4.4	
Mild	13.5	13.4	21.1	13.8		11.5	11.3	20.3	14.1	
Cardiac Function										
Pre-operative Intra-aortic Balloon Pump	10.2	10.3	8.7	8	<0.001	9.6	9.6	8.1	7.7	<0.001
History of Arrhythmia	12.7	12.7	14.3	12.9	0.016	13.5	13.4	16.1	14	<0.001
Ejection Fraction					0.014					<0.001
>=35 and <50	21.5	21.5	22.4	20.8		21	21	21.1	20.2	
<35	10.4	10.5	9.9	9.1		10.8	10.8	10.9	9.6	

Operative Status					<0.001					<0.001
Urgent	56	55.9	62.2	60.3		57.6	57.5	60.9	58.8	
Emergent/Salvage	4.9	4.9	4.1	2.9		4.6	4.6	2.9	2.7	

Comparison of (1) 1165 centers (other than those in Michigan) participating in the Society of Thoracic Surgeons Adult Cardiac Surgery Database (STS-nonMI), (2) 15 Michigan centers solely participating in the Michigan Society of Thoracic and Cardiovascular Surgeons Quality Collaborative (MI-CollaborativeOnly) to (3) 18 Michigan centers participating in the Michigan Society of Thoracic and Cardiovascular Surgeons Quality Collaborative plus implementing pneumonia-specific prevention recommendations additional pneumonia-specific fee (MI-CollaborativePlus)

Data are expressed as No. (%) unless otherwise indicated.

P-values are based on Pearson chi-square tests for all categorical row variables.

Supplementary Table 3. Intra- and Post-operative Characteristics Across Groups and Time

Characteristics	Pre-Intervention					Intervention				
	Overall	**STSnonMI**	**MI-CollaborativeOnly**	**MI-CollaborativePlus**	**p-value**	**Overall**	**STSnonMI**	**MI-CollaborativeOnly**	**MI-CollaborativePlus**	**p-value**
N	196,954	189,774	3,410	3,770		714,800	690,605	10,829	13,366	
Intra-operative										
Cardiopulmonary Bypass Utilization					<0.001					<0.001
Full	80.8	80.4	91.1	92.2		84.6	84.3	90.3	94.2	
None	18.1	18.5	8.5	7.6		14.4	14.6	9.4	5.8	
Cardiopulmonary Bypass Duration, mean (SD), minutes	95.7 (37.8)	95.3 (37.6)	93.7 (36.9)	113.5 (45.4)	<0.001	94.8 (37.4)	94.6 (37.3)	93.4 (35.6)	106.0 (41.4)	<0.001
Cross Clamp Duration, mean (SD), minutes	68.3 (29.4)	67.9 (29.1)	67.2 (30.0)	86.1 (38.7)	<0.001	68.5 (29.3)	68.2 (29.2)	67.4 (27.3)	82.2 (34.6)	<0.001
Nadir Hematocrit, mean (SD)	24.7 (4.8)	24.7 (4.8)	25.7 (4.8)	25.4 (4.8)	<0.001	25.2 (4.9)	25.2 (4.9)	25.9 (5.0)	25.7 (5.0)	<0.001
Blood Products Used	33.9	34.3	26.6	22.7	<0.001	28.5	28.8	23.7	19.0	<0.001
Red Blood Cells, mean (SD), number	1.81 (1.72)	1.81 (1.72)	1.80 (1.48)	1.67 (1.42)	0.15	1.7 (1.7)	1.7 (1.7)	1.5 (1.4)	1.6 (1.4)	<0.001
Antibiotic Delivery										

Appropriate Selection	97.7	97.7	97.5	97.6	0.77	98.6	98.6	98.9	99	<0.001
Appropriate Timing	98.9	98.9	98.9	99.1	0.63	98.9	98.9	98.7	98.6	0.006
Post-operative										
Blood Products Used	38.9	39.1	36.9	31.8	<0.001	31	31.1	31.2	25	<0.001
Red Blood Cells, mean (SD), number	2.5 (2.7)	2.5 (2.7)	2.6 (2.8)	2.6 (2.4)	0.012	2.4 (2.9)	2.4 (2.9)	2.4 (2.4)	2.3 (2.8)	0.0025
Prolonged Intubation	10.1	10.1	11.6	10.2	0.015	8.6	8.6	9.6	7.1	<0.001
Major Morbidity/Mortality	13.7	13.7	14.8	13.6	0.19	12.2	12.2	13.2	10.6	<0.001
Operative Mortality	2.4	2.4	2.1	1.7	0.016	2.3	2.3	2.1	1.8	<0.001
Post-operative Length of Stay, mean (SD), days	6.9 (5.1)	6.8 (5.1)	7.0 (5.2)	7.1 (4.8)	<0.001	6.8 (5.0)	6.8 (5.0)	7.3 (4.9)	6.9 (4.5)	<0.001
Antibiotic										
Appropriate Discontinuation	97.7	97.7	98.5	98.1	0.001	97.8	97.8	98.3	98.4	<0.001
Severe	4.3	4.2	8.7	4.4		4.3	4.2	6.4	4.4	
Moderate	6.2	6.1	7.6	5.4		5.3	5.3	7	4.4	
Mild	13.5	13.4	21.1	13.8		11.5	11.3	20.3	14.1	

Comparison of (1) 1165 centers (other than those in Michigan) participating in the Society of Thoracic Surgeons Adult Cardiac Surgery Database (STS-nonMI), (2) 15 Michigan centers solely participating in the Michigan Society of Thoracic and Cardiovascular Surgeons Quality Collaborative (MI-CollaborativeOnly) to (3) 18 Michigan centers participating in the Michigan Society of Thoracic and Cardiovascular Surgeons Quality Collaborative plus implementing pneumonia-specific prevention recommendations additional pneumonia-specific fee (MI-CollaborativePlus)

Data are expressed as No. (%) unless otherwise indicated.

P-values are based on Pearson chi-square tests for all categorical row variables.

Supplementary Table 4. Unadjusted Pneumonia Rates Across Clinical Subgroups

Characteristics	Pre-Intervention					Intervention				
	Overall	**STSnonMI**	**MI-CollaborativeOnly**	**MI-CollaborativePlus**	**p-value**	**Overall**	**STSnonMI**	**MI-CollaborativeOnly**	**MI-CollaborativePlus**	**p-value**
N	196,954	189,774	3,410	3,770		714,800	690,605	10,829	13,366	
Demographics										
Age Groups										
65-74	3	3	3.1	3.5	0.56	2.5	2.6	2.6	1.9	0.021
75-84	4.1	4.1	5.3	3	0.12	3.5	3.5	3.7	2.5	0.024
>=85	5.2	5.3	2.9	4	0.61	4.5	4.5	6.4	2.7	0.14
Race										
White	3	3	3.7	3	0.064	2.5	2.6	2.9	2	<0.001
Non-White	3.5	3.5	6.6	5.1	0.0006	3	3	3.8	3.1	0.22
Sex										
Female	3.2	3.2	5.1	3.5	0.0046	2.8	2.8	3.7	2	0.0006
Male	3	3	3.7	3.1	0.12	2.6	2.6	2.7	2.1	0.0061
Body Mass Index (kg/m2)										
<18.5	5.8	5.8	0	10.5	0.43	5.4	5.4	6	1.5	0.34
15.8-24.9	3.7	3.7	4.5	3.7	0.61	3.1	3.1	3.7	2.6	0.14
25.0-29.9	2.7	2.7	2.8	2.4	0.79	2.3	2.3	2.7	1.7	0.0055
30.0-34.9	2.8	2.8	4.4	2.6	0.015	2.4	2.4	2.3	2.1	0.32
35.0-39.9	3.5	3.4	7	4.3	0.0004	2.7	2.7	3.1	2.4	0.42

>=40	3.9	3.8	4.4	5.7	0.22	3.2	3.2	4.9	2.4	0.01
Operative Status										
Elective	2.3	2.2	2.5	3	0.17	1.9	1.9	2.2	1.6	0.065
Urgent	3.3	3.3	4.4	3.1	0.014	2.8	2.8	3.1	2.2	0.0017
Emergent/Salvage	7.7	7.6	12.8	8.2	0.07	6.9	6.9	8.9	6.8	0.39
Cigarette Smoking, Current										
No	2.7	2.7	30	2.6	0.69	2.2	2.2	2.4	1.7	0.004
Yes	4.5	4.4	7.7	5.1	<0.001	3.9	3.9	4.7	3.4	0.03
Chronic Lung Disease										
No	2.5	2.5	2.8	2.5	0.68	2	2	2.2	1.6	0.0031
Yes	4.9	4.9	6.3	5.3	0.071	4.2	4.2	4.2	3.3	0.041
Off-Pump Surgery										
No	2.7	2.7	2.4	3.5	0.69	2.3	2.3	2.1	2.1	0.87
Yes	3.2	3.2	4.3	3.2	0.0023	2.7	2.7	3.1	2.1	<0.001
Cardiopulmonary Bypass Duration (min)										
<60	2.3	2.3	2.12	2	0.93	1.9	1.9	1.1	1.8	0.1
60-89	2.7	2.7	4.6	2	0.0002	2.3	2.3	2.5	1.6	0.18
90-119	3.2	3.2	3.8	2.9	0.49	2.7	2.7	3.1	1.9	0.0044
>=120	4.4	4.4	5.8	4.4	0.26	3.8	3.8	5.5	2.7	<0.001
Intra-operative Red Blood Cell Transfusions Used										

No	2.3	2.3	3.4	2.3	0.0014	2	2	2.4	1.7	0.0025
Yes	4.6	4.6	6	6.4	0.006	4.2	4.2	4.9	3.8	0.12

Comparison of (1) 1165 centers (other than those in Michigan) participating in the Society of Thoracic Surgeons Adult Cardiac Surgery Database (STS-nonMI) (2) 15 Michigan centers solely participating in the Michigan Society of Thoracic and Cardiovascular Surgeons Quality Collaborative (MI- CollaborativeOnly) to (3) 18 Michigan centers participating in the Michigan Society of Thoracic and Cardiovascular Surgeons Quality Collaborative plus implementing pneumonia-specific prevention recommendations additional pneumonia-specific fee (MI-CollaborativePlus)

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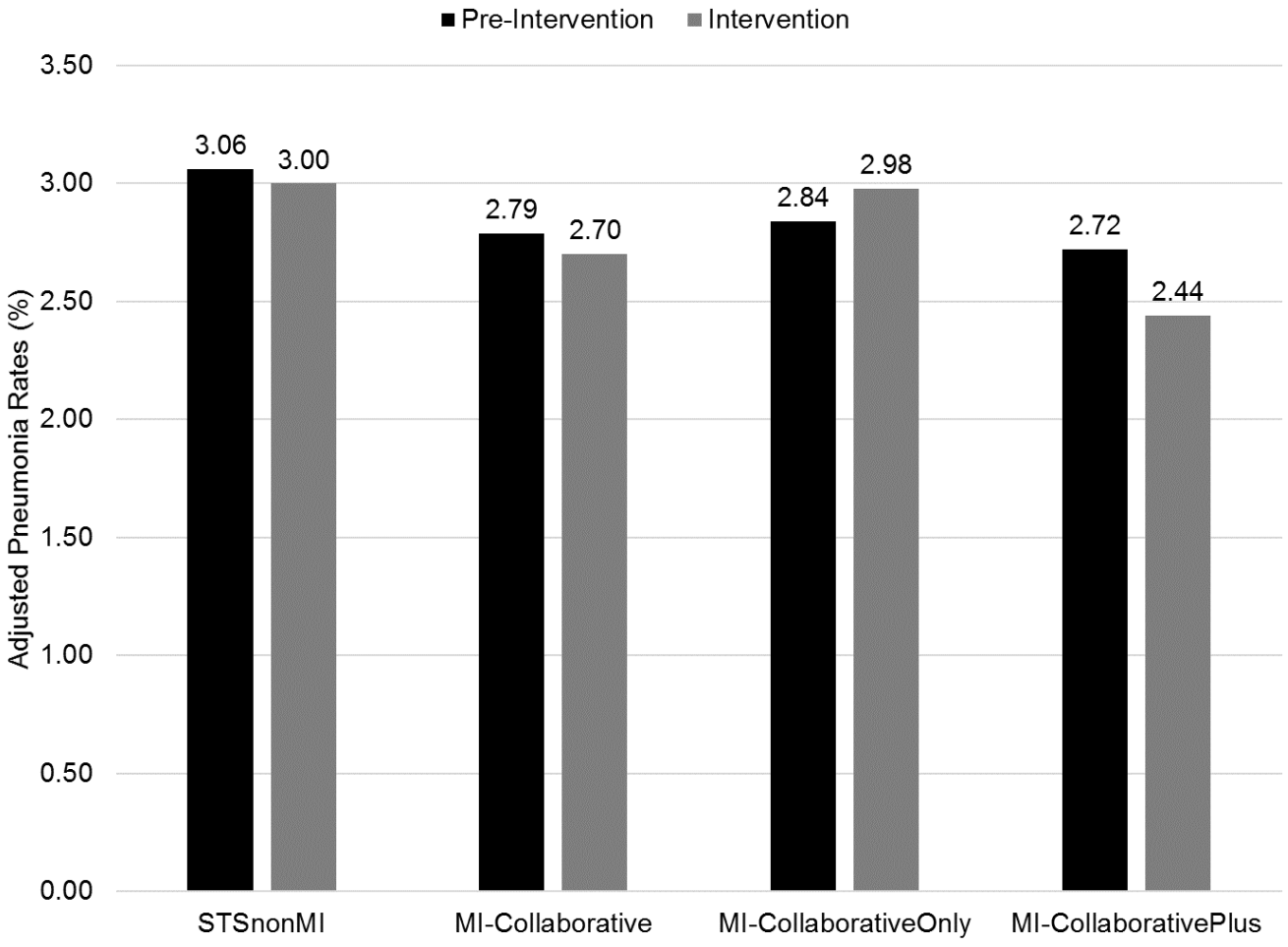
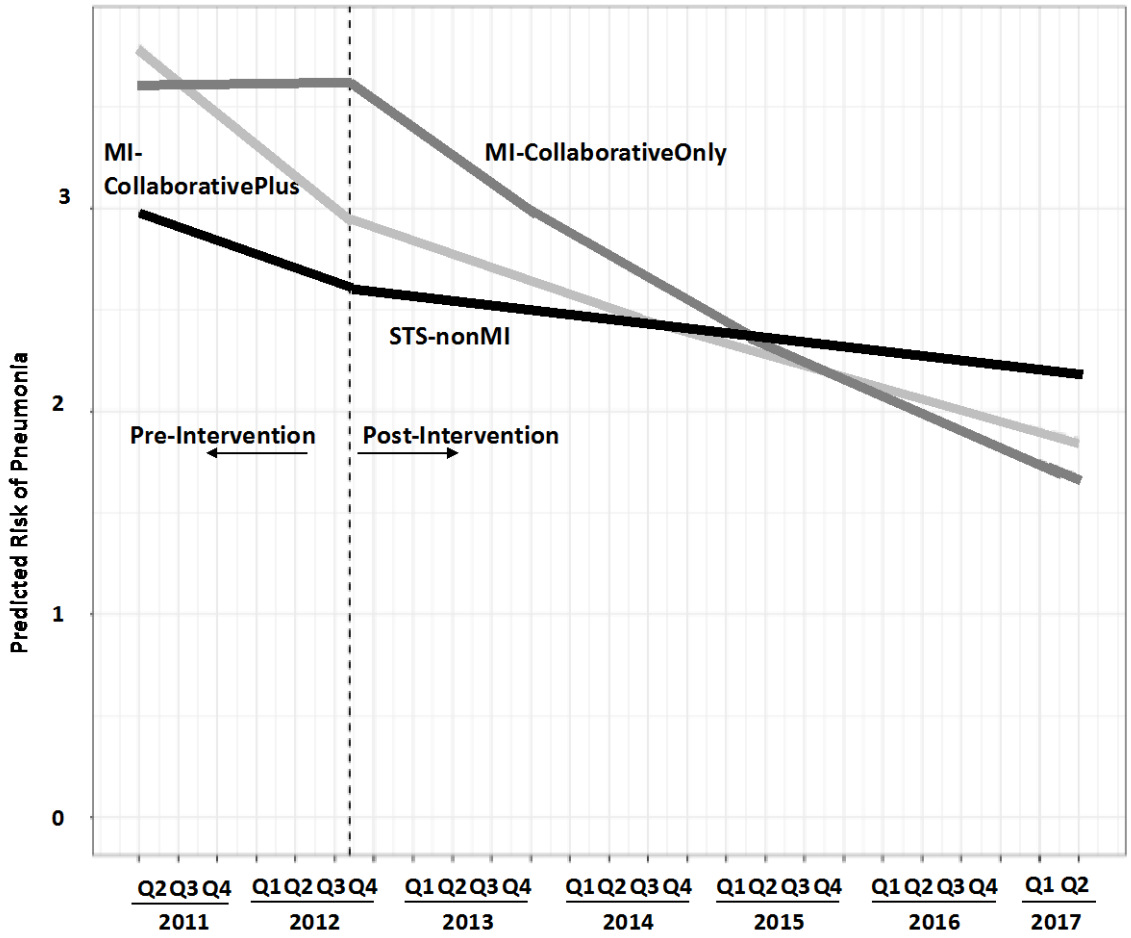
P-values are based on Pearson chi-square tests for all categorical row variables

Supplementary Figure 1. Adjusted Post-operative Pneumonia Rates by Group and Time Period.



Supplementary Figure 2. Predicted Post-operative Pneumonia Rates by Group and Calendar Quarter



Supplementary Figure Legends

Supplementary Figure 1: STS: Society of Thoracic Surgeons; MI: Michigan. STS-nonMI: Hospitals (other than those located in Michigan) that participated in the Society of Thoracic Surgeons Adult Cardiac Surgical Database; MI-Collaborative: 33 Michigan hospitals that participated a physician-led; MI-CollaborativeOnly: 15 Michigan hospitals that participated a physician-led collaborative but did not pursue implementing pneumonia-prevention recommendations; MI-CollaborativePlus: 18 Michigan hospitals that participated a physician-led collaborative and additionally implemented pneumonia-prevention recommendations

Supplementary Figure 2: STS: Society of Thoracic Surgeons; MI: Michigan. STS-nonMI: Hospitals (other than those located in Michigan) that participated in the Society of Thoracic Surgeons Adult Cardiac Surgical Database; MI-CollaborativeOnly: 15 Michigan hospitals that participated a physician-led collaborative but did not pursue implementing pneumonia-prevention recommendations; MI-CollaborativePlus: 18 Michigan hospitals that participated a physician-led collaborative and additionally implemented pneumonia-prevention recommendations

Supplementary References

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2. Likosky DS, Wallace AS, Prager RL, et al. Sources of Variation in Hospital-Level Infection Rates After Coronary Artery Bypass Grafting: An Analysis of The Society of Thoracic Surgeons Adult Heart Surgery Database. *Ann Thorac Surg.* 2015;100(5):1570-1575; discussion 1575-1576.
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