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Early Versus Late Adhesiolysis for Adhesive-Related Intestinal Obstruction: A Nationwide Analysis of Inpatient Outcomes

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Abstract

Background Classical teaching advocates watchful waiting for 2 days before operating on adhesive-related intestinal obstructions (AIOs). Our aim was to compare the clinical and cost outcomes of early versus late adhesiolysis for AIOs.

Design Patients undergoing adhesiolysis for AIOs from the 2007 Nationwide Inpatient Sample were stratified to early (≤2 days from admission) vs. late (>2 days) adhesiolysis. The primary outcome was in-hospital mortality and secondary outcomes were post-operative complications (POCs), post-operative length of stay (PLOS), and in-hospital cost.

Results From 5,443 patients who underwent adhesiolysis for AIOs, 53 and 47 % underwent early and late adhesiolysis, respectively. Late adhesiolysis patients were older (65.0 vs. 60.1 years) and more co-morbid compared to the early group ($p<0.05$). After adjustment with propensity score methods, late adhesiolysis patients had no difference in mortality (odds ratio [OR] 0.95, 95%-confidence intervals [CI] 0.67–1.36, $p=0.79$) or POCs (OR 1.01, 95%CI 0.89–1.14, $p=0.91$) compared to the early group, but had 9.8 % increased PLOS and 41.9 % increased in-hospital cost ($p<0.001$).

Conclusions The 2-day limit of watchful waiting is not associated with increased mortality or POCs for those patients undergoing adhesiolysis for an AIO. Late adhesiolysis, however, was associated with significantly increased PLOS and in-hospital cost compared to early adhesiolysis.

Keywords Intestinal obstruction · Small bowel obstruction · Adhesions · Adhesiolysis

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Introduction

Adhesive-related intestinal obstructions (AIOs) pose a significant challenge to the patient, surgeon and healthcare system. Over 94 % of patients form adhesions after abdominal surgery[1,2] and complications such as AIOs, most commonly in the small bowel, lead to expensive and prolonged hospital stays.[3,4] Patients may present with an intestinal obstruction years after an initial operation[5,6] and each presentation forebodes increased risk for recurrence.[7,8] While most AIOs resolve with non-operative management, a significant proportion require an operation,[9] whether an open or laparoscopic adhesiolysis. The optimal timing of adhesiolysis for these patients creates one of the greatest and oldest clinical dilemmas in general surgery: how long do you wait for an obstruction to resolve before operating?

Most surgeons advocate a maximum trial of 24–48 h of non-operative management, barring any earlier clinical deterioration, before proceeding to the operating room.[10–16] These management guidelines are supported by small retrospective studies from the 1920–1970s that observed increased mortality and post-operative complication rates in patients who underwent delayed surgery for intestinal obstruction.[17–20] No studies in the twenty-first century, however, have revisited the question of whether an early or late adhesiolysis as defined by the 48-h time limit is most clinically beneficial and/or cost-effective. Therefore, the aim of this study was to compare the clinical and cost outcomes for patients who underwent early versus late adhesiolysis for intestinal obstruction using a recent, and largest available, inpatient care database in the United States.

Material and Methods

We conducted a retrospective cohort study of the 2007 Nationwide Inpatient Sample (NIS).[21] The NIS is an annual survey of inpatient discharge records sponsored by the Agency for Healthcare Research and Quality (AHRQ). The 2007 NIS includes de-personalized data from 8,034,632 patient admission records from 1,044 hospitals in 40 states. Using sample weights, the survey represents 20 % of all US non-federal hospitals which includes academic institutions. Researchers must sign a data use agreement with AHRQ prior to use. Additional approval from the Institutional Review Board at Boston University Medical Center was obtained prior to beginning this study (IRB protocol # H-29346).

Cohort

Included in the study cohort were all adult patients (≥18 years) with a primary diagnosis of intestinal obstruction who subsequently underwent adhesiolysis as a primary procedure. Diagnoses and procedures were identified by the International Statistical Classification of Diseases and Related Health Problems, 9th revision, Clinical Modification (ICD-9CM) coding. Intestinal obstruction ICD-9CM codes were 560.9 or 560.81. Adhesiolysis ICD-9CM codes were 54.51 (laparoscopic) or 54.59 (open).

Exposure Variables

The primary exposure variable was days from admission to adhesiolysis. Patients who underwent adhesiolysis before or equal to 2 days after admission were classified in the early adhesiolysis group. Patients who received adhesiolysis more than 2 days after admission were classified in the late adhesiolysis group. The cut-off of 2 days was chosen a priori by the authors and based on consensus opinions from a wide range of surgical literature.[10–16] For the purposes of our study, 2 days is equivalent to 48 h.

As a secondary exploratory analysis, we varied the above cut-off day to 1 and 3–10 days after admission to re-define "early" versus "late" adhesiolysis groups and performed repeated outcome comparisons using the same statistical techniques as described below with the newly defined groups.

Patient Characteristics

Patient characteristics included age, sex, race, insurance type, median household income, and 29 co-morbidities. Co-morbidity data are provided with the 2007 NIS dataset and were created by AHRQ using an algorithm to classify co-morbidities by ICD-9CM coding.

Primary Outcome

The primary outcome was in-hospital mortality as reported by the 2007 NIS under each patient record. Deaths occurring after discharge were not included in the dataset and therefore were not part of the analysis.

Secondary Outcomes

Secondary outcomes were in-hospital post-operative complications (POCs), post-operative length of stay (PLOS), and total in-hospital cost. All-cause, non-fatal POCs were defined a priori and identified by ICD-9CM codes within predefined categories (see Appendix A).[22] PLOS was calculated as day of adhesiolysis subtracted from the total in-hospital length of stay. Total in-hospital cost is an included data element for each patient in the 2007 NIS.

Statistical Methods

We first compared group characteristics including demographics, co-morbidities and outcomes using two sample t tests for continuous measures and Chi-square tests for categorical measures. For the variables in-hospital cost and PLOS the gamma regression was used due to non-normal distribution of these variables.

Propensity score methods are increasingly utilized in the surgical literature and describe a statistical technique that attempts to balance the inherent differences in patient characteristics between two groups in observational studies before making outcome comparisons. In our study, for example, the propensity score is the calculated probability that a patient will be in the "early" adhesiolysis group based on the included patient covariates. This propensity score can then be used as a covariate in regression models or to match patients either directly or in stratified groups to make an "apples-to-apples" comparison between two groups. Like standard regression models, propensity score methods minimize potential confounding effects before making outcome comparisons. Propensity scores, however, do have some advantages over standard regression models and are particularly useful when comparing groups for relatively rare outcomes[23] and when balancing for large numbers of covariates.

For this study, we considered four outcome measures: mortality, POC, PLOS and total in-hospital cost. The multivariable analysis included two approaches in order to assess sensitivity of the results to the method of analysis: (1) multivariable modeling with backward elimination and (2) a propensity score method with adjustment for propensity score quintiles. For the multivariable modeling approach, all multivariable analyses included initially the following variables: age, gender, payment type, region, and all 29 co-morbidities (solid tumor, ulcer disease, valvular disease, immune deficiency syndrome, alcohol abuse, deficiency anemia, arthritis, chronic blood loss anemia, congestive heart failure (CHF), chronic pulmonary disease (CPD), coagulopathy, depression, diabetes mellitus uncomplicated, diabetes mellitus with complications, drug abuse, hypertension (HTN), hypothyroidism, liver disease, lymphoma, fluid/electrolyte disorders, metastatic cancer, other neurological disorders, obesity, paralysis, peripheral vascular disorders, psychoses, pulmonary circulation disorders, renal failure, weight loss). Then a backward selection procedure with 0.2 level of alpha to keep variables in the model was applied. Multivariable logistic regression was used to assess group differences in mortality and complications. As the distribution of PLOS and in-hospital cost variables were inherently right skewed, the log-normal regression model was used to assess for differences in PLOS and total in-hospital cost. For the propensity score method approaches, we constructed the propensity score[23] for being in the "early" procedure group using logistic regression and including all the variables shown to be significantly (≤0.05 level) different across the groups in the bivariate analysis. These variables were: age, payment type and co-morbidities (solid tumor, valvular disease, deficiency anemia, arthritis, CHF, CPD, depression, HTN, hypothyroidism, fluid/electrolyte disorders, metastatic cancer, renal failure, weight loss). The quintiles of the propensity score were then defined and we repeated the multivariable analyses described above first including the propensity quintile as a categorical covariate in the model and then secondly stratifying the sample based on the propensity quintile and repeating the multivariable analysis in each strata.

Finally, as a secondary exploratory analysis, we repeated the above analysis for redefined "early" and "late" procedure groups using different cut-off points. Nine additional analyses (for procedure days 1 and 3–10 post-admission) were therefore performed using propensity score methods to balance the groups before making adjusted outcome comparisons for mortality, POC, PLOS and total in-hospital cost.

For all tests, the type I error level was set at 0.05. All analyses were performed using SAS 9.2 (SAS Institute Inc., Cary, NC, USA).

Results

Cohort

In the 2007 NIS survey cohort (n=8,034,632), 38,848 adult patients (age≥18 years) with a primary diagnosis of intestinal obstruction were identified, and 5,443 subsequently underwent adhesiolysis as a primary procedure. Extrapolating to the nationwide population, approximately 190,901 patients (95% CI 181,670–200,131) were admitted to a non-federal hospital in the United States in 2007 with a primary diagnosis of intestinal obstruction, and 31,928 patients (95% CI 30,087–33,769) subsequently underwent adhesiolysis as a primary procedure (16.7 % of intestinal obstruction patients, 95% CI 16.6–16.9 %). Associated total in-hospital costs were $1.77 billion (95% CI $1.64 billion to $1.90 billion), and 829 patients (95% CI 704–954) died prior to discharge.

The early adhesiolysis group (days until adhesiolysis ≤2) included 2,897 patients (53.2 % of the cohort) and the late adhesiolysis group (days until adhesiolysis>2) included 2,546 patients (46.7 % of the cohort). The median number of days from admission until adhesiolysis was 1 (range 0–57).

Demographics and Co-morbidities

Baseline demographics and co-morbidities of the final cohort are summarized in Table 1 before and after propensity score adjustment. Late adhesiolysis patients were older (65.0 versus 60.1 years, respectively; p<0.001), predominantly female, differed in the distribution of payers (p<0.001), and had 14 co-morbidities with higher frequencies (p<0.05 for each co-morbidity), compared to early adhesiolysis patients. The 14 co-morbidities included: solid tumor without metastasis, valvular disease, anemia, rheumatoid arthritis, CHF, CPD, depression, hypertension, hypothyroidism, lymphoma, fluid/electrolyte disorders, metastatic cancer, renal failure and weight loss. Using propensity score methods, these differences were balanced prior to adjusted outcome analysis.

Outcomes

Unadjusted outcomes for early versus late adhesiolysis are shown in Table 2. Mortality (2.1 vs. 3.1 %, p=0.02),

Table 1 Baseline demographics and co-morbidities for the patients in the 2007 NIS who underwent adhesiolysis (n=5443) are shown below and divided into early (n=2897) and late (n=2546) groups as defined by an operation before or equal to 2 days after admission and greater than 2 days after admission, respectively. Included are unadjusted and adjusted comparisons (using propensity score methods) between demographics and co-morbidities with respective p values

Characteristic	Overall (N=5443)	Early procedure (N=2897)	Late procedure (N=2546)	Unadjusted p value	Adjusted p value
Demographics					
Age (years)					
Mean±SD	62.4±17.5	60.1±17.4	65±17.1	<0.001	0.91
Median and IQ range	63 (50–77)	60 (47–74)	67 (53–79)		
Gender N (%)				0.10	0.58
Male	2034 (37.4 %)	1112 (38.4 %)	922 (36.2 %)		
Female	3404 (62.6 %)	1782 (61.6 %)	1622 (63.8 %)		
Race N (%)				0.31	0.24
White	3316 (75 %)	1751 (75 %)	1565 (75 %)		
Black	605 (13.7 %)	308 (13.2 %)	297 (14.2 %)		
Hispanic	270 (6.1 %)	156 (6.7 %)	114 (5.5 %)		
Other	229 (5.2 %)	119 (5.1 %)	110 (5.3 %)		
ZIP income dollars (%)				0.38	0.42
$38,999 or less	1299 (24.5 %)	677 (24 %)	622 (25.1 %)		
$39,000–$47,999	1352 (25.5 %)	712 (25.2 %)	640 (25.8 %)		
$48,000–$62,999	1272 (24 %)	671 (23.8 %)	601 (24.2 %)		
$63,000 or more	1377 (26 %)	760 (27 %)	617 (24.9 %)		
Primary payer, N (%)				<0.001	0.84
Medicare	2679 (49.6 %)	1273 (44.4 %)	1406 (55.4 %)		
Medicaid	270 (5 %)	156 (5.4 %)	114 (4.5 %)		
Private/HMO	2061 (38.1 %)	1197 (41.7 %)	864 (34.1 %)		
Self-pay	247 (4.6 %)	155 (5.4 %)	92 (3.6 %)		
Other	148 (2.7 %)	87 (3 %)	61 (2.4 %)		
Clinical					
Solid tumor without metastasis, N (%)	116 (2.1 %)	50 (1.7 %)	66 (2.6 %)	0.03	0.83
Peptic ulcer disease excluding bleeding, N (%)	2 (0 %)	1 (0 %)	1 (0 %)	0.93	0.96
Valvular disease, N (%)	255 (4.7 %)	110 (3.8 %)	145 (5.7 %)	<0.001	0.93
Acquired immune deficiency syndrome, N (%)	11 (0.2 %)	6 (0.2 %)	5 (0.2 %)	0.93	0.99
Alcohol abuse, N (%)	100 (1.8 %)	60 (2.1 %)	40 (1.6 %)	0.17	0.24
Deficiency anemias, N (%)	712 (13.1 %)	290 (10 %)	422 (16.6 %)	<0.001	0.62
Rheumatoid arthritis/collagen vascular diseases, N (%)	131 (2.4 %)	55 (1.9 %)	76 (3 %)	0.01	0.99
Chronic blood loss anemia, N (%)	50 (0.9 %)	20 (0.7 %)	30 (1.2 %)	0.06	0.27
Congestive heart failure, N (%)	428 (7.9 %)	165 (5.7 %)	263 (10.3 %)	<0.001	0.57
Chronic pulmonary disease, N (%)	977 (17.9 %)	486 (16.8 %)	491 (19.3 %)	0.02	0.96
Coagulopathy, N (%)	122 (2.2 %)	57 (2 %)	65 (2.6 %)	0.15	0.59
Depression, N (%)	454 (8.3 %)	219 (7.6 %)	235 (9.2 %)	0.03	0.91
Diabetes, uncomplicated, N (%)	731 (13.4 %)	385 (13.3 %)	346 (13.6 %)	0.75	0.09
Diabetes with chronic complications, N (%)	80 (1.5 %)	45 (1.6 %)	35 (1.4 %)	0.58	0.11
Drug abuse, N (%)	89 (1.6 %)	49 (1.7 %)	40 (1.6 %)	0.73	0.55
Hypertension (combine uncomplicated and complicated), N (%)	2,499 (45.9 %)	1,233 (42.6 %)	1,266 (49.7 %)	<0.001	0.78
Hypothyroidism, N (%)	571 (10.5 %)	269 (9.3 %)	302 (11.9 %)	0.002	0.98
Liver disease, N (%)	85 (1.6 %)	42 (1.4 %)	43 (1.7 %)	0.48	0.46
Lymphoma, N (%)	33 (0.6 %)	12 (0.4 %)	21 (0.8 %)	0.05	0.14
Fluid and electrolyte disorders, N (%)	2,022 (37.1 %)	876 (30.2 %)	1,146 (45 %)	<0.001	0.97
Metastatic cancer, N (%)	140 (2.6 %)	43 (1.5 %)	97 (3.8 %)	<0.001	0.21

Table 1 (continued)

Characteristic	Overall (*N*=5443)	Early procedure (*N*=2897)	Late procedure (*N*=2546)	Unadjusted *p* value	Adjusted *p* value
Other neurological disorders, *N* (%)	312 (5.7 %)	160 (5.5 %)	152 (6 %)	0.48	0.36
Obesity, *N* (%)	272 (5 %)	150 (5.2 %)	122 (4.8 %)	0.51	0.66
Paralysis, *N* (%)	70 (1.3 %)	31 (1.1 %)	39 (1.5 %)	0.13	0.47
Peripheral vascular disorders, *N* (%)	278 (5.1 %)	134 (4.6 %)	144 (5.7 %)	0.08	0.91
Psychoses, *N* (%)	155 (2.8 %)	81 (2.8 %)	74 (2.9 %)	0.81	0.90
Pulmonary circulation disorders, *N* (%)	90 (1.7 %)	44 (1.5 %)	46 (1.8 %)	0.41	0.42
Renal failure, *N* (%)	338 (6.2 %)	142 (4.9 %)	196 (7.7 %)	<0.001	0.74
Weight loss, *N* (%)	434 (8 %)	142 (4.9 %)	292 (11.5 %)	<0.001	0.06

POC (26.8 vs. 29.9 %, $p=0.01$), PLOC (7.3 vs. 8.8 mean days, $p<0.001$) and in-hospital cost ($45,233 vs. $71,891, $p<0.001$) for early versus late adhesiolysis, respectively, were all significantly higher for patients undergoing late adhesiolysis. In subgroup analysis of POCs, late adhesiolysis patients had significantly higher rates of infectious (3.5 vs. 2.5 %, $p=0.02$), pulmonary (6.8 vs. 5.3 %, $p=0.02$) and systemic (1.6 vs. 0.9 %, $p=0.02$) complications compared to the early group.

Adjusted outcomes for mortality, POC, PLOS, and in-hospital cost are reported in Table 3 after balancing covariates with propensity score methods for early (≤2 days) versus late adhesiolysis (>2 days). No difference in mortality (OR 0.95, 95% CI 0.67–1.36, $p=0.79$) or POCs (OR 1.01, 95%CI 0.89–1.14, $p=0.91$) was estimated between the two groups. Patients undergoing late adhesiolysis, however, had significantly increased mean PLOS (9.8 % increase in mean days, $p<0.001$) and mean in-hospital cost (41.9 % increase in mean cost, $p<0.001$) compared to the early group.

Exploratory Analysis with Different Cut-Off Days After Admission

Repeat statistical analysis using propensity score methods to balance covariate differences between early versus late adhesiolysis groups at different cut-off days (1 and 3–10 days post-admission) showed that mortality significantly increased when adhesiolysis was performed 8 days after admission (OR 2.06, CI 1.21–3.53, $p<0.01$, Table 4) while no differences in POCs were observed (Table 5).

Discussion

The American College of Surgeons aptly states that “One of the most difficult tasks in general surgery is deciding when to operate on a patient with intestinal obstruction.”[10] Our study, based on a recent, national and large cohort of patients who specifically underwent adhesiolysis for AIO,

Table 2 Unadjusted outcomes for early versus late adhesiolysis show that in-hospital mortality and post-operative complications (POCs) are significantly different between the two groups. Post-operative length of stay (PLOS) and in-hospital cost are significantly increased with late adhesiolysis. Specific complications are defined in Appendix A

Outcome	Overall (*N*=5443)	Early procedure (*N*=2897)	Late procedure (*N*=2546)	*p* value
Mortality *N* (%)	138 (2.5 %)	60 (2.1 %)	78 (3.1 %)	0.02
Complications *N* (%)	1535 (28.2 %)	775 (26.8 %)	760 (29.9 %)	0.01
Mechanical	73 (1.3 %)	40 (1.4 %)	33 (1.3 %)	0.79
Infectious	160 (2.9 %)	71 (2.5 %)	89 (3.5 %)	0.02
Urinary	56 (1 %)	28 (1 %)	28 (1.1 %)	0.63
Pulmonary	326 (6 %)	153 (5.3 %)	173 (6.8 %)	0.02
Gastrointestinal	878 (16.1 %)	446 (15.4 %)	432 (17 %)	0.12
Cardiovascular	143 (2.6 %)	75 (2.6 %)	68 (2.7 %)	0.85
Systemic	67 (1.2 %)	26 (0.9 %)	41 (1.6 %)	0.02
Operative/procedural	193 (3.5 %)	105 (3.6 %)	88 (3.5 %)	0.74
Post-op length of stay (mean days)	8±7	7.3±7	8.8±7	<0.001
In-hospital cost (mean dollars)	57,719.8±64,754.7	45,233.2±49,020.6	71,891.8±76,477.3	<0.001

Table 3 Adjusted outcomes after balancing covariates with propensity score methods for early versus late adhesiolysis show that in-hospital mortality and post-operative complications (POCs) are not significantly different between the two groups. Post-operative length of stay (PLOS) and in-hospital cost are significantly increased with late adhesiolysis. Included as reference for each outcome are the detailed quintile analyses calculated using the propensity score method to derive the overall adjusted odds ratio for each outcome

Outcome	Adjusted odds/means ratio	Lower confidence limit	Upper confidence limit	*p* value
Mortality	0.95	0.67	1.36	0.79
Quintile 1	0.93	0.55	1.55	0.77
Quintile 2	1.48	0.76	2.87	0.25
Quintile 3	0.69	0.25	1.89	0.47
Quintile 4	0.21	0.03	1.74	0.15
Quintile 5	1.09	0.10	12.30	0.94
Complications	1.01	0.89	1.14	0.91
Quintile 1	0.70	0.54	0.92	0.009
Quintile 2	1.06	0.81	1.37	0.67
Quintile 3	1.17	0.90	1.53	0.23
Quintile 4	1.28	0.97	1.71	0.09
Quintile 5	0.89	0.64	1.25	0.51
Post-op length of stay	1.10	1.06	1.14	<0.0001
Quintile 1	1.02	0.94	1.10	0.62
Quintile 2	1.09	1.02	1.17	0.02
Quintile 3	0.99	0.92	1.07	0.78
Quintile 4	1.12	1.03	1.21	0.005
Quintile 5	1.33	1.22	1.45	<0.001
In-hospital cost	1.42	1.36	1.48	<0.001
Quintile 1	1.40	1.27	1.54	<0.001
Quintile 2	1.45	1.34	1.58	<0.001
Quintile 3	1.25	1.14	1.37	<0.001
Quintile 4	1.43	1.31	1.57	<0.001
Quintile 5	1.63	1.50	1.78	<0.001

suggests that the historically based answer of 2 days cannot be applied carte blanche. Instead, our analysis found that patients in the United States who underwent adhesiolysis in 2007 for intestinal obstruction after 2 days of admission had similar mortality and POC rates compared to those patients who underwent adhesiolysis within 2 days of admission when controlling for the clinical differences between the groups. These findings provide cautious reassurance to the surgeon who, for a variety of clinical and non-clinical reasons, may choose to manage an AIO non-operatively for more than 2 days. In an era of heightened fiscal responsibility, however, our analysis provides an important caveat by showing that late adhesiolysis was associated with a significant increase in PLOS (9.8 % increased days) and total in-hospital cost (41.9 % increased cost) compared to early adhesiolysis.

Table 4 Exploratory analysis for in-hospital mortality using propensity score methods by choosing different cut-off days from the time of admission show that in-hospital mortality significantly increased when adhesiolysis was performed 8 days after admission

Hospital day cut-off	Adjusted odds ratio	Lower 95%CL	Upper 95% CL	*p* value
1	1.05	0.68	1.62	0.81
2	0.95	0.67	1.36	0.79
3	1.20	0.84	1.71	0.31
4	1.32	0.91	1.92	0.14
5	1.34	0.88	2.02	0.17
6	1.26	0.79	2.02	0.33
7	1.58	0.94	2.64	0.08
8	2.06	1.21	3.53	0.01
9	2.57	1.43	4.60	0.002
10	2.84	1.48	5.44	0.002

In the 2007 NIS, 53 % of patients who underwent adhesiolysis for AIO were operated on within 2 days after admission. The remaining 47 % of patients were operated on 2 days after their admission, challenging the classic axiom, “Never let the sun set on a bowel obstruction,” as not all surgeons followed historically based guidelines for operating on a patient with an AIO within 24 to 48 h of an admission. There may be several explanations for these operative delays. First, it

Table 5 Exploratory analysis for post-operative complications (POCs) using propensity score methods by choosing different cut-off days from the time of admission show that post-operative complications are not significantly different between early versus late adhesiolysis groups even up to 10 days after admission

Hospital day cut-off	Adjusted odds ratio	Lower 95%CL	Upper 95%CL	*p* value
1	1.17	1.01	1.34	0.03
2	1.00	0.89	1.14	0.91
3	0.99	0.87	1.13	0.87
4	0.91	0.79	1.06	0.24
5	0.92	0.77	1.09	0.33
6	0.92	0.75	1.12	0.39
7	0.87	0.68	1.11	0.27
8	0.88	0.66	1.17	0.39
9	0.90	0.64	1.26	0.53
10	0.77	0.51	1.17	0.22

would be naïve and simplistic to assume that operative decisions are based solely on a 48-h stop clock that starts from the time of admission. A better assumption would be that patients are taken to the operating room based on a multitude of constantly changing factors, primarily clinical, radiological, and even logistical ones. Second, surgeons may be cautious to operate on high-risk patients and consequently delay surgery with the hopes of having the obstruction resolve non-operatively. Indeed, patients in the 2007 NIS who underwent late adhesiolysis were significantly older and more co-morbid than the early group as shown in Table 1. Moreover, unadjusted outcome comparisons showed higher mortality, POCs, PLOS, and in-hospital cost for the late adhesiolysis group (Table 2). Delaying surgery for these patients may have some merit as several studies,[12,24] including our own initial regression analyses [data not shown], suggest that older age and co-morbidities such as congestive heart failure and coagulopathies are significant predictors for mortality and POCs. Third, in contrast to the obstructed patient with evidence of strangulated bowel, wider ambiguity in operative timing arises in the patient with no evidence of strangulation, which occurs in 87 to 94 % of initial presentations.[16] Observational studies on patients managed non-operatively have shown that non-strangulated obstructions can resolve between 2 to 14 hospital days and reportedly even beyond.[25–27] Based on these reasons, it was therefore not surprising to see that a large proportion of patients underwent adhesiolysis after 2 days in the 2007 NIS.

Our observation that mortality risk for patients after adhesiolysis is not increased after 2 days of admission seems to contradict work from other retrospective studies that suggest 48 h is the longest safe period for non-operative management for AIO and that delayed surgery actually does harm to the patient.[12,28] Important differences in study design may account for these different conclusions. First, these prior studies included other etiologies such as hernias, gallstones and volvuli as a cause of obstruction in their cohort of patients. The primary operative procedures were thus not limited to adhesiolysis and included bowel resections and hernia repairs. Our cohort was composed specifically of patients with intestinal obstructions caused by adhesions and our findings are thus relevant to this particular population which no other study has directly addressed. Second, several of these studies failed to rigorously control for differences in patient characteristics. By using the robustness of the propensity score methods with all of the covariates as provided by the NIS, we were able to adjust for important differences before making outcome comparisons. Third, while all studies, including our own, were retrospective in design, our analysis was based on the 2007 NIS, which confers important statistical advantages as a large, representative multicenter cohort of 8,034,632 patients. Our findings are based on a snapshot of all adhesiolysis procedures performed in the US in 2007 for intestinal obstruction and, insofar as limited by the sampling parameters of the 2007 NIS, these conclusions are applicable through the population for that year.

The economic impact from adhesion-related complications such as intestinal obstructions on the US healthcare system continues its astronomical rise with estimates from 1994 at $1.3 billion dollars[4] to over $5.0 billion dollars in 2005.[3] Despite significant improvements in perioperative care, these rising numbers reflect the slow progress in reducing the morbid complications associated with adhesions. In our study, patients undergoing late adhesiolysis incurred an additional 9.8 % increase in post-operative days of hospitalization and 41.9 % increase in in-hospital cost per patient (Table 3). These findings are not trivial and on a cost analysis would suggest that early adhesiolysis is advantageous in reducing overall hospital cost. These findings are consistent with those studied in the other surgical literature which have shown that early operation for hip fractures, for instance, reduce costs and length of stay[29] and are therefore advantageous. It is important to highlight, however, that our current analysis compares only those patients who underwent an adhesiolysis operation and does not compare the operative group, whether early or late, to the 83.3 % of obstructed patients in the 2007 NIS who did not have adhesiolysis as a primary procedure. Such a larger analysis will be important in future studies and consequently our analysis and findings are applicable only to the specifically defined population of patients with a primary diagnosis of AIO who underwent adhesiolysis as a primary procedure.

Mortality rates for intestinal obstruction after surgical intervention have made substantial declines from levels of 60 % in the early 20th century to 20 % by 1945 to less than 5 % by 1969.[17] These reductions were largely due to the use of proximal decompression with nasogastric tubes, improved diagnosis using radiographic studies and advancements in perioperative care.[17] Post-operative complication rates after adhesiolysis have varied more widely secondary to varying definitions, but have been observed from 14 to 32 %.[6,30] As shown in Table 2, unadjusted mortality from patients who underwent adhesiolysis for intestinal obstruction ranged from 2.1 % in the early group to 3.1 % in the late group, who were notably older and sicker. After adjusting for differences in age and co-morbidities with propensity score methods, there was no observed difference in mortality between early versus late adhesiolysis groups until the observed 8-day limit (Table 4). Additionally, no differences in overall POCs were observed between the early and late adhesiolysis groups in the 2007 NIS, even past the above 8-day limitation observed for mortality (Table 5). The relative plateau in mortality and morbidity rates after adhesiolysis, even in 2007, suggest that surgeons are maximizing the perioperative resources available for safely taking care of obstructed patients after adhesiolysis. While continued efforts should be directed towards improving these outcomes, additional improvements may be gained by a more careful and expeditious selection of those patients who definitively require an operation.

The pioneering work of Owen H. Wangensteen[31] on identifying and managing those patients who require an operation is as relevant today as it was in the early 20th century. While our study observed that adhesiolysis was significantly associated with an increased mortality risk after 8 days of admission for AIOs, this finding is underscored by the take-home message that earlier adhesiolysis is still likely better, especially with respect to decreasing lengths of stay and hospital costs. Progress in the early identification of those patients likely to fail medical management and require an operation has advanced since the days of Wangensteen. Classically, clinical endpoints such as peritoneal signs, fever, or leukocytosis[30] have been used to help determine when to operate, although none of these measures are singularly reliable.[16] More recently, a meta-analysis by Branco et al.[32] that included 14 prospective studies concluded that orally administered water-soluble contrast agents can be used to identify those patients who can be managed non-operatively. The presence of contrast in the colon within 4–24 h after administration was highly predictive for non-operative resolution of the obstruction. Use of this diagnostic technique significantly reduced the need for surgery and length of stay, both parameters that drive hospital costs. In light of our findings, which show the economic benefits of early adhesiolysis compared to late adhesiolysis, using such diagnostic techniques may help reduce the number of patients who undergo late adhesiolysis.

Limitations

An advantage of propensity score methods is that any associations between the exposure and outcome variables are conditionally independent of the covariates used to estimate the propensity score. However, residual confounding can still occur from unmeasured covariates. The specific classification of an intestinal obstruction as complete or partial, for example, is not detailed by ICD-9CM codes and may be unequally distributed between the early and late group. Similarly, the 2007 NIS lacks radiographic information on "high" versus "low"-grade obstructions and also lacks clinical elements that could identify patient symptoms, duration of those symptoms before admission, physical findings, prior abdominal operations, nutritional status, laboratory endpoints, and surgeon preferences that might explain why certain patients underwent an early as opposed to late adhesiolysis or vice versa. These are important limitations that are inherent to retrospective studies of large, administrative databases such as the 2007 NIS. Our findings and conclusions are therefore very specific and only applicable to our strictly selected cohort of patients.

In an attempt to control for these inherent limitations, our study identified a priori those patients with a primary diagnosis of AIO who underwent adhesiolysis as a primary procedure within the 2007 NIS. We did not include those patients who underwent bowel resection or those patients with secondary or even tertiary procedures of adhesiolysis as we chose to be extremely strict in selecting our cohort at the primary level for both diagnosis and procedure codes. While recognizing the potential weaknesses with such an approach, we believed a priori in this study that any further combination of data elements (i.e., secondary, tertiary, quaternary and higher levels of diagnoses and procedure codes) within the 2007 NIS database would have added additional layers of complexity and further assumptions of multi-diagnoses and multi-procedural in-hospital courses that would again not be readily interpretable in an administrative database. Additionally, we looked specifically only at those patients who received an operation and did not analyze the non-operative group of patients with a primary diagnosis of AIO. Future studies with more recent NIS data and other databases that incorporate detailed clinical data, such as the National Surgical Quality Improvement Program (NSQIP) database, will be necessary to address these limitations.

Conclusions

Patients with AIOs who underwent adhesiolysis in the United States in 2007 had no significantly increased risk of mortality or morbidity if operated on after 2 days of admission compared to those who received an earlier operation when controlling for clinical differences between the two groups. Risk of mortality, however, was observed to increase after 8 days of admission for those patients who underwent adhesiolysis in 2007, which will require further investigation. These data suggest that the historically based 48-h time limit of waiting by itself does not determine clinical outcomes such as mortality or POCs for those patients undergoing later adhesiolysis for an AIO, but instead is associated with increased PLOS and in-hospital cost compared to early adhesiolysis.

Our study provides cautious reassurance to surgeons by showing that from a high-level administrative view we are operating on obstructed patients safely while acknowledging that at the bedside, judgment decisions are being made that our study does not capture. We also hope to emphasize, however, that this high-level view shows that later operations are costly and increase post-operative length of stay, which surgeons may not see from the bedside.

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Appendix A

Table 6 ICD-9 codes used for post-operative complications (POCs) as previously described by Guller et al.[22]

Complication	Examples	ICD-9 code
Mechanical wound complications	Post-op hematoma, seroma, dehiscence	998.83, 998.12, 998.13, 998.3, 998.6
Infection complications	Post-op abscess, wound infection	998.5, 998.59, 998.51
Urinary complications	Post-op urinary tract infection, retention	997.5
Pulmonary complications	Post-op pneumonia, pulmonary edema	997.3, 518.5, 512.1
Gastrointestinal complications	Post-op ileus, obstruction, pancreatitis	997.4
Cardiovascular complications	Post-op pulmonary embolism, stroke, arrest	997.79, 415.11, 997.02, 997.2, 997.1
Systemic complications	Post-op fever, shock	998.0, 998.89
Operative/procedural complications	Foreign body, bleeding complicating procedure	998.2, 998.4, 998.11

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