Seasonality and Readmission after Heart Failure, Myocardial Infarction, and Pneumonia

Neel M. Butala , Eric A. Secemsky, Jason H. Wasfy,
Kevin F. Kennedy, and Robert W. Yeh

Objective. To investigate whether hospital readmission after admission for heart failure (HF), myocardial infarction (MI), and pneumonia varies by season.

Data Sources. All patients in 2005–2009 Healthcare Cost and Utilization Project State Inpatient Databases for New York and California hospitalized for HF, MI, or pneumonia.

Study Design. The relationship between discharge season and unplanned readmission within 30 days was evaluated using multivariate modified Poisson regression.

Principal Findings. Cohorts included 869,512 patients with HF, 448,945 patients with MI, and 813,593 patients with pneumonia. While admissions varied widely by season, readmission rates only ranged from 25.0 percent (spring) to 25.6 percent (winter) for HF ($p > .05$), 18.9 percent (summer) to 20.0 percent (winter) for MI ($p < .001$), and 19.4 percent (spring) to 20.3 percent (summer) for pneumonia ($p < .001$). In adjusted models, in New York, there was lower readmission in spring and fall (RR: 0.98, 95% CI: 0.96–0.99 for both) after admission for HF and higher readmission in spring (RR: 1.04, 95% CI: 1.01–1.07) after MI. In California, there was lower readmission in spring and winter (RR: 0.95, 95% CI: 0.93–0.96 and RR: 0.96, 95% CI: 0.94–0.98, respectively) after pneumonia.

Conclusions. Given marked seasonality in incidence and mortality of HF, MI, and pneumonia, the modest seasonality in readmissions suggests that readmissions may be more related to non–seasonally dependent factors than to the seasonal nature of these diseases.

Key Words. Internal medicine, access/demand/utilization of services, health care organizations and systems, hospitals, seasonality, readmissions

Seasonality in disease processes has been described for millennia (Lloyd, Chadwick, and Mann 1978). Only recently have large population databases enabled researchers to better characterize these trends for common diseases. In particular, seasonality in heart failure (HF), acute myocardial infarction

(MI), and pneumonia has now been well documented in multiple populations (Ornato et al. 1996; Seretakakis et al. 1997; Spencer et al. 1998; Boulay et al. 1999; Kloner, Poole, and Perritt 1999; Säynäjäkangas, Keistinen, and Tuuponen 2001; Stewart et al. 2002; Dowell et al. 2003; Gerber et al. 2006). Nevertheless, despite established seasonal patterns in incidence of, hospitalization for, and mortality from these diseases, it is unclear whether readmission after hospitalization for these diseases varies by season. Reducing readmission after HF, MI, and pneumonia has become a leading priority for many health systems given that these were the initial conditions for which the Centers for Medicare and Medicaid Services (CMS) imposed financial penalties for readmissions in 2013 (James 2013). However, it has been difficult to determine which factors may result in readmission after hospitalization for these conditions (Ross et al. 2008; Desai et al. 2009; Au et al. 2012).

While seasonality has been observed in readmission for certain common conditions, such as asthma or infection after hip replacement (Kane et al. 2014; Vicendese et al. 2014), results on seasonality and readmission in context of HF, MI, and pneumonia have been mixed. Some studies have shown higher risk of readmission in winter, whereas others have shown higher risk of readmission in summer or no effect at all (Palepu et al. 2003; Park et al. 2014; Tisminetzky et al. 2015). However, all of these studies have been single-center reports with small sample sizes and limited adjustment for other characteristics. Thus, there remains a gap in the literature on the effect of seasonality on readmission after HF, MI, and pneumonia.

The purpose of this study was to expand on the current literature and determine whether re-hospitalization after admission for HF, MI, and pneumonia varies by season using a large multistate sample. The results of this study can improve understanding of the relative contribution of seasonality with regard to other nonseasonal factors in leading to readmission and set the stage for further investigation into mechanisms to mitigate risk of readmission after these conditions.

Address correspondence to Robert W. Yeh, M.D., M.Sc., M.B.A., Smith Center for Outcomes Research in Cardiology, Beth Israel Deaconess Medical Center, 375 Longwood Avenue, Suite 440, Boston, MA 02215; e-mail: ryeh@bidmc.harvard.edu. Neel M. Butala, M.D., M.B.A., is with the Department of Medicine, Massachusetts General Hospital, Boston, MA. Eric A. Secemsky, M.D., M.Sc., and Jason H. Wasfy, M.D., M.Phil., are with the Cardiology Division, Department of Medicine, Massachusetts General Hospital, Boston, MA. Kevin F. Kennedy, M.S., is with the Saint Luke's Mid America Heart Institute/UMKC, Kansas City, MO.

METHODS

Participants and Study Design

All adult patients in the Healthcare Cost and Utilization Project State Inpatient Databases (SIDs) for New York and California between January 1, 2005, and November 30, 2011, were included, and three separate condition-specific cohorts of patients with hospitalizations for primary discharge diagnosis of HF, MI, or pneumonia were derived (HCUP, 2005-2009). The SIDs include all inpatient discharge records from all nonfederal, short-term, general, and other specialty hospitals, excluding hospital units of institutions, regardless of payer and thus create a near 100 percent sample of inpatient discharges. Among SIDs with longitudinal data, New York and California were chosen for both their large state populations and their differing amounts of seasonal variation in temperatures due to different climates. HF, MI, and pneumonia were defined using the same International Classification of Diseases, Ninth Revision codes used to define publicly reported readmissions measures by CMS (Keenan et al. 2008; Krumholz et al. 2011; Lindenauer et al. 2011). All hospitalizations where a patient was an out-of-state resident, left against medical advice, was transferred to another hospital, or expired while in hospital were excluded. Only the first readmission within 30 days of an index hospitalization was considered. All subsequent admissions after 30 days from discharge were evaluated as another index hospitalization.

Variables

The primary exposure was a set of dummy variables indicating season classified as fall (October–December), winter (January–March), spring (April–June), and summer (July–September, as reference category) during date of discharge from index hospitalization. The primary outcome in this study was a binary variable indicating whether a patient had an unplanned readmission to a hospital for any cause within 30 days of discharge from index hospitalization. Planned readmissions were defined based on algorithms used to create publicly reported measures by CMS and were excluded (Horwitz et al. 2011). Variables indicating state and an interaction between season and state were included given the a priori hypothesis of potentially different seasonal effects stemming from disparate climates in New York and California. Additional variables examined as covariates in adjusted models included calendar year, age, race, gender, length of stay, and an array of 29 comorbidity measures as defined by the Agency for Healthcare

Research and Quality based on the Elixhauser comorbidity index (Elixhauser et al. 1998).

Statistical Analysis

Baseline characteristics of variables listed above for all patients were tabulated by season, and chi-squared tests or Student *t*-tests were used to evaluate for any significant differences. Raw rates of admissions and readmissions were plotted by month for HF, MI, and pneumonia to inspect visually for trends. Next, modified Poisson regression was used with hospital site as a random effect, readmission as the dependent variable, and a set of dummy variables indicating season as the independent variables. The model also included calendar year, state, and an interaction between season and state. Models then sequentially adjusted for demographic covariates (age, race, and gender) and clinical covariates (length of stay and comorbidities). As a robustness check to address possible misspecification of seasons, analyses were repeated with an array of dummy variables indicating month instead of season. We additionally examined the most frequent readmission primary diagnoses grouped according to Clinical Classifications Software (CCS) code (Elixhauser, Steiner, and Palmer 2016), and, in supplemental analyses conducted post hoc, we restricted our sample to readmission only for the primary diagnosis of index admission. All analyses were performed using *SAS* version 9.4 (SAS Institute Inc., Cary, NC).

RESULTS

Final study cohorts included 869,512 patients with HF, 448,945 patients with MI, and 813,593 patients with pneumonia (Figure S1). Total hospital admissions, readmissions, and readmission rates by condition and season are detailed in Table 1 (further broken down by state in Table S1; full baseline characteristics in Table S2 and S3). Total hospital admissions varied widely by season for all three conditions examined: in winter relative to summer, there were 17.7 percent more admissions for HF, 6.3 percent more admissions for MI, and 51.3 percent more admissions for pneumonia (all $p < .001$). Total unplanned readmissions also tracked closely with total hospital admissions in concert and varied by season: In winter relative to summer, there were 18.0 percent more absolute readmissions for HF, 12.2 percent more absolute readmissions for MI, and 46.8 percent more absolute readmissions for pneumonia. However, the wide seasonal variation in the absolute number of readmissions was due to the

Table 1: Total Admissions and Readmission Rate by Season for HF, MI, and Pneumonia

	Total	Season					p-Value*
		Winter: Dec/Jan/Feb	Spring: Mar/Apr/May	Summer: Jun/Jul/Aug	Fall: Sep/Oct/Nov		
Heart failure							
Total admissions	869,512	231,500	236,726	196,758	204,528		<.001
Unplanned 30-day readmission	220,681 (25.4%)	59,262 (25.6%)	59,255 (25.0%)	50,237 (25.5%)	51,927 (25.4%)		.705
Planned 30-day readmission	6,697 (0.8%)	1,786 (0.8%)	1,915 (0.8%)	1,474 (0.7%)	1,522 (0.7%)		.097
Myocardial infarction							
Total admissions	448,945	114,680	115,963	107,848	110,454		<.001
Unplanned 30-day readmission	87,404 (19.5%)	22,896 (20.0%)	22,876 (19.7%)	20,402 (18.9%)	21,230 (19.2%)		<.001
Planned 30-day readmission	8,976 (2.0%)	2,225 (1.9%)	2,435 (2.1%)	2,118 (2.0%)	2,198 (2.0%)		.932
Pneumonia							
Total admissions	813,593	248,572	224,894	164,293	175,834		<.001
Unplanned 30-day readmission	161,250 (19.8%)	49,001 (19.7%)	43,688 (19.4%)	33,371 (20.3%)	35,190 (20.0%)		<.001
Planned 30-day readmission	2,975 (0.4%)	901 (0.4%)	817 (0.4%)	610 (0.4%)	647 (0.4%)		.679

*p-Value for total admissions calculated using chi-squared test of goodness of fit assuming no seasonality. All other p-values calculated using chi-squared test of independence.

variation in total discharges and not variation in readmission rates per discharge. Unplanned readmission rates after discharge ranged from 25.0 percent in spring to 25.6 percent in winter for HF ($p > .05$), 18.9 percent in summer to 20.0 percent in winter for MI ($p < .001$), and 19.4 percent in spring to 20.3 percent in summer for pneumonia ($p < .001$). Monthly total hospital admissions for each condition and associated readmission rates are plotted in Figure 1.

After statistical adjustment, differences in the risk of readmission by season remained modest in both New York and California (Table 2 and Figure S2; unadjusted model in Table S4). In New York, among patients admitted with HF, there was a slightly lower risk of readmission in spring and fall relative to summer (RR 0.98, 95% CI: 0.96–0.99 for both). Among patients in New York admitted with MI, there was a slightly higher risk of readmission in spring relative to summer (RR 1.04, 95% CI 1.01–1.07). Lastly, for patients in New York admitted with pneumonia, risk of readmission did not vary significantly by season ($p = .071$). In California, among patients admitted with HF, while seasonality variables were jointly significant ($p = .042$), no individual season had a significantly different in risk of readmission relative to summer. Among patients in California admitted with MI, risk of readmission did not vary significantly by season ($p = .065$). Among patients in California admitted with pneumonia, there was a slightly lower risk of readmission in spring and winter relative to summer (RR 0.95, 95% CI: 0.93–0.96 and RR 0.96, 95% CI: 0.94–0.98, respectively). Figure S3 details the results of a robustness check repeating our analyses with month instead of season.

Table 3 lists the five most common readmission primary diagnoses, grouped according to CCS codes, for HF, MI, and pneumonia by season. In each season, the most common cause of readmission for each condition was the index primary diagnosis itself (36 percent for HF, 16 percent for MI, and 22 percent for pneumonia overall). When multivariate analysis of association between seasonality and risk-adjusted readmission for index primary diagnosis only was repeated (Table S5), there was no association between seasonality and readmission after HF or MI, although the slightly lower risk of readmission in spring relative to summer after pneumonia persisted (RR 0.96, 95% CI: 0.92–0.99).

DISCUSSION

This study is the first to examine the effect of seasonality on risk of readmission for patients with HF, MI, and pneumonia using a large multistate sample over multiple years. While we found some statistically significant differences in

Figure 1: (a) Total Admissions and Readmission Rate by Month for HF; (b) Total Admissions and Readmission Rate by Month for MI; (c) Total Admissions and Readmission Rate by Month for Pneumonia [Color figure can be viewed at wileyonlinelibrary.com]

Table 2: Adjusted Association between Season and Readmission in HF, MI, and Pneumonia by State

State	Season	HF		MI		Pneumonia	
		RR (95% CI)	p-Value	RR (95% CI)	p-Value	RR (95% CI)	p-Value
NY	Spring (Mar–May)	.98 (.96, .99)	.008	1.04 (1.01, 1.07)	.008	.98 (.96, 1.01)	.155
	Summer (Jun–Aug)	Reference	—	Reference	—	Reference	—
	Fall (Sep–Nov)	.98 (.96, .99)	.008	1.00 (.97, 1.03)	.90	.97 (.95, 1.00)	.029*
	Winter (Dec–Feb)	1.0 (.98, 1.01)	.65	1.03 (1.0, 1.06)	.065	1.00 (.97, 1.02)	.81
	Overall season p-value		.006		.021		.071
CA	Spring (Mar–May)	.99 (.97, 1.00)	.095	1.02 (.99, 1.04)	.19	.95 (.93, .96)	<.001
	Summer (Jun–Aug)	Reference	—	Reference	—	Reference	—
	Fall (Sep–Nov)	1.0 (.98, 1.01)	.79	.99 (.97, 1.02)	.69	1.00 (.98, 1.02)	.94
	Winter (Dec–Feb)	1.01 (.99, 1.02)	.31	1.02 (1.0, 1.05)	.062	.96 (.94, .98)	<.001
	Overall season p-value		.042		.065		<.001
p-Value for state-season interaction			.34		.65		<.001

*p-Value does not meet threshold for significance after Bonferroni adjustment for multiple comparisons (significance level is 0.05/3 = 0.0167).
CI, confidence interval; HF, heart failure; MI, myocardial infarction.

Table 3: Primary Readmission Diagnosis by Season for Patients Initially Admitted with HF, MI, and Pneumonia

Condition/Diagnosis (by CCS Code)	Season				
	Winter (n) (% of Column)	Spring (n) (% of Column)	Summer (n) (% of Column)	Fall (n) (% of Column)	Total (n) (% of Column)
HF readmissions					
Congestive heart failure	21,488 (36.3%)	21,535 (36.3%)	18,197 (36.2%)	19,167 (36.9%)	80,387 (36.4%)
Rehabilitation care	2,511 (4.2%)	2,367 (4.0%)	1,961 (4.0%)	2,011 (3.9%)	8,850 (4.0%)
Septicemia	2,205 (3.7%)	2,089 (3.5%)	1,809 (3.6%)	1,949 (3.8%)	8,052 (3.7%)
Hypertension with complications and secondary hypertension	2,136 (3.6%)	2,137 (3.6%)	1,799 (3.6%)	1,916 (3.7%)	7,988 (3.6%)
Pneumonia	2,476 (4.2%)	2,087 (3.5%)	1,513 (3.0%)	1,696 (3.3%)	7,772 (3.52%)
MI readmissions					
Acute myocardial infarction	3,534 (15.4%)	3,535 (15.5%)	3,241 (15.9%)	3,420 (16.1%)	13,730 (15.7%)
Congestive heart failure	3,209 (14.0%)	3,223 (14.1%)	2,608 (12.8%)	2,859 (13.5%)	11,899 (13.6%)
Rehabilitation care	1,796 (7.8%)	1,777 (7.8%)	1,455 (7.1%)	1,576 (7.4%)	6,604 (7.6%)
Coronary atherosclerosis and other heart disease	1,482 (6.5%)	1,574 (6.9%)	1,505 (7.4%)	1,584 (7.5%)	6,145 (7.0%)
Nonspecific chest pain	983 (4.3%)	1,117 (4.9%)	1,068 (5.2%)	1,033 (4.9%)	4,201 (4.8%)
Pneumonia readmissions					
Pneumonia	11,014 (22.5%)	9,546 (21.9%)	7,188 (21.5%)	7,553 (21.5%)	35,301 (21.9%)
Septicemia	3,315 (6.8%)	2,936 (6.7%)	2,579 (7.7%)	2,564 (7.3%)	11,394 (7.1%)
Congestive heart failure	3,191 (6.5%)	2,776 (6.4%)	1,939 (5.8%)	2,230 (6.3%)	10,136 (6.3%)
Chronic obstructive pulmonary disease and bronchiectasis	2,761 (5.6%)	2,355 (5.4%)	1,609 (4.8%)	1,873 (5.3%)	8,598 (5.3%)
Rehabilitation care	2,572 (5.3%)	2,289 (5.2%)	1,571 (4.7%)	1,609 (4.6%)	8,041 (5.0%)

CCS, Clinical Classifications Software; HF, heart failure; MI, myocardial infarction.

readmission by season given our large sample size, the absolute magnitude of difference was small. Given marked seasonality documented in both incidence and mortality of these diseases, the lack of seasonality in readmissions suggests that readmissions may be more related to generalized non-seasonally dependent processes than to factors contributing to the seasonal nature of these diseases.

Our finding of lack of significant effect of seasonality in readmission after HF, MI, and pneumonia is particularly interesting given prior evidence demonstrating seasonality in incidence, hospitalization, and mortality for patients with these diseases. Numerous studies from diverse settings have found increased rates of HF hospitalization or mortality in winter months (Boulay et al. 1999; Martínez-Sellés et al. 2002; Stewart et al. 2002; Feldman et al. 2004; Ogawa et al. 2007; Barnett, De Looper, and Fraser 2008; Gotsman et al. 2011). Similarly, in our study, we find a strong seasonality effect in hospitalization for patients with HF, with 17.7 percent more admissions in winter relative to summer. However, we do not find overwhelming evidence of meaningful seasonality in readmissions for HF in the raw data or in our adjusted models, even though HF was the most common readmission diagnosis. In context of MI, several large population and registry-based studies across the world have found higher incidence and mortality from MI in winter (Sayer et al. 1997; Seretakakis et al. 1997; Spencer et al. 1998; Sheth et al. 1999; Gerber et al. 2006). This is comparably seen in our study, in which we find seasonality in hospitalization for MI, with 6.3 percent more admissions in winter relative to summer. There was a small, but statistically significant decrease in readmissions in spring relative to summer in New York. This is consistent with a small study based in Massachusetts, which looked at seasonality and readmission after MI and found a higher gross readmission rate in winter and spring, but this did not reach statistical significance given small sample size (Tisminetzky et al. 2015). In context of pneumonia, many diverse studies have found increases in incidence of respiratory bacterial and viral infections and hospitalization for community-acquired pneumonia in winter or seasons of low temperature (Kim et al. 1996; Lieberman and Friger 1999; Säynäjäkangas, Keistinen, and Tuuponen 2001; Dowell et al. 2003; Talbot et al. 2005; Lin et al. 2009; Weinberger et al. 2014). Similarly, we find a strong seasonality effect in hospitalization for patients with pneumonia with 51.3 percent more admissions in winter relative to summer. In our adjusted model, while we do find a modestly lower risk of readmission in winter and spring relative to summer in California, we do not find a significant difference in readmission by season in New York.

Taken together, our findings suggest that the mechanisms underlying the observed patterns in readmission for patients initially hospitalized with HF, MI, and pneumonia are not seasonally dependent. Seasonality in HF and MI is thought to stem from exposure to colder temperatures, which can lead to adrenergic activation, impaired coronary vasodilation, and increased systemic vasoconstriction leading to increased cardiac afterload (Sayer et al. 1997; Seretakakis et al. 1997; The Eurowinter Group 1997; Feldman et al. 2004; Gerber et al. 2006; Ahmed et al. 2008). Seasonality in pneumonia is thought to be related variation in pathogens and greater host susceptibility in colder temperature (Dowell et al. 2003; Talbot et al. 2005; Herrera-Lara et al. 2013; Jain et al. 2015). Half of all readmissions after MI and HF stem from cardiac diagnoses, and one-fifth of winter admissions for HF are attributable to respiratory disease (Ranasinghe et al. 2014). In our data, we find that the most common cause of readmission in our study is the primary admission diagnosis itself. Thus, one might expect marked seasonality in readmissions if they were related more to the aforementioned intrinsic disease processes that vary by season. However, we do not find such an effect. In fact, when analysis is restricted only to readmission for the primary condition, the modest seasonal differences in our primary analysis all but disappear. Additionally, despite the greater seasonal temperature variation in New York relative to California, the lack of a significant state–season interaction for HF or MI readmission further underscores the relative importance of non-temperature-dependent phenomena in readmission after these conditions. While the physiologic pathways that lead to increased admissions in winter for HF, MI, and pneumonia may contribute to a subset of the readmissions after these diseases, the majority of readmissions seem driven less by these pathways and more by other factors.

The mechanism underlying the observed pattern of readmissions may derive primarily from generalized non–seasonally dependent factors known to influence readmissions. For instance, readmissions may be driven by nonmedical factors, such as lower education, low income or socioeconomic status, unemployment, poor living situation, lack of social support, and risky behaviors, such as smoking or drug use (Calvillo-King et al. 2013; Hu, Gonsahn, and Nerenz 2014; Barnett, Hsu, and McWilliams 2015; Damiani et al. 2015). Additionally, readmissions may stem from medical consequences of a hospitalization leading to a posthospitalization syndrome (Krumholz 2013), a generalized vulnerability to illness among recently discharged patients, which may stem from alterations in nutrition, perturbations in sleep–wake cycle, deconditioning, and delirium that occur

as a result of the hospitalization process. Furthermore, readmissions may be affected by care coordination at discharge such as providing adequate education, connecting with outpatient providers, or ensuring adequate outpatient follow-up (Peikes et al. 2009; Hernandez et al. 2010). A combination of these non-seasonally dependent factors likely outweighs the contribution of any seasonality intrinsic disease processes of HF, MI, and pneumonia.

Our results have implications for both clinicians and hospitals in efforts to reduce readmissions. Our findings suggest that addressing generalized non-seasonally dependent factors may be more impactful in reducing readmissions than interventions targeted toward condition-specific seasonally dependent processes. This is consistent with literature suggesting generalized approaches to reduce readmissions may be more successful than disease-specific interventions (Dharmarajan et al. 2013a, b). Clinicians must not only focus on adequate treatment of the pathophysiology of the index admission but also be more astute in recognizing nonmedical problems that may lead to readmissions and mitigating in-hospital factors leading to the posthospitalization syndrome. Additionally, instead of focusing on condition-specific initiatives, hospitals may better serve their patients by holistically addressing general in-hospital care processes as well as coordination of care on discharge.

Our findings should be interpreted in context of our limitations. First, in aggregating days of the year into four seasons, there is a chance that misspecification of timing defining seasons could have biased our results toward the null. However, we examined variation in readmissions rates by month, and no clinically significant difference was found. Second, there is a chance that the seasonality in mortality from HF, MI, and pneumonia may have led to a bias toward the null. However, the in-hospital mortality rate varied at most by 0.8 percent between any two seasons for any of the conditions, and, while we did not capture out-of-hospital deaths, the percentage of out-of-hospital deaths after these diseases is relatively low (Keenan et al. 2008; Krumholz et al. 2011; Lindenauer et al. 2011). Finally, although California may not have the same seasonality in climate as other states, we find similar seasonal patterns of admission for HF, MI, and pneumonia between New York and California (Table S1), which suggests any seasonally dependent process for disease incidence is not attenuated by climate differences between these states. Additionally, we stratified our results by state to limit any potential bias of differential climate between California and New York.

CONCLUSIONS

Overall, we do not find evidence supporting a clinically significant effect of seasonality on risk of readmission after hospitalization for HF, MI, and pneumonia. Our results suggest that variation in readmissions may be driven more by non-seasonally affected factors than by factors contributing to the seasonal nature of these diseases. Further attention should be paid to addressing generalized non-condition-specific factors that they may have a more significant effect on risk of readmission than overarching seasonal patterns of disease. Moreover, further research into which factors in particular can mitigate seasonal risk and lead to reducing readmissions is warranted.

ACKNOWLEDGMENTS

Joint Acknowledgment/Disclosure Statement: Financial support for the project comes from the Richard and Susan Smith Center for Outcomes Research at Beth Israel Deaconess Medical Center.

Disclosures: None.

Disclaimer: None.

REFERENCES

- Ahmed, A., I. Aboshady, S. M. Munir, S. Gondi, A. Brewer, S. D. Gertz, D. Lai, N. A. Shaik, K. Shankar, and A. Deswal. 2008. "Decreasing Body Temperature Predicts Early Rehospitalization in Congestive Heart Failure." *Journal of Cardiac Failure* 14 (6): 489–96.
- Au, A. G., F. A. McAlister, J. A. Bakal, J. Ezekowitz, P. Kaul, and C. van Walraven. 2012. "Predicting the Risk of Unplanned Readmission or Death within 30 Days of Discharge after a Heart Failure Hospitalization." *American Heart Journal* 164 (3): 365–72.
- Barnett, A. G., M. De Looper, and J. F. Fraser. 2008. "The Seasonality in Heart Failure Deaths and Total Cardiovascular Deaths." *Australian and New Zealand Journal of Public Health* 32 (5): 408–13.
- Barnett, M. L., J. Hsu, and J. M. McWilliams. 2015. "Patient Characteristics and Differences in Hospital Readmission Rates." *Journal of the American Medical Association Internal Medicine* 175 (11): 1803–12.
- Boulay, F., F. Berthier, O. Sisteron, Y. Gendreike, and P. Gibelin. 1999. "Seasonal Variation in Chronic Heart Failure Hospitalizations and Mortality in France." *Circulation* 100 (3): 280–6.

- Calvillo-King, L., D. Arnold, K. J. Eubank, M. Lo, P. Yunyongying, H. Stieglitz, and E. A. Halm. 2013. "Impact of Social Factors on Risk of Readmission or Mortality in Pneumonia and Heart Failure: Systematic Review." *Journal of General Internal Medicine* 28 (2): 269–82.
- Damiani, G., E. Salvatori, G. Silvestrini, I. Ivanova, L. Bojovic, L. Iodice, and W. Ricciardi. 2015. "Influence of Socioeconomic Factors on Hospital Readmissions for Heart failure and Acute Myocardial Infarction in Patients 65 Years and Older: Evidence from a Systematic Review." *Clinical Interventions in Aging* 10: 237.
- Desai, M. M., B. D. Stauffer, H. H. Feringa, and G. C. Schreiner. 2009. "Statistical Models and Patient Predictors of Readmission for Acute Myocardial Infarction: A Systematic Review." *Circulation: Cardiovascular Quality and Outcomes* 2 (5): 500–7.
- Dharmarajan, K., A. F. Hsieh, Z. Lin, H. Bueno, J. S. Ross, L. I. Horwitz, J. A. Barreto-Filho, N. Kim, S. M. Bernheim, and L. G. Suter. 2013a. "Diagnoses and Timing of 30-day Readmissions after Hospitalization for Heart Failure, Acute Myocardial Infarction, or Pneumonia." *Journal of the American Medical Association* 309 (4): 355–63.
- Dharmarajan, K., A. F. Hsieh, Z. Lin, H. Bueno, J. S. Ross, L. I. Horwitz, J. A. Barreto-Filho, N. Kim, L. G. Suter, and S. M. Bernheim. 2013b. "Hospital Readmission Performance and Patterns of Readmission: Retrospective Cohort Study of Medicare Admissions." *British Medical Journal* 347: f6571.
- Dowell, S. F., C. G. Whitney, C. Wright, C. E. Rose Jr, and A. Schuchat. 2003. "Seasonal Patterns of Invasive Pneumococcal Disease." *Emerging Infectious Diseases* 9 (5): 573–9.
- Elixhauser, A., C. Steiner, and L. Palmer. 2016. "Clinical Classifications Software (CCS), 2015." U.S. Agency for Healthcare Research and Quality.
- Elixhauser, A., C. Steiner, D. R. Harris, and R. M. Coffey. 1998. "Comorbidity Measures for Use with Administrative Data." *Medical Care* 36 (1): 8–27.
- Feldman, D. E., R. Platt, V. Dery, C. Kapetanakis, D. Lamontagne, A. Ducharme, N. Giannetti, M. Frenette, and E. Beck. 2004. "Seasonal Congestive Heart Failure Mortality and Hospitalisation Trends, Quebec 1990–1998." *Journal of Epidemiology and Community Health* 58 (2): 129–30.
- Gerber, Y., S. J. Jacobsen, J. M. Killian, S. A. Weston, and V. L. Roger. 2006. "Seasonality and Daily Weather Conditions in Relation to Myocardial Infarction and Sudden Cardiac Death in Olmsted County, Minnesota, 1979 to 2002." *Journal of the American College of Cardiology* 48 (2): 287–92.
- Gotsman, I., D. Zwas, D. Admon, C. Lotan, and A. Keren. 2011. "Seasonal Variation in Hospital Admission in Patients with Heart Failure and Its Effect on Prognosis." *Cardiology* 117 (4): 268–74.
- HCUP State Inpatient Databases (SID). *Healthcare Cost and Utilization Project (HCUP), 2005–2009*. Rockville, MD: Agency for Healthcare Research and Quality. Available at www.hcup-us.ahrq.gov/sidoverview.jsp
- Hernandez, A. F., M. A. Greiner, G. C. Fonarow, B. G. Hammill, P. A. Heidenreich, C. W. Yancy, E. D. Peterson, and L. H. Curtis. 2010. "Relationship between Early Physician Follow-up and 30-day Readmission among Medicare Beneficiaries

- Hospitalized for Heart Failure." *Journal of the American Medical Association* 303 (17): 1716–22.
- Herrera-Lara, S., E. Fernández-Fabrellas, Á. Cervera-Juan, and R. Blanquer-Olivas. 2013. "Do Seasonal Changes and Climate Influence the Etiology of Community Acquired Pneumonia?" *Archivos de Bronconeumología (English Edition)* 49 (4): 140–5.
- Horwitz, L., C. Partovian, Z. Lin, J. Herrin, J. Grady, M. Conover, J. Montague, C. Dillaway, K. Bartczak, J. Ross, S. Bernheim, E. Drye, and H. M. Krumholz. 2011. "Hospital-Wide (All-Condition) 30-Day Risk-Standardized Readmission Measure, Draft Measure Methodology Report."
- Hu, J., M. D. Gonsahn, and D. R. Nerenz. 2014. "Socioeconomic Status and Readmissions: Evidence from an Urban Teaching Hospital." *Health Affairs* 33 (5): 778–85.
- Jain, S., W. H. Self, R. G. Wunderink, S. Fakhran, R. Balk, A. M. Bramley, C. Reed, C. G. Grijalva, E. J. Anderson, and D. M. Courtney. 2015. "Community-Acquired Pneumonia Requiring Hospitalization among US Adults." *New England Journal of Medicine* 373 (5): 415–27.
- James, J. 2013. "Medicare Hospital Readmissions Reduction Program." *Health Affairs* 34 (2): 1–5.
- Kane, P., C. Chen, Z. Post, K. Radcliff, F. Orozco, and A. Ong. 2014. "Seasonality of Infection Rates after Total Joint Arthroplasty." *Orthopedics* 37 (2): e182–6.
- Keenan, P. S., S.-L. T. Normand, Z. Lin, E. E. Drye, K. R. Bhat, J. S. Ross, J. D. Schuur, B. D. Stauffer, S. M. Bernheim, and A. J. Epstein. 2008. "An Administrative Claims Measure Suitable for Profiling Hospital Performance on the Basis of 30-day All-Cause Readmission Rates among Patients with Heart Failure." *Circulation: Cardiovascular Quality and Outcomes* 1 (1): 29–37.
- Kim, P. E., D. M. Musher, W. P. Glezen, M. C. Rodriguez-Barradas, W. K. Nahm, and C. E. Wright. 1996. "Association of Invasive Pneumococcal Disease with Season, Atmospheric Conditions, Air Pollution, and the Isolation of Respiratory Viruses." *Clinical Infectious Diseases* 22 (1): 100–6.
- Kloner, R. A., W. K. Poole, and R. L. Perritt. 1999. "When Throughout the Year Is Coronary Death Most Likely to Occur? A 12-Year Population-Based Analysis of More Than 220,000 Cases." *Circulation* 100 (15): 1630–4.
- Krumholz, H. M. 2013. "Post-Hospital Syndrome—An Acquired, Transient Condition of Generalized Risk." *New England Journal of Medicine* 368 (2): 100–2.
- Krumholz, H. M., Z. Lin, E. E. Drye, M. M. Desai, L. F. Han, M. T. Rapp, J. A. Mattera, and S.-L. T. Normand. 2011. "An Administrative Claims Measure Suitable for Profiling Hospital Performance Based on 30-day All-Cause Readmission Rates among Patients with Acute Myocardial Infarction." *Circulation: Cardiovascular Quality and Outcomes* 4 (2): 243–52.
- Lieberman, D., and M. Friger. 1999. "Seasonal Variation in Hospital Admission for Community-Acquired Pneumonia: A 5-Year Study." *Journal of Infection* 39 (2): 134–40.
- Lin, H.-C., C.-C. Lin, C.-S. Chen, and H.-C. Lin. 2009. "Seasonality of Pneumonia Admissions and Its Association with Climate: An Eight-Year Nationwide Population-Based Study." *Chronobiology International* 26 (8): 1647–59.

- Lindenauer, P. K., S. L. T. Normand, E. E. Drye, Z. Lin, K. Goodrich, M. M. Desai, D. W. Bratzler, W. J. O'Donnell, M. L. Metersky, and H. M. Krumholz. 2011. "Development, Validation, and Results of a Measure of 30-day Readmission Following Hospitalization for Pneumonia." *Journal of Hospital Medicine* 6 (3): 142–50.
- Lloyd, G. E. R., J. Chadwick, and W. N. Mann. 1978. *Hippocratic Writings*. Volume 451. London: Penguin.
- Martínez-Sellés, M., J. A. G. Robles, L. Prieto, J. A. Serrano, R. Muñoz, E. Frades, and J. Almendral. 2002. "Annual Rates of Admission and Seasonal Variations in Hospitalizations for Heart Failure." *European Journal of Heart Failure* 4 (6): 779–86.
- Ogawa, M., F. Tanaka, T. Onoda, M. Ohsawa, K. Itai, T. Sakai, A. Okayama, and M. Nakamura. 2007. "A Community Based Epidemiological and Clinical Study of Hospitalization of Patients with Congestive Heart Failure in Northern Iwate, Japan." *Circulation Journal* 71 (4): 455–9.
- Ornato, J. P., M. A. Peberdy, N. C. Chandra, and D. E. Bush. 1996. "Seasonal Pattern of Acute Myocardial Infarction in the National Registry of Myocardial Infarction." *Journal of the American College of Cardiology* 28 (7): 1684–8.
- Palepu, A., H. Sun, L. Kuyper, M. T. Schechter, M. V. O'Shaughnessy, and A. H. Anis. 2003. "Predictors of Early Hospital Readmission in HIV-Infected Patients with Pneumonia." *Journal of General Internal Medicine* 18 (4): 242–7.
- Park, L., D. Andrade, A. Mastey, J. Sun, and L. Hicks. 2014. "Institution Specific Risk Factors for 30 day Readmission at a Community Hospital: A Retrospective Observational Study." *BMC Health Services Research* 14 (1): 40.
- Peikes, D., A. Chen, J. Schore, and R. Brown. 2009. "Effects of Care Coordination on Hospitalization, Quality of Care, and Health Care Expenditures among Medicare Beneficiaries: 15 Randomized Trials." *Journal of the American Medical Association* 301 (6): 603–18.
- Ranasinghe, I., Y. Wang, K. Dharmarajan, A. F. Hsieh, S. M. Bernheim, and H. M. Krumholz. 2014. "Readmissions after Hospitalization for Heart Failure, Acute Myocardial Infarction, or Pneumonia among Young and Middle-Aged Adults: A Retrospective Observational Cohort Study." *PLoS Medicine* 11 (9): e1001737.
- Ross, J. S., G. K. Mulvey, B. Stauffer, V. Patlolla, S. M. Bernheim, P. S. Keenan, and H. M. Krumholz. 2008. "Statistical Models and Patient Predictors of Readmission for Heart Failure: A Systematic Review." *Archives of Internal Medicine* 168 (13): 1371–86.
- Sayer, J. W., P. Wilkinson, K. Ranjadayalan, S. Ray, B. Marchant, and A. Timmis. 1997. "Attenuation or Absence of Circadian and Seasonal Rhythms of Acute Myocardial Infarction." *Heart* 77 (4): 325–9.
- Säynäjäkangas, P., T. Keistinen, and T. Tuuponen. 2001. "Seasonal Fluctuations in Hospitalisation for Pneumonia in Finland." *International Journal of Circumpolar Health* 60 (1): 34–40.
- Seretakakis, D., P. Lagiou, L. Lipworth, L. B. Signorello, K. J. Rothman, and D. Trichopoulos. 1997. "Changing Seasonality of Mortality from Coronary Heart Disease." *Journal of the American Medical Association* 278 (12): 1012–4.

- Sheth, T., C. Nair, J. Muller, and S. Yusuf. 1999. "Increased Winter Mortality from Acute Myocardial Infarction and Stroke: The Effect of Age." *Journal of the American College of Cardiology* 33 (7): 1916–9.
- Spencer, F. A., R. J. Goldberg, R. C. Becker, and J. M. Gore. 1998. "Seasonal Distribution of Acute Myocardial Infarction in the Second National Registry of Myocardial Infarction 1." *Journal of the American College of Cardiology* 31 (6): 1226–33.
- Stewart, S., K. McIntyre, S. Capewell, and J. J. McMurray. 2002. "Heart Failure in a Cold Climate: Seasonal Variation in Heart Failure-Related Morbidity and Mortality." *Journal of the American College of Cardiology* 39 (5): 760–6.
- Talbot, T. R., K. A. Poehling, T. V. Hartert, P. G. Arbogast, N. B. Halasa, K. M. Edwards, W. Schaffner, A. S. Craig, and M. R. Griffin. 2005. "Seasonality of Invasive Pneumococcal Disease: Temporal Relation to Documented Influenza and Respiratory Syncytial Viral Circulation." *American Journal of Medicine* 118 (3): 285–91.
- The Eurowinter Group. 1997. "Cold Exposure and Winter Mortality from Ischaemic Heart Disease, Cerebrovascular Disease, Respiratory Disease, and All Causes in Warm and Cold Regions of Europe." *Lancet* 349 (9062): 1341–6.
- Tisminetzky, M., D. D. McManus, N. Erskine, J. S. Saczynski, J. Yarzelski, E. Granillo, J. Gore, and R. J. Goldberg. 2015. "Thirty-day Hospital Readmissions in Patients with Non-ST-Segment Elevation Acute Myocardial Infarction." *American Journal of Medicine* 128 (7): 760–5.
- Vicendese, D., M. J. Abramson, S. C. Dharmage, M. L. Tang, K. J. Allen, and B. Erbas. 2014. "Trends in Asthma Readmissions among Children and Adolescents over Time by Age, Gender and Season." *Journal of Asthma* 51 (10): 1055–60.
- Weinberger, D. M., Z. B. Harboe, C. Viboud, T. G. Krause, M. Miller, K. Mølbak, and H. B. Konradsen. 2014. "Pneumococcal Disease Seasonality: Incidence, Severity and the Role of Influenza Activity." *European Respiratory Journal* 43 (3): 833–41.

SUPPORTING INFORMATION

Additional supporting information may be found online in the supporting information tab for this article:

Appendix SA1: Author Matrix.

Table S1. (a) Total Admissions and Readmission Rate by Season for HF, MI, and Pneumonia in NY; (b) Total Admissions and Readmission Rate by Season for HF, MI, and Pneumonia in CA.

Table S2. (a) Full Baseline Characteristics by Season for Patients with HF; (b) Full Baseline Characteristics by Season for Patients with MI; (c) Full Baseline Characteristics by Season for Patients with Pneumonia.

Table S3. (a) Hospital Characteristics for HF Cohort; (b) Hospital Characteristics for MI Cohort; (c) Hospital Characteristics for Pneumonia Cohort.

Table S4. Unadjusted Association between Season and Readmission in HF, MI, and Pneumonia by State.

Table S5. Adjusted Association between Season and Readmission for Index Admission Only in HF, MI, and Pneumonia by State.

Figure S1. (a) Flowchart for Creation of HF Cohort; (b) Flowchart for Creation of MI Cohort; (c) Flowchart for Creation of Pneumonia Cohort.

Figure S2. (a) Seasonal Effect of Unplanned Readmission after HF Admission; (b) Seasonal Effect of Unplanned Readmission after MI Admission; (c) Seasonal Effect of Unplanned Readmission after Pneumonia Admission.

Figure S3. (a) Monthly Effect of Unplanned Readmission after HF Admission; (b) Monthly Effect of Unplanned Readmission after MI Admission; (c) Monthly Effect of Unplanned Readmission after Pneumonia Admission.