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Intensive Care Unit Occupancy and Patient Outcomes

Theodore J. Iwashyna, MD, PhD, **Andrew A. Kramer, PhD**, and **Jeremy M. Kahn, MD, MSc**
Hospital of the University of Pennsylvania - Pulmonary & Critical Care Medicine, 836 W. Gates 3400 Spruce Street Philadelphia Pennsylvania 19104, United States

Abstract

Rationale—Although ICUs with higher overall patient volume may achieve better outcomes than lower volume ICUs, there are few data on the effects of increasing patient loads on patients within the ICU.

Objectives—To examine the association of ICU occupancy on the patient outcomes within the same ICU.

Methods—We examined 200,499 patients in 108 ICUs using the Acute Physiology and Chronic Health Evaluation IV database in 2002 - 2005. Daily census on the day of admission was determined for each patient and defined in relation to the mean census. We used conditional logistic regression to compare inpatient outcomes of patients admitted on high census days to those admitted in the same ICU on low census days. We controlled for severity of illness at the patient level using data on clinical, demographic and physiologic variables on admission to the ICU.

Measurements and Main Results—Patients admitted on high census days had the same odds of inpatient mortality or transfer to another hospital as patients admitted on average or on low census days. These findings were robust to multiple alternative definitions of day of admission census and were confirmed in several subgroup analyses.

Conclusions—The ICUs in this data set are able to function as high-reliability organizations. They are able to scale up their operations to meet the needs of a wide-range of operating conditions while maintaining consistent patient mortality outcomes.

Keywords

Intensive care; mortality; volume; high-reliability organizations

Introduction

There is growing interest in concentrating critically ill patients into a smaller number of intensive care units (ICUs). This interest arises due to the increasing demand for critical care by a growing population at risk, (1) due to hospital closures, (2) as the result of payer-initiatives to achieve economies of scale, (3) and because of possible policy decisions to implement a regionalized system of care. (4,5)

Contact Author: Theodore J. Iwashyna, T: (267) 240-1354 F: (215) 614-0869, iwashyna@alumni.Princeton.edu.

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TJI has no potential or real conflicts of interest with this manuscript. AAK has no conflicts of interest; however, AAK an employee of the Cerner Corporation and own stock in such, which provides the APACHE data systems used as a basis of the analysis. JMK has no potential or real conflicts of interest with this manuscript.

Several studies demonstrate that high volume ICUs provide improved outcomes for a range of serious conditions. (6-13) However, these cross-sectional studies do not address the effect of *increasing* patient volume within a hospital on outcomes; that is, they demonstrate average effects rather than marginal effects, although the marginal effects are quite relevant from a policy perspective. Results of studies of the effect of changes in patient volume on outcomes have been mixed. (14-16) We are unaware of any multi-center studies focusing on the relationship between day-to-day patient volume and ICU outcomes in the U.S.

In this study, we examine the association of daily ICU occupancy with the outcomes of patients admitted to that ICU on that day. We study a range of critical illnesses within the Acute Physiology and Chronic Health Evaluation (APACHE) IV database, containing detailed clinical and physiologic information on patients admitted to 108 ICUs. Day-of-admission census is our primary exposure variable because of the importance of rapid initial treatment for outcomes in many critical illnesses. (17-19) A fixed effects model is used at the ICU level to compare patients to others admitted within the same ICU, but on a different day.

Methods

Study Population and Data

Data came from patients admitted to ICUs participating in the APACHE clinical information system from January 2002 through June 2005. These units were diverse in size, geographic region, and teaching status. The APACHE program prospectively collects physiologic, clinical, demographic, and admission source data. Data are entered by teams who undergo intensive training and receive regular quality reviews. These data support several risk-adjustment models of ICU outcomes. (20-22)

All patients admitted to APACHE ICUs were eligible for the study. Patients undergoing coronary artery bypass grafting (CABG) were excluded as they have different risk-adjustment profiles than other critically ill patients. (21,22) We also excluded ICUs caring for fewer than 100 patients in the data and the first 100 patients at a site to insure that our census measures were stable. Only a patient's first admission to the ICU during any given hospitalization was analyzed.

This manuscript was considered exempt from review by the University of Pennsylvania Institutional Review Board.

Variables

Our exposure of interest is the census of each ICU on the day of ICU admission. Census is defined as the total number of patients who spent at least 2 hours in each ICU on the calendar day on which a given patient was admitted. The mean census of each ICU across the study period was computed. In order to take into account differences between ICUs in their size and inherent uncertainty in determining the total capacity in each ICU, ICU census is analyzed as the ratio of the day-of-admission census to the mean census, divided into deciles. As sensitivity analyses, models were re-estimated using other parameterizations of our key exposure variable. We avoided using “mean census during the patient's ICU stay” or some similar construct as ICU census after admission for a patient is endogenous to our outcomes.

The primary outcomes were in-hospital mortality and discharge to another hospital. As a secondary outcome we examined length of stay in the ICU, which is recorded directly in the database; for these analyses we excluded 16,400 patients in 8 ICU's whose precise entrance and exit times within a given day are not in the dataset.

Risk Adjustment

Risk adjustment was performed using the APACHE IV risk adjustment formulae. The risk equations include the day one acute physiology score, age, select chronic health items, primary diagnosis, hospital admission source, pre-ICU length of stay, whether or not a sedated patient could have their Glasgow coma score assessed, whether or not a patient was receiving invasive mechanical ventilation, and whether or not the patient had received emergency surgery, as described elsewhere. (21,22) Separate risk adjustment formulae are available for inpatient mortality and ICU length of stay.

For regressions examining the association with discharge to another hospital, we have adjusted for APACHE IV-predicted risk of death as a marker of severity of illness, as we are unaware of a validated risk-adjustment model for that precise outcome.

Statistical Analysis

In key analyses, the relationship between census and outcome was examined using multivariable conditional logistic and linear regression, adjusting for APACHE risk of death. All regression models were parameterized with an ICU-level fixed effect in order to fully control for all shared, time-invariant characteristics of the ICU (including the nominal capacity of the ICU – “how many beds the unit has”), without having to measure those characteristics. (23) Individual-level risk-adjusted predicted outcome was included in all regression models with linear, quadratic and cubic terms to insure flexibility. The regression results can be interpreted as the effect of the day-of-admission census comparing each patient to other patients admitted to the *same* ICU. An adjusted R^2 measure is reported in the Appendix for each regression, re-scaled as maximum R^2 is less than one for a dichotomous outcome. (24) Analyses were carried out in Stata 9.2 and SAS 9.0-9.2.

Results

We examined 200,499 patients admitted to 108 ICUs in 46 hospitals. Patient characteristics are in Table 1. The mean age was 61.5 years; the median Acute Physiology Score was 34. 63.1% of patients were discharged home, 13.3% died during their hospitalization. Characteristics of the ICUs are in Table 2. The average daily census was 12.8 across ICUs, with a median of 11 and an interquartile range of 9 to 15.

There was wide variability in the day-of-admission census. The lowest decile of patients were admitted to ICU's with a census at 65% of their mean daily census; the highest decile of patients were admitted to ICU's operating at 147% of their mean daily census.

Response to Unusually High Daily Census

Severity of illness as measured by Acute Physiology Scores (APS) of patients did not markedly change with increasing occupancy of the ICU. (Figure 1) In a fixed effects model comparing patients to other patients in the same ICU, there was a small decline in mean APS with increasing patient occupancy. (Appendix Table, A.I.) Patients admitted on the highest census days had an APS 2.57 (+/- 0.26 SE, $p < 0.0001$) lower than those on the lowest census days (comparing deciles 1 and 10).

There was little difference in mortality with increasing census on day of admission. As shown in Figure 2 *without adjustment*, patients admitted on the highest census days were slightly *less* likely to die as an inpatient; there was *no* increase in rates of transfers of patients to other hospitals with increasing census. As shown in Figure 3, there was *no* significant change in mortality with increasing census when a fixed effects regression is used to compare patients to others within the same ICU, and after adjustment for differences in predicted inpatient mortality using APACHE IV. (Appendix Table A.II; the joint test for the occupancy variables was insignificant at p=0.149.) Moreover, the estimates are quite precise, ruling out large associations – patients in the highest decile have an odds ratio for inpatient mortality of 0.98 (95% CI 0.91, 1.06) relative to those in decile 6 (the mean census). (Figure 3) Fixed effects models confirmed that there was no significant increase in rates of transfer to other hospitals with increasing census. (Appendix Table A.III.)

Unadjusted length of stay in the ICU decreased modestly with increasing volume. This apparent effect disappeared when APACHE IV predicted length of stay was included as a covariate in the fixed effects regression. (Appendix Table A.IV.)

Sustained (14 Day) High Census

A very similar pattern was seen when examining the effects of the census over the 14 days prior to and including the day of admission. This was parameterized as a ratio of the 14-day moving average census to the mean census across the study period. There was no clinically significant change in the odds of death with increasing 14-day census in unadjusted or the fixed effects regression models. (See Figure 3 and Appendix Table A.V.) In the regression, the joint test for the occupancy variables was insignificant (p=0.21) Of note, there was an effect of occupancy on rates of transfers to other hospitals (joint test, p=0.0032), however, transfers were more common on days of the *lowest* occupancy. (Table A.VI)

Sensitivity Analyses

We conducted several sensitivity tests in order to confirm our mortality results, as shown in Table 3. In no case was there evidence of increased mortality with increased patient load.

Discussion

Our results demonstrate that unusually high census on day-of-admission is *not* associated with clinically meaningful negative outcomes among critically ill patients across a range of conditions. This result was robust to alternative specifications of day-of-admission census, and was true in important subgroups, including the subset of highest acuity patients. This results is consistent with some US and UK past work (14,15) although the results contradict a single-center study in a UK ICU. (16) While individual practitioners may suffer from the effects of increased workload, (25) the existing organizational structure in the ICUs in our data appear to be able to buffer patients from any mortal adverse effects of that increased workloads.

Why Might Increasing Census Worsen Patient Outcomes?

In economics, the finding of so-called “declining marginal productivity” is common. Beyond a certain point, a worker can not manufacture an item as quickly as the previous one. In the healthcare, this effect has been robustly studied in the Emergency Department (ED) crowding literature. Patients seen during busy periods in the ED have longer inpatient lengths of stay and poorer care. (26-28) Australian data suggests that ED crowding may even be associated with increased all-cause mortality. (29,30) These results dovetail with the literature demonstrating improved outcome for patients with lower nursing ratios. (16,25,31)

Given these prior results suggesting that mortality of ICU patients would be increasing with day-of-admission census, our findings are reassuring. We find no evidence of a meaningful increase in mortality across a broad-range of observed census ratios. Our analysis has intentionally focused at the organizational level of the ICU as a whole. We look at the total number of patients cared for by an ICU in a day, as that may be under control of ICU managers and policy directors. This complements other research that has taken a more micro-level, looking at the workloads of a particular practitioner. At the organizational level, diverse compensating mechanisms exist to support individual practitioners. While studying the effectiveness of individual-level approaches (e.g. reducing nursing workloads) is valuable, there are also policy implications from studying the organizational aggregate effect.

Our data suggest that these ICUs are able to function as high-reliability organizations. They are able to safely scale up their operations as needed to meet the demands of a wide-range of operating conditions while maintaining consistent patient mortality outcomes. (32,33) This is true when increased demand is acute – measured at a single-day level – or more chronic, measured across 2 weeks of sustained activity. Given the pessimism about the reliability of health care organizations, this finding is encouraging and suggests an area for detailed process studies. (34,35) Our data do not allow us to investigate the particular processes that generate this aggregate mortality result, nor do they guarantee that the results are present for other measures of quality. But our data have important implications for regionalization of critical care, disaster planning, and selection of high quality critical care.

Implications

Regionalization is generally understood as a process of centralizing the care of patients of some type in designated centers of excellence, as in trauma and neonatal care. (36) Trauma networks have been associated with remarkable improvements in outcomes. (37-41) Leading critical care organizations are engaged in a discussion of regionalization of non-trauma critical care. (5,12)

Analyses of the potential value of regionalization have emphasized the difference between average outcomes for patients cared for in low volume versus high volume hospital. Thus Krumholz and colleagues suggest that nearly 10,000 AMI patients might be saved each year were they to receive the same quality of care provided by the best hospitals.(42) Similar results have been found for non-post-operative mechanical ventilation. (43) These analyses assume, without data, that the *average* effectiveness of the ICU is the same as the *marginal* effect of the ICU. That is, they assume that ICUs will be able to provide the same quality of care for the patients during high occupancy as they have for the average of the preceding patients. The present study supports such an assumption, at least in the short-term.

In particular, the present study suggests that when assigning patients to providers to maximize the quality of care, across the observed range of variability, the highest quality providers are able to maintain their quality even at workloads much above their mean census. This implies, but does not prove, the viability of regionalization strategies, and related approaches such as concentrating high-risk procedures (3,44) and when designing evacuations during disasters. Our results suggest that these ICUs maintain high quality despite high census – if the unit will accept the patient, it may be safe to send them.

Limitations

Our results have several limitations. First, they may not be generalize to all ICUs. The APACHE hospitals invested in information technology, and may not be representative of ICUs in the U.S. – or of the more constrained ICU resources typical of other developed countries. (45) Second, in any observational study an unobserved confounder might be present. Such a confounder would need to be associated with improved survival in the ICU and more common on high census days to explain our results. Third, given the importance of early response for several key critical illnesses, we have chosen to focus on census on day-of-admission. For some conditions, particularly safety-related complications such as catheter-related blood stream infections, the workload throughout the entire ICU stay may be more important. Fourth, limitations of our data require that we use inpatient mortality and inpatient discharge destination as key outcomes. We hope that replications of this work will use unambiguous 30

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day outcomes. Fifth, our data do not address the outcomes of patients who could not be admitted to the ICU due to high census, so we cannot speak to population health effects—high census days may affect outcomes on the hospital ward or ED. Finally, we have chosen to use a minimally parametric fixed effects estimator. As such, our standard errors may be somewhat less precise than a model that made more restrictive assumptions; however, our point estimates suggest only very small effects, if any.

Conclusions

A diverse set of ICUs seems able to maintain consistent mortality outcomes across a range of daily censuses. Some ICUs display a hallmark of high reliability organizations: consistent outcomes despite wide range of operating conditions. Further, this implies, but does not yet prove, that patients may be concentrated in high volume ICUs without overwhelming those ICUs, and without thereby losing the potential benefits of concentration.

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Appendix Table: Fixed Effects Regression Results

All regressions control for APACHE IV predicted mortality *except* as indicated.

Table A.I

	Outcome	APS	*No Control for APACHE prediction*	
	Obs Used	183774		
	Subgroup	All		
		Beta	95%CI LL	95%CI UL
Lower Census	Decile 1	reference		
	Decile 2	-0.299	-0.811	0.212
	Decile 3	-0.539	-1.053	-0.026
	Decile 4	-0.570	-1.093	-0.048
Ratio to Mean Census	Decile 5	-0.801	-1.317	-0.285
	Decile 6	-0.641	-1.171	-0.111
	Decile 7	-0.942	-1.457	-0.427
	Decile 8	-1.349	-1.869	-0.830
Higher Census	Decile 9	-1.781	-2.295	-1.267
	Decile 10	-2.570	-3.085	-2.055
	F-Test for all Deciles	16.39	9 d.f., p=	<.0001
	R-Squared	0.049149		

Table A.II

	Outcome	In-Hospital Death		
	Strata	108		
	Obs Used	196877		
	Subgroup	All		
		Odds Ratio	95%CI LL	95%CI UL
Lower Census	Decile 1	1.01	0.939	1.086
	Decile 2	0.952	0.886	1.023
	Decile 3	0.972	0.905	1.044
	Decile 4	0.986	0.917	1.059
Ratio to Mean Census	Decile 5	0.934	0.868	1.005
	Decile 6	reference		
	Decile 7	0.985	0.916	1.06
	Decile 8	1.051	0.977	1.13

	Outcome	In-Hospital Death		
Higher Census	Decile 9	0.995	0.925	1.071
	Decile 10	0.983	0.911	1.062
	Wald Test for All Deciles	13.3162	9 d.f., p=	0.1488
	Rescaled R-Squared	0.3943		

Table A.III

	Outcome	Transferred to Another Hospital		
	Strata	108		
	Obs Used	196877		
	Subgroup	All		
		Odds Ratio	95%CI LL	95%CI UL
Lower Census	Decile 1	1.074	0.98	1.176
	Decile 2	1.024	0.934	1.123
	Decile 3	1.056	0.963	1.158
	Decile 4	0.99	0.899	1.09
Ratio to Mean Census	Decile 5	1.016	0.922	1.119
	Decile 6	reference		
	Decile 7	0.946	0.86	1.041
	Decile 8	0.957	0.869	1.054
Higher Census	Decile 9	1.029	0.937	1.129
	Decile 10	0.95	0.864	1.045
	Wald Test for All Deciles	16.4675	9 d.f., p=	0.0577
	Rescaled R-Squared	0.0042		

Table A.IV

	Outcome	ICU LOS	* Controls for APACHE-predicted LOS *	
	Obs Used	178657		
	Subgroup	Full ICU LOS Data		
		Beta	95%CI LL	95%CI UL
Lower Census	Decile 1	0.143	0.018	0.268
	Decile 2	0.056	-0.067	0.179
	Decile 3	0.025	-0.097	0.148
	Decile 4	0.088	-0.034	0.211
Ratio to Mean Census	Decile 5	0.117	-0.007	0.242
	Decile 6	reference		
	Decile 7	-0.052	-0.177	0.073
	Decile 8	0.017	-0.107	0.141
Higher Census	Decile 9	0.031	-0.094	0.156
	Decile 10	0.048	-0.081	0.177
	F-Test for all Deciles	1.77	9 d.f., p=	0.0689
	R-Squared	0.186215		

Table A.V

	Outcome	In-Hospital Death		
	Strata	108		
	Obs Used	196877		
	Subgroup	All		
		Odds Ratio	95%CI LL	95%CI UL
Lower Census	Decile 1	1.073	0.997	1.155
	Decile 2	1.028	0.957	1.104
	Decile 3	1.03	0.96	1.106
14 Day Ratio to Mean Census	Decile 4	1.02	0.951	1.095
	Decile 5	1.003	0.935	1.076
	Decile 6	reference		
	Decile 7	1.052	0.981	1.128

	Outcome	In-Hospital Death		
	Decile 8	1.039	0.968	1.115
Higher Census	Decile 9	1.102	1.027	1.183
	Decile 10	1.02	0.946	1.1
	Wald Test for All Deciles	12.1474	9 d.f., p=	0.2051
	Rescaled R-Squared	0.3943		

Table A.VI

	Outcome	Transferred to Another Hospital		
	Strata	108		
	Obs Used	196877		
	Subgroup	All		
		Odds Ratio	95%CI LL	95%CI UL
Lower Census	Decile 1	1.029	0.935	1.133
	Decile 2	1.122	1.026	1.227
	Decile 3	1.085	0.991	1.187
14 Day Ratio to Mean Census	Decile 4	1.119	1.022	1.225
	Decile 5	1.023	0.933	1.121
	Decile 6	reference		
	Decile 7	1.005	0.916	1.103
	Decile 8	0.953	0.868	1.046
Higher Census	Decile 9	1.01	0.921	1.108
	Decile 10	0.997	0.906	1.097
	Wald Test for All Deciles	24.7881	9 d.f., p=	0.0032
	Rescaled R-Squared	0.0043		

Table A.VII

	Outcome	In-Hospital Death		
	Strata	108		
	Obs Used	60454		
	Subgroup	Post-Operative Patients		
		Odds Ratio	95%CI LL	95%CI UL
Lower Census	Decile 1	1.176	0.954	1.449
	Decile 2	1.026	0.837	1.258
	Decile 3	1.021	0.836	1.247
	Decile 4	0.966	0.788	1.185
Ratio to Mean Census	Decile 5	0.95	0.768	1.176
	Decile 6	reference		
	Decile 7	0.961	0.776	1.19
	Decile 8	1.04	0.852	1.27
Higher Census	Decile 9	0.963	0.783	1.185
	Decile 10	0.99	0.797	1.23
	Wald Test for All Deciles	6.0775	9 d.f., p=	0.7321
	Rescaled R-Squared	0.1961		

Table A.VIII

	Outcome	In-Hospital Death		
	Strata	108		
	Obs Used	136423		
	Subgroup	Non-Post-Operative Patients		
		Odds Ratio	95%CI LL	95%CI UL
Lower Census	Decile 1	0.973	0.897	1.054
	Decile 2	0.936	0.864	1.014
	Decile 3	0.961	0.887	1.04
	Decile 4	0.989	0.914	1.071
Ratio to Mean Census	Decile 5	0.934	0.861	1.012

	Outcome	In-Hospital Death		
	Decile 6	reference		
	Decile 7	0.986	0.909	1.069
	Decile 8	1.054	0.971	1.144
Higher Census	Decile 9	1.012	0.933	1.098
	Decile 10	0.99	0.909	1.079
	Wald Test for All Deciles	13.8071	9 d.f., p=	0.1294
	Rescaled R-Squared	0.3994		

Table A.IX

	Outcome	In-Hospital Death		
	Strata	107		
	Obs Used	15464		
	Subgroup	High Predicted Risk of Death		
		Odds Ratio	95%CI LL	95%CI UL
Lower Census	Decile 1	1.023	0.867	1.207
	Decile 2	0.876	0.747	1.029
	Decile 3	0.995	0.85	1.166
	Decile 4	0.936	0.798	1.098
Ratio to Mean Census	Decile 5	0.943	0.803	1.107
	Decile 6	reference		
	Decile 7	0.962	0.819	1.13
	Decile 8	1.168	0.986	1.384
Higher Census	Decile 9	0.997	0.844	1.179
	Decile 10	0.928	0.78	1.104
	Wald Test for All Deciles	14.3608	9 d.f., p=	0.1101
	Rescaled R-Squared	0.1138		

Table A.X

	Outcome	In-Hospital Death		
	Strata	108		
	Obs Used	152133		
	Subgroup	Weekday Admissions		
		Odds Ratio	95%CI LL	95%CI UL
Lower Census	Decile 1	1.013	0.928	1.105
	Decile 2	0.924	0.848	1.007
	Decile 3	0.968	0.890	1.052
	Decile 4	0.977	0.899	1.062
Ratio to Mean Census	Decile 5	0.934	0.858	1.016
	Decile 6	reference		
	Decile 7	0.979	0.901	1.064
	Decile 8	1.043	0.960	1.133
Higher Census	Decile 9	0.971	0.894	1.054
	Decile 10	0.969	0.889	1.056
	Wald Test for All Deciles	11.953	9 d.f., p=	0.216
	Rescaled R-Squared	0.390		

Table A.XI

	Outcome	In-Hospital Death		
	Strata	108		
	Obs Used	44744		
	Subgroup	Weekend Admissions		
		Odds Ratio	95%CI LL	95%CI UL
Lower Census	Decile 1	0.999	0.872	1.145
	Decile 2	0.999	0.871	1.145
	Decile 3	0.974	0.848	1.120
	Decile 4	0.994	0.861	1.147

	Outcome	In-Hospital Death		
Ratio to Mean Census	Decile 5	0.927	0.799	1.076
	Decile 6	reference		
	Decile 7	1.003	0.859	1.170
	Decile 8	1.094	0.937	1.278
Higher Census	Decile 9	1.117	0.948	1.316
	Decile 10	1.060	0.887	1.268
	Wald Test for All Deciles	8.1966	9 d.f., p=	0.5145
	Rescaled R-Squared	0.405		

Table A.XII

	Outcome	In-Hospital Death		
	Strata	37		
	Obs Used	67163		
	Subgroup	Non-Teaching Hospital		
		Odds Ratio	95%CI LL	95%CI UL
Lower Census	Decile 1	0.974	0.852	1.113
	Decile 2	0.903	0.79	1.033
	Decile 3	0.952	0.828	1.095
	Decile 4	0.927	0.8	1.075
Ratio to Mean Census	Decile 5	0.919	0.799	1.056
	Decile 6	reference		
	Decile 7	0.968	0.839	1.118
	Decile 8	1.019	0.892	1.164
Higher Census	Decile 9	0.947	0.825	1.088
	Decile 10	0.993	0.865	1.14
	Wald Test for All Deciles	6.6208	9 d.f., p=	0.6765
	Rescaled R-Squared	0.4025		

Table A.XIII

	Outcome	In-Hospital Death		
	Strata	30		
	Obs Used	62958		
	Subgroup	Small Teaching Hospital		
		Odds Ratio	95%CI LL	95%CI UL
Lower Census	Decile 1	0.941	0.828	1.07
	Decile 2	0.904	0.793	1.031
	Decile 3	0.987	0.87	1.119
	Decile 4	0.91	0.801	1.035
Ratio to Mean Census	Decile 5	0.881	0.77	1.008
	Decile 6	reference		
	Decile 7	0.92	0.809	1.046
	Decile 8	0.979	0.85	1.126
Higher Census	Decile 9	0.973	0.854	1.109
	Decile 10	0.91	0.798	1.038
	Wald Test for All Deciles	7.8223	9 d.f., p=	0.5522
	Rescaled R-Squared	0.382		

Table A.XIV

	Outcome	In-Hospital Death		
	Strata	41		
	Obs Used	66756		
	Subgroup	Member of Council of Teaching Hospitals (COTH)		
		Odds Ratio	95%CI LL	95%CI UL
Lower Census	Decile 1	1.108	0.978	1.254
	Decile 2	1.029	0.918	1.155
	Decile 3	0.949	0.848	1.061

	Outcome	In-Hospital Death		
	Decile 4	1.077	0.967	1.198
Ratio to Mean Census	Decile 5	0.973	0.867	1.093
	Decile 6	reference		
	Decile 7	1.044	0.93	1.172
	Decile 8	1.124	1.002	1.261
Higher Census	Decile 9	1.043	0.927	1.174
	Decile 10	1.011	0.875	1.167
	Wald Test for All Deciles	12.889	9 d.f., p=	0.1677
	Rescaled R-Squared	0.3981		

Table A.XV

	Outcome	In-Hospital Death		
	Strata	108		
	Obs Used	196877		
	Subgroup	All		
		Odds Ratio	95%CI LL	95%CI UL
Lower Census	Decile 1	0.958	0.890	1.030
	Decile 2	0.958	0.892	1.030
	Decile 3	0.947	0.882	1.016
Absolute Difference from Mean Census	Decile 4	0.943	0.877	1.014
	Decile 5	0.928	0.862	0.999
	Decile 6	reference		
	Decile 7	0.93	0.864	1.001
	Decile 8	0.995	0.925	1.069
Higher Census	Decile 9	0.999	0.928	1.075
	Decile 10	0.946	0.875	1.023
	Wald Test for All Deciles	10.335	9 d.f., p=	0.324
	Rescaled R-Squared	0.3942		

Table A.XVI

	Outcome	In-Hospital Death		
	Strata	108		
	Obs Used	178775		
	Subgroup	Only first visit of first hospitalization		
		Odds Ratio	95%CI LL	95%CI UL
Lower Census	Decile 1	1.011	0.937	1.092
	Decile 2	0.953	0.883	1.028
	Decile 3	0.967	0.896	1.042
	Decile 4	0.987	0.915	1.065
Ratio to Mean Census	Decile 5	0.931	0.862	1.007
	Decile 6	reference		
	Decile 7	0.995	0.921	1.076
	Decile 8	1.036	0.959	1.119
Higher Census	Decile 9	0.994	0.920	1.074
	Decile 10	0.986	0.909	1.070
	Wald Test for All Deciles	10.6621	9 d.f., p=	0.2996
	Rescaled R-Squared	0.4013		

Table A.XVII

	Outcome	Admitted after Cardiac Arrest		
	Strata	108		
	Obs Used	196877		
	Subgroup	All		
		Odds Ratio	95%CI LL	95%CI UL
Lower Census	Decile 1	1.041	0.893	1.213

	Outcome	Admitted after Cardiac Arrest		
	Decile 2	1.065	0.915	1.241
	Decile 3	0.974	0.835	1.137
	Decile 4	0.953	0.816	1.113
Ratio to Mean Census	Decile 5	1.072	0.917	1.253
	Decile 6	reference		
	Decile 7	1.042	0.893	1.217
	Decile 8	1.016	0.866	1.191
Higher Census	Decile 9	0.959	0.821	1.121
	Decile 10	0.919	0.784	1.078
	Wald Test for All Deciles	8.4609	9 d.f., p=	0.4885
	Rescaled R-Squared	0.0003		

Table A.XVIII

	Outcome	Readmission to ICU within 7 Days of Discharge		
	Strata	108		
	Obs Used	196877		
	Subgroup	All		
		Odds Ratio	95%CI LL	95%CI UL
Lower Census	Decile 1	1.001	0.891	1.125
	Decile 2	0.986	0.88	1.105
	Decile 3	1.02	0.911	1.143
	Decile 4	1.078	0.963	1.206
Ratio to Mean Census	Decile 5	0.944	0.839	1.062
	Decile 6	reference		
	Decile 7	1.007	0.895	1.132
	Decile 8	1.004	0.896	1.126
Higher Census	Decile 9	1.034	0.922	1.16
	Decile 10	1.002	0.889	1.129
	Wald Test for All Deciles	5.9396	9 d.f., p=	0.7459
	Rescaled R-Squared	0.0105		

Table A.XIX

	Outcome	ICU LOS	* Controls for APACHE-predicted LOS *	
	Obs Used	178657		
	Subgroup	Full ICU LOS Data		
		Beta	95%CI LL	95%CI UL
Lower Census	Decile 1	-0.007	-0.131	0.117
	Decile 2	0.004	-0.115	0.124
	Decile 3	0.016	-0.102	0.135
14 Day Ratio to Mean Census	Decile 4	-0.041	-0.159	0.077
	Decile 5	-0.022	-0.140	0.095
	Decile 6	reference		
	Decile 7	0.034	-0.083	0.151
	Decile 8	-0.051	-0.170	0.067
Higher Census	Decile 9	-0.005	-0.127	0.117
	Decile 10	0.069	-0.057	0.196
	F-Test for all Deciles	0.61	9 d.f., p=	0.7886
	R-Squared	0.829409		

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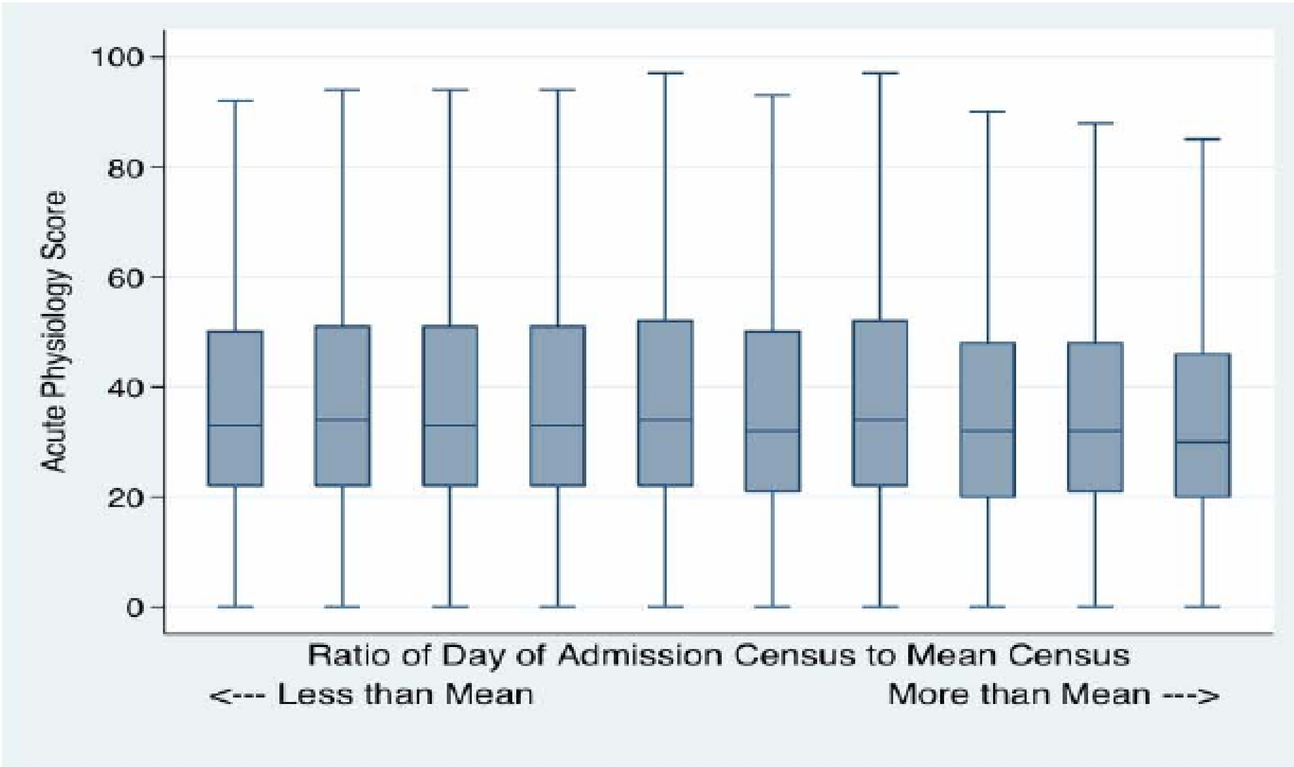


Figure 1. Unadjusted Acute Physiology Score

Across Deciles of Census Ratio. Box plot shows the median (center line) and interquartile range (box). There is little meaningful association with Census (on the horizontal axis).

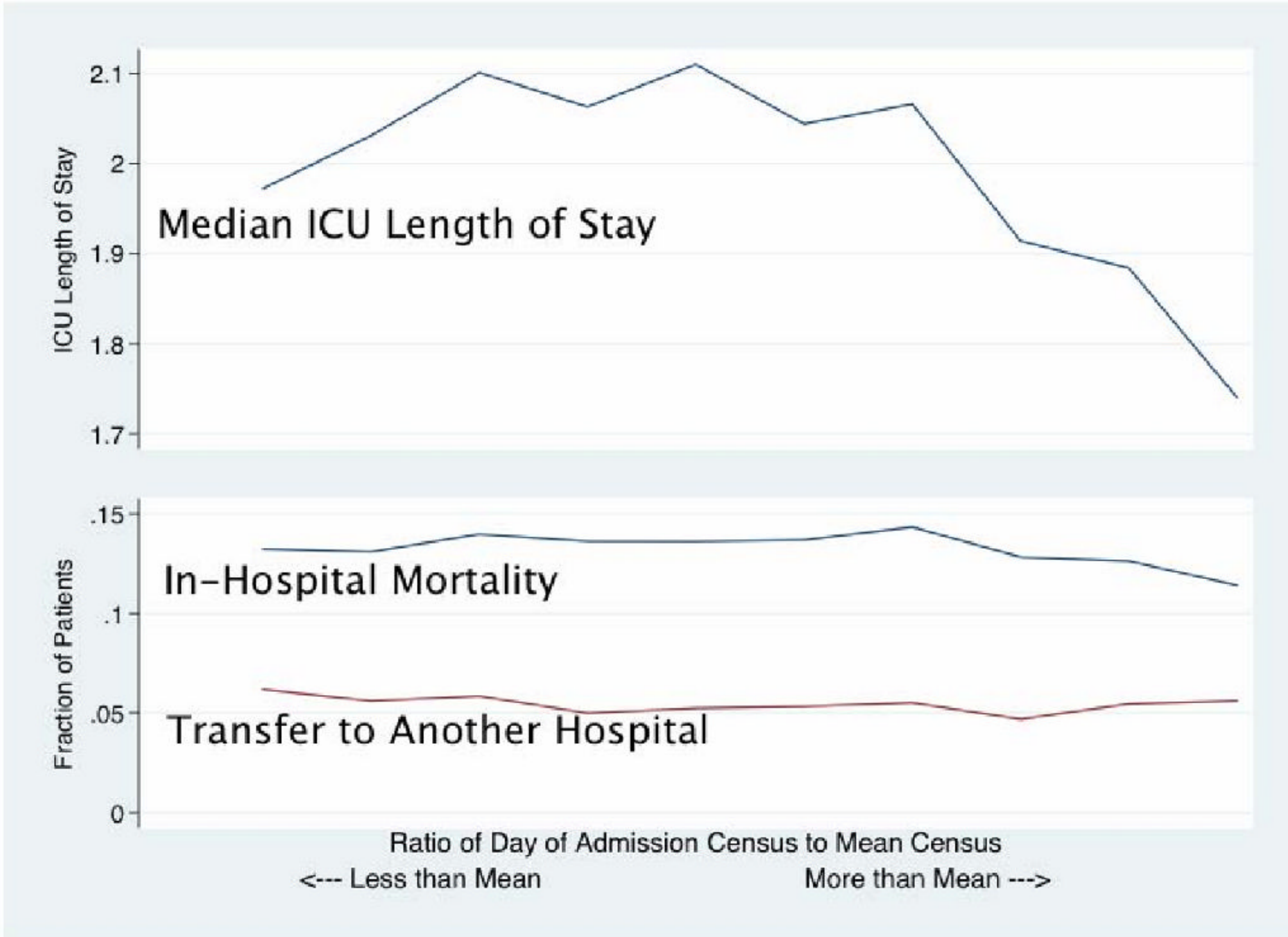
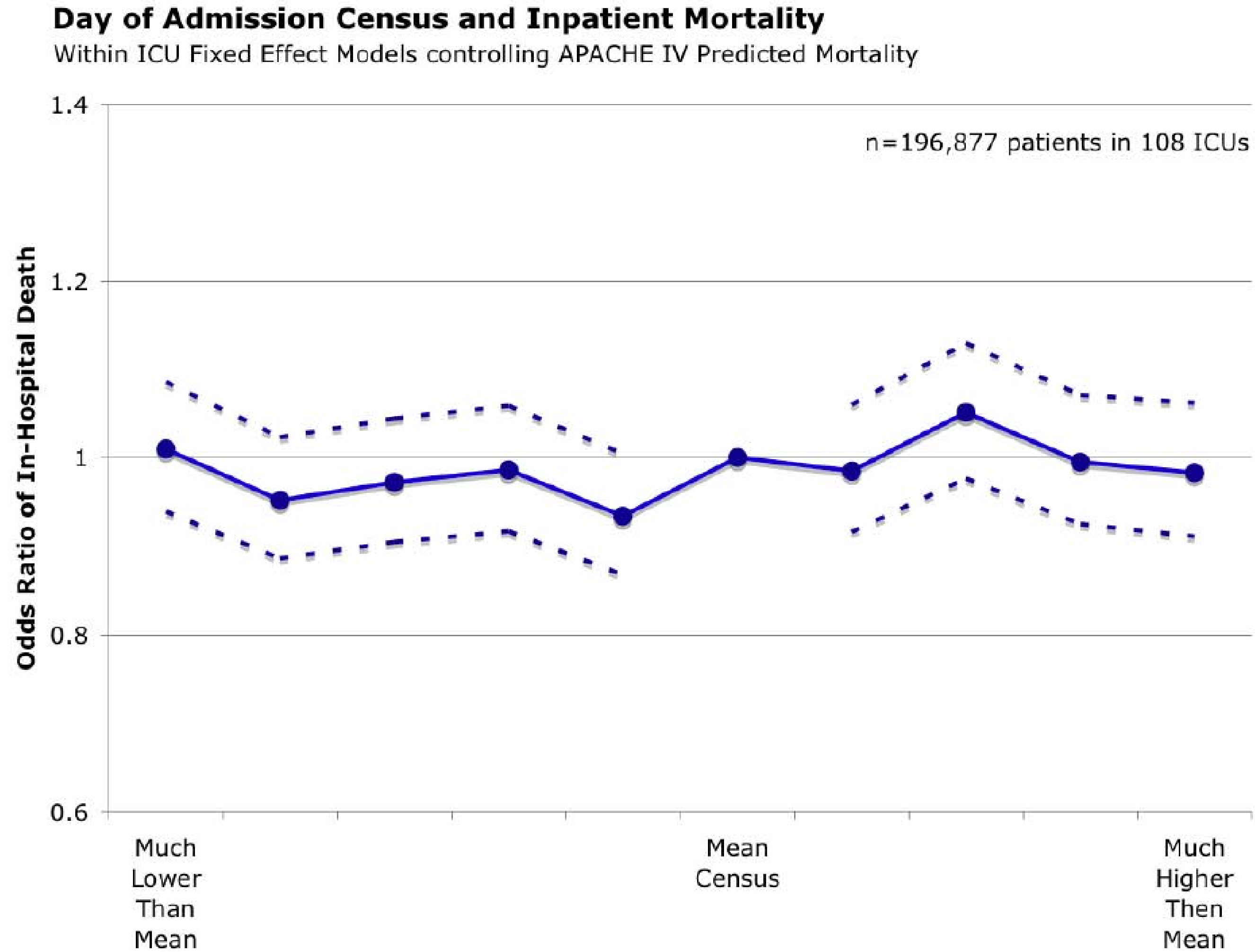


Figure 2. Unadjusted Mortality, Transfer Rates and ICU LOS
Across Deciles of Census Ratio (on the horizontal axis).


Day of Admission Census and Inpatient Mortality
Within ICU Fixed Effect Models controlling APACHE IV Predicted Mortality
n=196,877 patients in 108 ICUs
Odds Ratio of In-Hospital Death
1.4
1.2
1
0.8
0.6
Much Lower Than Mean
Mean Census
Much Higher Then Mean

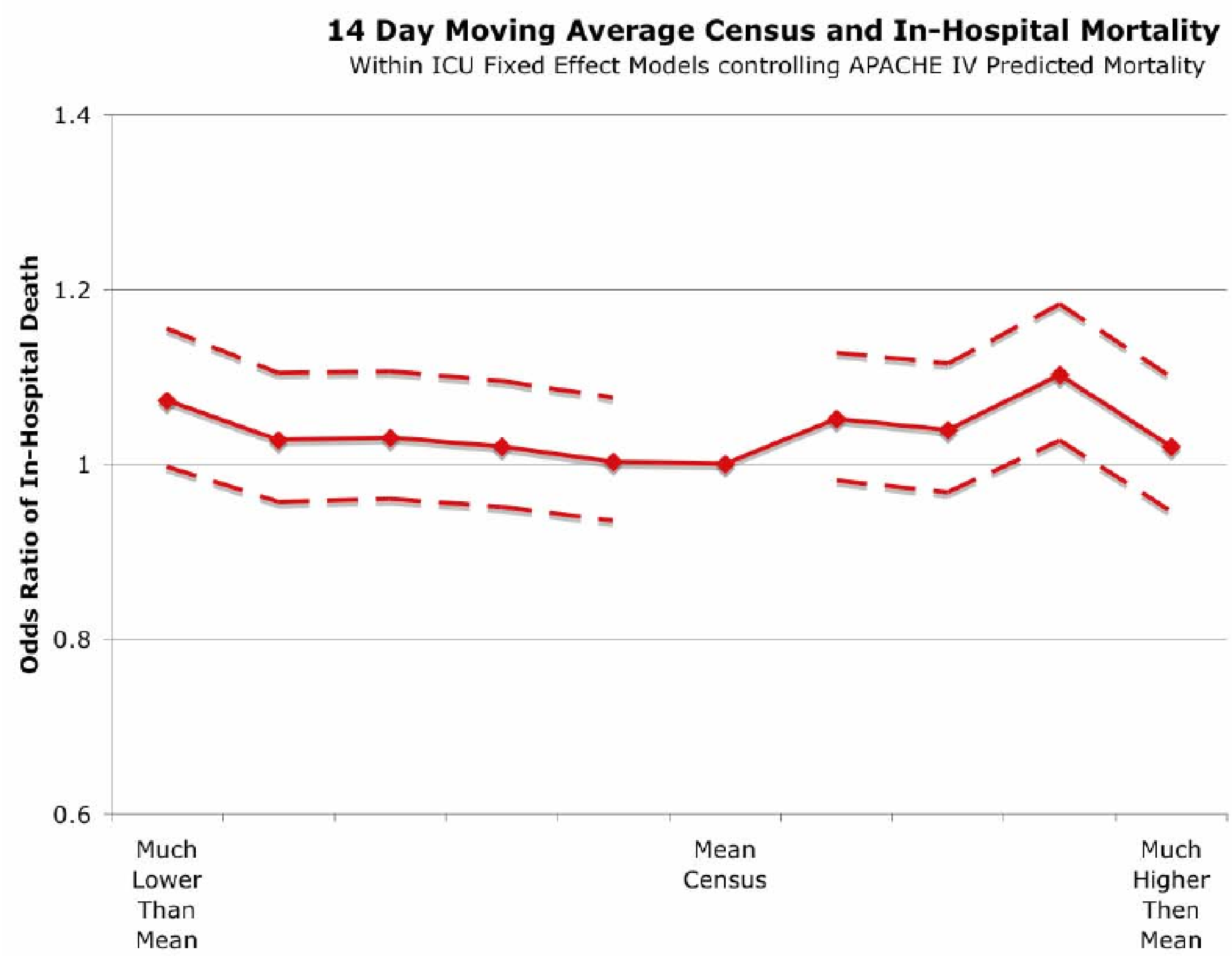


Figure 3. Conditional Logistic Regression for Mortality

Ratio of Census to Mean Census Parameterized as Separate Indicator Variables for Each Decile and with Decile 6 as reference category.

Table 1

Patient Characteristics (n = 200,499)

	Mean	S.D.
Age	61.54	17.60
In-Hospital Death	13.26%	(n = 26,583)
Emergent Surgery	5.81%	(n = 11,654)
Post-Operative	30.50%	(n = 61,158)
Predicted Mortality	13.83%	
ICU Length of Stay	3.94	6.29
Predicted ICU Length of Stay	3.69	2.32
Admission Source		
Operating Room	30.50%	(n = 61,157)
Emergency Department	37.43%	(n = 75,038)
Floor	17.72%	(n = 35,524)
Transfer FROM another Hospital	8.66%	(n = 17,369)
Direct Admission	5.69%	(n = 11,411)
Discharge Destination		
Home	63.06%	(n = 126,433)
TO Another Hospital	5.45%	(n = 10,919)
Dead	13.26%	(n = 26,583)
Skilled Nursing Facility	11.53%	(n = 23,112)
Other	5.27%	(n = 10,575)
Missing	1.43%	(n = 2,877)
Admission Diagnoses		
Cardiac	16.40%	(n = 32,880)
Sepsis	5.67%	(n = 11,371)
Pneumonia	3.90%	(n = 7,810)
Other Pulmonary (including COPD)	8.92%	(n = 17,884)
Neurological (including Neurosurgery)	13.72%	(n = 27,513)
Trauma	7.40%	(n = 14,829)
Other Surgery	15.26%	(n = 30,604)
All Other Admitting Diagnoses	28.73%	(n= 57,608)

Table 2

ICU characteristics (n=108)

Mean Daily Census	12.8	
Median Daily Census	11	
Interquartile Range for Daily Census	9 - 15	
Median Total Patients	1831	
Interquartile Range for Total Patients	1107 - 2869	
Teaching Status		
Member, Council of Teaching Hospitals	38.0%	(n = 41)
Small Teaching Hospital	27.8%	(n = 30)
Non-Teaching Hospital	34.3%	(n = 37)
ICU Type		
General	35.2%	(n = 38)
Medical	4.6%	(n = 5)
Cardiac	5.6%	(n = 6)
Neurological	8.3%	(n = 9)
Cardiothoracic	25.0%	(n = 27)
Surgical	19.4%	(n = 21)
Trauma	1.9%	(n = 2)

Table 3

Sensitivity Analyses

Our results were consistent across all of these analyses; full regression results are presented in the Appendix.

Subpopulations of Potential Interest:

- Surgical patients (Table A.VII)
- Non-surgical patients (Table A.VIII)
- Patients with predicted inpatient mortality of greater than 50% (Table A.IX)
- Patients admitted on weekdays (Table A.X)
- Patients admitted on weekends (Table A.XI)
- Non-teaching hospitals (Table A.XII)
- Small teaching hospitals (Table A.XIII)
- Members of the Council of Teaching Hospitals (Table A.XIV)

Alternative Parameterizations:

- Absolute (rather than relative) difference between day-of-admission census and mean census (Table A.XV)
- Using only the first ICU stay of the first hospitalization for each patient (Table A.XVI)

Alternative Outcomes:

- No increased rate of admission to ICU with cardiac arrest on high census days (Table A.XVII)
- No increased rate of readmission to ICU within 7 days of discharge among patients admitted on higher census days (Table A.XVIII)