Associations Between In-Hospital Mortality, Health Care Utilization, and Inpatient Costs With the 2011 Resident Duty Hour Revision

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ABSTRACT

Background The Accreditation Council for Graduate Medical Education (ACGME) has mandated revisions to residents' work hours to improve patient safety and enhance resident education and wellness. The impact on clinical outcomes on a national level is poorly understood.

Objective We examined data from before and after the ACGME 2011 duty hour revision and looked for differences between teaching and nonteaching US hospitals.

Methods A retrospective observational study of patients admitted to hospitals in the 2-year periods before and after the 2011 duty hour revision was conducted, utilizing a nationally representative data set. We compared patient and hospital characteristics using standardized differences. With nonteaching hospitals serving as the control group, we used multiple group interrupted time series segmented regression analysis to test for postrevision level and trend changes in mortality, length of stay (LOS), and costs.

Results We examined more than 117 million hospitalizations. At teaching and nonteaching hospitals, trends in mortality and LOS in prerevision and postrevision periods were not significantly different (all $P > .05$). A significant monthly reduction in cost per hospitalization was noted postrevision at teaching hospitals ($P = .019$) but not at nonteaching hospitals ($P = .62$). In the 2 years following the 2011 revision, there was a monthly reduction in cost per hospitalization ($-\$52.28$; 95% confidence interval $-\$116.90$ to $-\$12.32$; $P = .026$) at teaching relative to nonteaching hospitals.

Conclusions There were no differences in mortality or LOS between teaching and nonteaching hospitals. However, there was a small decrease in cost per hospitalization at teaching hospitals following the 2011 revision.

Introduction

Long shifts and insufficient rest for residents have been implicated in medical errors and safety lapses at teaching hospitals.^{1–4} Furthermore, the high-intensity and heavy workload of residency training may contribute to distress and burnout, which in turn may adversely affect residents' education and professional development.^{5–7} Substantive changes in resident duty hours were mandated by the Accreditation Council for Graduate Medical Education (ACGME), first in 2003, next in 2011, and then again in 2017,⁸ with the goals of enhancing residents' receptivity to learning, boosting their professional growth, and improving their well-being.⁹ There was speculation that clinical outcomes at teaching hospitals, those with embedded residency training programs, would improve following the revisions due to enhanced attentiveness of trainees and better supervision.

Safety metrics and mortality rates for specific patient populations and particular inpatient units in

teaching hospitals have remained largely unchanged in studies comparing outcomes before and after the revisions.^{10–12} Resident duty hour restrictions have necessitated more handoffs, defined as “transitioning care to another clinician through the transfer of information, responsibility, and authority.”^{13–15} The influence of increased handoffs on the efficiency of care delivery, measured by length of stay (LOS), costs, and charges, has not been clearly described. Because nonteaching hospitals' operations should not have changed as a result of the duty hour revision, this control group can be utilized to understand the effect of the requisite revision. This study's objectives were to determine whether mortality rates and health care utilization measures among hospitalized adults worsened at teaching hospitals in the 2-year period after the ACGME 2011 duty hour revision, and whether there were any corollary changes seen at nonteaching hospitals. The 2011 revision was specifically targeted for this inquiry because the mandated changes were particularly substantial, and it is the most recent revision for which national hospital data are accessible, given the multiyear lag in its availability.

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Methods

Study Design and Source of Data

This was a retrospective cohort study of adult patients admitted to US hospitals. We used the Agency for Healthcare Research and Quality Healthcare Cost and Utilization Project–Nationwide Inpatient Sample (HCUP-NIS) database from 2009 to 2013 to assemble a nationally representative data set of hospitalized patients in the United States.

The NIS is the largest publicly available all-payer inpatient health care database in the United States.¹⁶ It approximates a 20% stratified sample of all US hospital discharges from 46 participating states. Unweighted, the NIS contains data from more than 7 million hospital stays each year. Weighted to represent all admissions, it estimates more than 35 million hospitalizations annually, representing approximately 95% of US hospitalizations. Eligible hospitals are stratified according to ownership, teaching status, geographic region, bed size, and urban/rural location. Bed size categories are based on the number of short-term acute care beds in a hospital and are specific to the hospital's location and teaching status. The classification of urban or rural hospital location centers on the core-based statistical area codes based on data from the 2000 census.¹⁷

Study Cohorts

All adults admitted to hospitals participating in the NIS from July 1, 2009, to June 30, 2013, were included in the study population, encompassing 2 years of hospitalizations before and after the July 1, 2011, ACGME duty hour revision. The initial sample included more than 147 million patients. We excluded patients whose age was below 18 years or missing, were transferred from another hospital, or were from hospitals missing a teaching status designation, resulting in a patient population of more than 117 million (FIGURE 1). This patient population was further stratified by hospital teaching status (ie, teaching versus nonteaching), designated based on data obtained from the American Hospital Association Annual Survey of Hospitals. A hospital is classified as a teaching hospital if any of 3 criteria are met: (1) it has an ACGME-approved residency program; (2) it is a member of the Council of Teaching Hospitals; or (3) it has a ratio of full-time equivalent interns and residents to beds of 0.25 or higher.¹⁷ Patients were assigned to the prerevision or postrevision cohort if their admission date fell within the 2 years prior to or after July 1, 2011.

What was known and gap

The Accreditation Council for Graduate Medical Education made revisions to residents' work hours in 2011, and the effect it had on clinical outcomes is not well understood.

What is new

A retrospective observational study of patients admitted to hospitals in the 2-year periods before and after the 2011 duty hour revision, with nonteaching hospitals serving as a control group.

Limitations

Characterization of a hospital's teaching status could have led to some hospitals with smaller training programs being misclassified. Due to the observational nature of the study, causal inferences cannot reliably be drawn.

Bottom line

Mortality rates and length of stay did not differ significantly between teaching and nonteaching hospitals. Teaching hospitals demonstrated a small decrease in hospitalization costs after the 2011 revision.

Outcome Measures

We examined in-hospital mortality rates, defined as the proportion of patients who died during the hospitalization, multiplied by 1000. In-hospital mortality rates were further adjusted for age, sex, and comorbidity burden. Total hospital charges represent the dollar amount that hospitals bill for the entire hospital stay. The HCUP secures and shares data that contain hospital-specific cost-to-charge ratios based on all-payer inpatient cost. This cost information is obtained from the hospital accounting reports collected by the Centers for Medicare & Medicaid Services.¹⁸ Total hospitalization costs were calculated as total hospital charges multiplied by the corresponding hospital cost-to-charge ratio. Costs were adjusted for inflation using the year-specific Consumer Price Index provided by the US Bureau of Labor Statistics, with 2015 as the index base.¹⁹ A second health care resource utilization measure, LOS, was also evaluated across the period of change at both hospital types. These patient-level outcomes were aggregated to provide monthly averages during the study period, resulting in 48 data points across 4 years.

Approval for using NIS patient-level data was obtained from the Institutional Review Board of Johns Hopkins University and the HCUP.

Statistical Analysis

Weighting of patient-level observations was implemented to obtain estimates for the entire US population of hospitalized patients during the time period analyzed. Patient- and hospital-level characteristics were compared using standardized differences, calculated as the difference in means or proportions divided

FIGURE 1

Patient Selection for 2011 Accreditation Council for Graduate Medical Education Revision (Nationwide Input Sample [NIS] July 2009–June 2013)

by a pooled estimate of the standard deviation. Compared with traditional significance testing, standardized differences are not as sensitive to sample size and are useful in identifying meaningful differences. Typically, an absolute standardized difference of more than 10% is considered to be clinically meaningful.^{20,21}

To determine the immediate and sustained effects of the 2011 revision on outcomes at teaching hospitals, we used segmented regression, a form of interrupted time series analysis. This quasi-experimental design model enables the use of a comparison group to enhance internal validity. In such a design, outcomes may not be independent over time and autocorrelation can arise. Failure to account for this issue may lead to underestimated standard errors. In our analysis, we used the Newey-West standard errors and applied the Cumby-Huizinga test for autocorrelation to ensure that we fit a model that accounts for the correct autocorrelation structure (up to 12 lags tested) between adjacent individual monthly measurements.^{22,23} A linear regression model was then used to assess whether the implementation of the 2011 revision was associated with a shift in the level and trend of postrevision outcomes at teaching hospitals compared with those of the prerevision period, while also using nonteaching hospitals as a comparison group. The changes of levels are calculated around the time of implementation (July 2011), while the trend corresponds to the slope of the fitted line for outcomes

across the pre and post periods. The primary independent variables in our analyses were time (in months, 2 years before start of the revision through 2 years postrevision follow-up), intervention (whether a given month was before or after the index revision initiation date of July 1, 2011), and time after intervention (time in months after the revision initiation date). All hypothesis tests were 2-sided and used a significance level of $P < .05$. Statistical comparisons were performed using Stata 13.0 (StataCorp Inc, College Station, TX).

Results

Study Population

Between July 1, 2009, and June 30, 2013, there were 117,087,577 hospitalizations that met study inclusion criteria. The mean age of patients was 57 years. A total of 60% (70,130,168) were female, 62% (72,871,757) were white, 45% (53,270,079) were insured under Medicare, and 62% (72,514,269) and 88% (102,820,893) were admitted to large and urban hospitals, respectively. TABLE 1 shows both patient and hospital characteristics for the prerevision and postrevision periods by hospital teaching status. Prerevision and postrevision patient subpopulations were similar with respect to most of the measured baseline characteristics at teaching and nonteaching hospitals, with a few exceptions, such as larger size and location, across teaching hospitals. When the overall teaching and nonteaching hospitals' populations were

compared, patients in teaching hospitals were younger, less likely to be white, less likely to have Medicare as primary insurance, and more likely to be urban and in the northeastern United States (TABLE 1).

Mortality Rates

Mortality was stable at teaching hospitals during both the prerevision period (-0.06 deaths per 1000 hospitalization months; 95% confidence interval [CI] -0.14 to 0.01 ; $P=.12$) and the postrevision period ($+0.03$ deaths per 1000 hospitalization months; 95% CI -0.055 to 0.12 ; $P=.48$). In addition, there was no significant change in the trends in mortality rates across the time periods before and after the 2011 revision ($+0.09$; 95% CI -0.02 to 0.21 ; $P=.11$). Similar trends were noted in nonteaching hospitals (TABLE 2). When comparing the change in mortality rates at teaching hospitals to that of nonteaching hospitals, no statistically significant differences were noted ($+0.07$; 95% CI -0.09 to 0.24 ; $P=.38$; FIGURE 2A). Following the 2011 revision, there were no changes in mortality levels at either teaching (-0.35 ; 95% CI -1.78 to 1.07 ; $P=.63$) or nonteaching (-0.45 ; 95% CI -1.91 to 0.99 ; $P=.54$) hospitals.

Length of Hospital Stay

At the teaching hospitals, LOS was fairly constant during both the prerevision period ($+0.01$ days per month; 95% CI -0.01 to 0.02 ; $P=.17$) and the postrevision period (-0.01 days per month; 95% CI -0.04 to 0.01 ; $P=.24$). There was no significant change in the LOS trends before and after the 2011 revision (-0.02 days; 95% CI -0.05 to 0.01 ; $P=.086$). Similar trends were noted in nonteaching hospitals (TABLE 2). Modest changes in LOS of patients at teaching hospitals were not statistically significantly different (0.00 days; 95% CI -0.26 to 0.26 ; $P=.39$; FIGURE 2B) compared with the LOS at nonteaching hospitals. Immediately following the 2011 revision, there was no change in LOS at either teaching (-0.01 ; 95% CI -0.22 to 0.20 ; $P=.92$) or nonteaching (-0.01 ; 95% CI -0.17 to 0.14 ; $P=.88$) hospitals.

Hospitalization Costs

Costs at teaching hospitals increased significantly at a rate of $\$35.36$ per hospitalization month (95% CI 11.07 to 59.65 , $P=.005$) during the prerevision period, and then decreased at a rate of $\$26.75$ per hospitalization month (95% CI 71.61 to 18.10 , $P=.24$) during the postrevision period. Compared with the prerevision period, patients at teaching hospitals experienced a significant reduction in

FIGURE 2

Plot of Adjusted Mortality Rates (A), Length of Hospital Stay (B), and Hospitalization Costs (C) at Teaching and Nonteaching Hospitals 2 Years Before and After the 2011 ACGME Duty Hour Revision

Note: Mortality rates were calculated every month as number of deaths over total population during that month multiplied by 1000. Mortality rates were then further adjusted for age, sex, and comorbidity.

TABLE 1
Patient and Hospital Characteristics: Before and After 2011 Accreditation Council for Graduate Medical Education Duty Hour Revision by Hospital Teaching Status (July 1, 2009–June 30, 2013)

Characteristics	Teaching Hospitals			Nonteaching Hospitals			Absolute Standardized Difference (Teaching Versus Nonteaching Populations)
	Prerevision (July 1, 2009– June 30, 2011) (n = 26,841,721)	Postrevision (July 1, 2011– June 30, 2013) (n = 28,013,057)	Absolute Standardized Difference ^a	Prerevision (July 1, 2009– June 30, 2011) (n = 32,193,853)	Postrevision (July 1, 2011– June 30, 2013) (n = 30,038,946)	Absolute Standardized Difference ^a	
Patient							
Age, y, mean ± SD	55 ± 20	56 ± 20	5.00	59 ± 21	59 ± 21	0.24	17.06
Female	58.8	59.1	0.61	60.9	60.5	0.82	3.59
Race, %							
White	54.4	58.3	7.87	65.2	69.7	9.61	22.75
Black	17.8	17.7	0.26	9.7	10.4	2.33	22.43
Hispanic	10.2	10.7	1.63	9.3	9.3	0.07	3.89
Other ^b	17.6	13.3	11.92	15.8	10.6	15.41	5.99
Primary payer, % ^c							
Medicare	40.4	42.7	4.67	48.2	49.8	3.20	14.91
Medicaid	17.7	17.1	1.58	14.0	14.2	0.57	9.04
Private/HMO insurance	31.4	30.5	1.95	28.8	26.8	4.46	1.84
Self-pay	6.3	5.5	3.40	5.0	5.2	0.91	3.47
Elective admission, %	28.1	26.8	2.91	24.9	24.4	1.16	6.34
Weekend admission, %	18.9	19.0	0.25	20.0	20.4	1.00	3.12
Charlson Comorbidity Index, %							
0	44.3	43.1	2.42	42.9	42.0	1.82	2.46
1	21.1	20.9	0.49	23.2	22.8	0.95	4.83
≥ 2	34.6	36.0	2.93	33.9	35.2	2.73	1.64
Hospital, %							
Geographical region							
Northeast	28.0	26.0	4.51	13.6	13.7	0.29	33.59
Midwest	23.8	24.0	0.47	21.1	21.0	0.10	6.83

TABLE 1
Patient and Hospital Characteristics: Before and After 2011 Accreditation Council for Graduate Medical Education Duty Hour Revision by Hospital Teaching Status (July 1, 2009–June 30, 2013) (continued)

Characteristics	Teaching Hospitals			Nonteaching Hospitals			Absolute Standardized Difference (Teaching Versus Nonteaching Populations)
	Prerevision (July 1, 2009–June 30, 2011) (n = 26,841,721)	Postrevision (July 1, 2011–June 30, 2013) (n = 28,013,057)	Absolute Standardized Difference ^a	Prerevision (July 1, 2009–June 30, 2011) (n = 32,193,853)	Postrevision (July 1, 2011–June 30, 2013) (n = 30,038,946)	Absolute Standardized Difference ^a	
South	33.7	35.5	3.78	42.5	42.0	1.01	15.75
West	14.5	14.5	0.08	22.8	23.3	1.19	22.01
Size							
Small	12.4	15.2	8.12	11.9	12.5	1.83	4.88
Medium	23.9	27.4	8.02	24.0	25.3	3.02	2.44
Large	63.7	57.4	12.92	64.1	62.2	3.94	5.56
Location							
Rural	2.0	0.3	15.99	21.2	22.7	3.62	68.86
Urban	98.0	99.7	15.99	78.8	77.3	3.62	68.86

Abbreviation: HMO, health maintenance organization.

^a Absolute standardized difference (%) calculated for postrevision versus prerevision. Typically, an absolute standardized difference more than 10% is considered to be clinically meaningful (shown in bold here).

^b Includes patients self-identifying as Asian/Pacific Islanders and patients self-identifying as Native American, as well as patients with missing data on race.

^c Data do not add to 100%, as information on other insurances is not shown.

TABLE 2

Segmented Regression Estimates of Changes in Trends and Levels in Teaching and Nonteaching Hospitals Across the 2011 Accreditation Council for Graduate Medical Education (ACGME) Duty Hour Revision^a

Parameter	Points Estimate (95% CI) July 1, 2009–June 30, 2013		
	Mortality ^b	Length of Stay ^c	Hospitalization Costs ^c
Prerevision trend, teaching hospitals	−0.06 (−0.14 to 0.01)	0.01 (−0.01 to 0.02)	35.36 (11.07 to 59.65)
Postrevision trend, teaching hospitals	0.03 (−0.06 to 0.12)	−0.01 (−0.04 to 0.01)	−26.75 (−71.61 to 18.10)
Change in trends across the 2 periods, teaching hospitals	0.09 (−0.02 to 0.21)	−0.02 (−0.05 to 0.01)	−62.11 (−113.68 to −10.55)
Prerevision trend, nonteaching hospitals	−0.01 (−0.08 to 0.06)	0.01 (−0.01 to 0.01)	12.76 (−11.02 to 36.54)
Postrevision trend, nonteaching hospitals	0.01 (−0.08 to 0.11)	−0.01 (−0.02 to 0.01)	2.93 (−27.04 to 32.91)
Change in trends across the 2 periods, nonteaching hospitals	0.02 (−0.10 to 0.14)	−0.02 (−0.03 to 0.01)	−9.83 (−48.75 to 29.10)
Difference of change in trend following revision, teaching versus nonteaching hospitals	0.07 (−0.09 to 0.24)	−0.01 (−0.05 to 0.02)	−52.28 (−116.90 to −12.32)
Change in level following revision, teaching hospitals	−0.35 (−1.78 to 1.07)	−0.01 (−0.22 to 0.20)	317 (117 to 551)
Change in level following revision, nonteaching hospitals	−0.45 (−1.91 to 0.99)	−0.01 (−0.17 to 0.14)	−199 (−630 to 232)
Difference of change in level following revision, teaching versus nonteaching hospitals	0.10 (−1.93 to 2.14)	0.00 (−0.26 to 0.26)	516 (196 to 928)

Abbreviation: CI, confidence interval.

^a Bolded numbers represent statistically significant differences in the trends or levels. Levels noted in this table are measured immediately before and after ACGME rule implementation.

^b Mortality rate is measured as the number of deaths per 1000 hospitalizations each month adjusted for age, sex, and comorbidities.

^c Length of stay and hospitalization costs are measured in days and USD, respectively.

hospitalization costs after the 2011 revision (−62.11; 95% CI −113.68 to −10.55; $P = .019$). Hospitalization cost trends in nonteaching hospitals during the prerevision and postrevision periods were not statistically significant (TABLE 2). Compared with nonteaching hospitals, patients at teaching hospitals experienced a statistically significant downward trend over the ensuing 2 years after the 2011 revision (−52.29; 95% CI −162.90 to −12.32; $P = .011$; TABLE 2; FIGURE 2C). Immediately following the 2011 revision, there was an increase in hospitalization costs at teaching hospitals (317; 95% CI 117 to 551; $P = .003$), but not at nonteaching hospitals (−199; 95% CI −630 to 232; $P = .36$).

Additional analyses were undertaken to account for seasonality up to a lag of 12 for data in TABLE 2. The results of these repeated analyses did not change any of the reported findings.

Discussion

This analysis, utilizing information from a national database for time periods before and after the ACGME's 2011 duty hour revision, differs from prior research examining the impact of this mandate by comparing outcomes at all teaching hospitals to a

control group, representing all nonteaching hospitals. This approach, which analyzed data from millions of hospitalizations, reveals that mortality did not differ across the work hour revision periods at teaching hospitals or nonteaching hospitals. The interrupted time series component of the analysis was helpful to demonstrate the negligible changes in LOS at both teaching hospitals and nonteaching hospitals across the time periods in question. The nonteaching hospital control group made it apparent that minor cost savings seen at teaching hospitals were maintained across the 2-year period following the 2011 revision.

Many studies characterizing the consequences of duty hour revisions have explored the perspectives of various stakeholders, including residents, residency program directors, and teaching faculty.^{24–30} Other research delved into the economic impact of the changes—the ways in which the reduction in volume or capacity of the low-cost resident workforce had adversely impacted hospitals' margins.³¹ Some articles focused on errors and preventable adverse events associated with the increased number of handoffs attributed to shorter shifts.^{32–36} The analysis by Denson and colleagues³⁷ of a retrospective cohort of

adult patients admitted to a university-affiliated hospital across the 2011 revision actually described a trend toward higher all-cause in-hospital mortality; inferences about the implications of more resident handoffs were suggested as an explanation. Babu et al³⁸ used the NIS to evaluate the effect of the 2003 duty hour restrictions on hospitalized patients who underwent brain tumor and cerebrovascular procedures, and they concluded that the duty hour changes were associated with worse outcomes, namely higher complication rates. As noted in our results, the frequency of mortality is fortunately rather low, making it a fairly insensitive measure for detecting changes associated with staffing or workforce amendments. The large study population in our study provided ample power to look at mortality, and there were no statistically significant changes in the death rate with the implementation of the 2011 revision.

Several limitations of this study should be considered. First, due to the characterization of a hospital's teaching status generated by HCUP-NIS, it is possible that some hospitals with smaller training programs may have been misclassified. Second, data from teaching hospitals do not exclusively represent the effect of changes on the teaching services. Rather, it may be diluted by patients cared for on nonteaching services within these institutions.^{39,40} Third, it is possible in an observational study that unobserved or unmeasured variables may have influenced the results. While there are some distinguishing characteristics of nonteaching hospitals that make them an imperfect control group (such as size and region), this is the largest cohort for comparison. Picking only a subset of nonteaching hospitals to serve as the control group would have introduced other biases. Finally, it is impossible to know the extent to which teaching hospitals, training programs, and actual residents complied with the duty hour regulations.

The insights from our analyses may be useful for informing future revisions to residents' work hour standards. These findings also highlight the importance of control groups in observational studies, including medical education research. In hopes of realizing true reform, the next phase of research that explores the effect of the most recent 2017–2018 ACGME work hour revision will need to focus on clinical and educational outcomes.

Conclusion

Across the time periods before and after the 2011 ACGME duty hour revision was in effect, mortality rates and LOS did not change significantly between teaching and nonteaching hospitals. Teaching

hospitals, however, demonstrated a small decrease in hospitalization costs after the 2011 revision.

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