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Association of hospital volume with readmission rates: a retrospective cross-sectional study

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ABSTRACT

OBJECTIVE

To examine the association of hospital volume (a marker of quality of care) with hospital readmission rates.

DESIGN

Retrospective cross-sectional study.

SETTING

4651US acute care hospitals.

STUDY DATA

6 916 644 adult discharges, excluding patients receiving psychiatric or medical cancer treatment.

MAIN OUTCOME MEASURES

We used Medicare fee-for-service data from 1 July 2011 to 30 June 2012 to calculate observed-to-expected, unplanned, 30 day, standardized readmission rates for hospitals and for specialty cohorts medicine, surgery/gynecology, cardiorespiratory, cardiovascular, and neurology. We assessed the association of hospital volume by quintiles with 30 day, standardized readmission rates, with and without adjustment for hospital characteristics (safety net status, teaching status, geographic region, urban/rural status, nurse to bed ratio, ownership, and cardiac procedure capability. We also examined associations with the composite outcome of 30 day, standardized readmission or mortality rates.

RESULTS

Mean 30 day, standardized readmission rate among the fifth of hospitals with the lowest volume was 14.7 (standard deviation 5.3) compared with 15.9 (1.7) among the fifth of hospitals with the highest volume ($P < 0.001$). We observed the same pattern of lower readmission rates in the lowest versus highest volume hospitals in the specialty cohorts for medicine (16.6 v 17.4, $P < 0.001$), cardiorespiratory (18.5 v 20.5, $P < 0.001$), and neurology (13.2 v 14.0, $p = 0.01$) cohorts; the cardiovascular cohort, however, had an inverse association (14.6 v 13.7, $P < 0.001$). These associations remained after adjustment for hospital characteristics except in the cardiovascular cohort, which became non-significant, and the surgery/gynecology cohort, in which the lowest volume fifth of hospitals had significantly higher standardized readmission rates than the highest volume fifth (difference 0.63 percentage points (95% confidence interval 0.10 to 1.17), $P = 0.02$). Mean 30 day, standardized mortality or readmission rate was not significantly different between highest and lowest volume fifths (20.4 v 20.2, $P = 0.19$) and was highest in the middle fifth of hospitals (range 20.6–20.8).

CONCLUSIONS

Standardized readmission rates are lowest in the lowest volume hospitals—opposite from the typical association of greater hospital volume with better outcomes. This association was independent of hospital characteristics and was only partially attenuated by examining mortality and readmission together. Our findings suggest that readmissions are associated with different aspects of care than mortality or complications.

Introduction

There is a well established relationship between volume of work and outcomes in healthcare, particularly for surgery. High patient volume for practitioners or hospitals has been associated with reduced complications or mortality after numerous surgical procedures^{1–11} as well as some non-surgical conditions.^{12–14} As a result, the Leapfrog Group has advocated that patients be steered towards institutions with higher volume for certain procedures,¹⁵ and the Agency for Healthcare Research and Quality has created seven metrics of facility volume for major surgical procedures.^{16 17} The Centers for Medicare and Medicaid Services publicly reports these volume measures for US acute care hospitals to inform consumer choice.¹⁸

To date, only a few studies have examined the association of surgical volume with a different outcome: readmission. Of these, some have found that increased volume is associated with reduced readmission rates,^{19 21} but several have not.^{22 25} One study of patients with heart failure found that low volume hospitals had slightly higher readmission rates.²⁶ To our knowledge, there are no other studies of volume and readmission in medical patients.

Given the intense national focus on improving transitions in care coupled with continued uncertainty as to the best means of doing so, it is important to understand whether increased patient volume is associated with better performance on readmission rates. Higher hospital volume may be associated with lower readmission rates, as is the case for other outcomes. However, readmission represents a different (but overlapping) quality domain than mortality and complications, reflecting not only the technical quality and safety of inpatient care but attention to care transitions,²⁷ patient care strategies that address increased patient frailty after hospitalization,²⁸ and post-acute care coordination and follow-up.^{29 30} A high patient volume and turnover might impede the provision of high quality transitional care instead of facilitating better outcomes. Furthermore, since clinicians are often unaware of readmissions,³¹ institutions may not be able to improve

practice in response to readmissions in the same way they are able to respond to visible complications or inpatient mortality.³² It is also possible that the lower mortality rate of high volume hospitals produces more opportunity for surviving patients to be readmitted. Finally, effects might differ according to patient population. Increased patient volume might reduce readmission rates for surgical patients by increasing technical skill, because readmissions in these patients are often related to postoperative complications. Higher volume might not, however, promote better performance on transitional care for non-surgical patients. There are, therefore, several reasons to hypothesize that readmissions may not have the same relationship with volume as other outcomes such as complications and mortality.

Consequently, we examined the association between risk-standardized readmission rates and hospital volume for Medicare patients in order to determine whether there is a volume-outcome relationship for readmissions overall and for cohorts of patients by specialty.

Methods

Study data

We used 2010–12 Medicare inpatient claims data combined with the Medicare enrollment file to obtain data on discharges, risk adjustment variables, and outcomes.

Study cohort

For this analysis, we adopted the cohort definition of the publicly reported, hospital-wide, 30 day readmission measure.^{33–34} Briefly, we included all discharges between 1 July 2011 and 30 June 2012 from US short term acute care or critical access hospitals of patients who had Medicare fee-for-service insurance, were aged ≥ 65 years, and who were discharged alive, not against medical advice, and not transferred to another acute care hospital. We excluded patients admitted for medical treatment of cancer or primary psychiatric disease. In addition, we excluded patients without one year of prior enrollment in Medicare fee-for-service or without one month of post-discharge enrollment. Patients discharged from cancer hospitals exempt from fee-for-service were excluded from the measure. Multiple index admissions by the same patient could be included if each met eligibility criteria.

Outcome measure

Our primary outcome was based on the publicly reported, hospital-wide readmission measure. This measure assigns inpatients to one of five cohorts: medicine, surgery/gynecology, cardiorespiratory, cardiovascular, and neurology. Each cohort is modeled separately using hierarchical logistic regression to construct five standardized predicted-to-expected risk ratios, which are then pooled to create a single hospital metric.³⁵

The hierarchical models used by the publicly reported measure use shrinkage estimators which have the known property of weighting the predictions for smaller volume hospitals towards the mean. While that

approach is appropriate for public reporting of individual hospitals to avoid misclassifying small hospitals as outliers, this analysis examines small volume hospitals collectively and is specifically interested in determining performance of small volume hospitals. Consequently, to avoid shrinkage, we modified the publicly reported measure approach and calculated observed-to-expected risk ratios for each cohort instead of predicted-to-expected ratios.

The expected number of readmissions is calculated using a standard logistic regression model, accounting for clustering through generalized estimating equations, and adjusting for age, principal diagnosis, and 30 comorbidity indicators based on Part A claims—which include claims for hospital care, skilled nursing facility care, and hospice and home health services—during the year before admission. Comorbidities coded during the index hospitalization are also included if they were not likely to be in-hospital complications of care. Readmissions to any hospital are counted in the outcome. However, planned readmissions are excluded according to an algorithm that takes into account major procedures occurring during readmission and the principal diagnosis of the readmission.³⁶ We calculated the hospital-wide standardized readmission rate by obtaining the weighted mean of the cohort ratios, multiplied by the mean national readmission rate for ease of interpretation. Our secondary outcomes were the five specialty cohort ratios at each hospital, each multiplied by the mean national readmission rate for that cohort.

As another secondary analysis, we constructed predicted-to-expected ratios in accordance with the approach used in public reporting. The predicted and expected numbers of readmissions are calculated using hierarchical logistic regression models and the same risk variables as above; the calculation for the predicted number of readmissions includes a hospital-specific effect. We expected to see smaller differences between the lowest volume hospitals and the highest volume hospitals using this approach, given the known shrinkage towards the mean for small volume hospitals.

Finally, since mortality is often higher in low volume centers, potentially putting fewer patients at risk for readmission, we repeated the main analysis using a combined outcome of readmission or mortality to determine whether competing mortality risk explained any findings.

Independent variables

Our primary independent variable of interest was hospital volume, which we defined as the number of index admissions included in the measure. In this way we prevented a high readmission rate from biasing the volume categorization. For analysis, we excluded hospitals with fewer than 25 qualifying cases and then divided the remaining hospitals by quintiles into five groups based on each hospital's number of index discharges in 2010. In analyses of specialty cohorts, we categorized hospitals into volume fifths based on their number of discharges in each cohort. Thus a hospital might be in a

high volume group for one specialty cohort but a low volume group for a different specialty cohort.

We included eight hospital characteristics as covariates, identified from the 2010 American Hospital Association annual survey, that have been associated with readmission³⁷: safety net status (a public hospital or a private hospital with a Medicaid caseload more than one standard deviation above the state average for private hospitals³⁸), hospital ownership (not for profit, private, or public), teaching status (member of Council of Teaching Hospitals, minor teaching hospital, non-teaching), nurse-to-bed ratio (divided by quartiles), availability of cardiac procedures (capable of cardiac bypass surgery, capable only of cardiac catheterization, not capable of either), urban status (defined according to the National Center for Health Statistics classification³⁹), and geographic region (US Census Bureau division).

Statistical analysis

We calculated mean (standard deviation) and median (interquartile range) by volume fifth for the hospital-wide standardized readmission rate. We used linear regression to assess the volume effect on the overall standardized readmission rate, testing if other volume groups were significantly different from the highest volume group. We first assessed the volume effect without adjusting for any other hospital characteristics. We then repeated the linear regression analysis with the eight aforementioned hospital characteristics included to examine if the volume effect would be different after adjusting for hospital characteristics. To determine if any potential volume effect differed by specialty, we repeated the same analyses for each of the five specialty cohorts.

All analyses were conducted using SAS 9.2 (SAS Institute, Cary, NC). P values less than 0.05 are considered statistically significant, and all reported P values are two sided. The Yale University Investigational Review Board approved this study.

Results

Study cohort

The final sample included 6916 644 admissions to 4651 hospitals. The number of unplanned readmissions and admissions overall and in each specialty cohort, categorized by volume group, is shown in Table 1. Among the specialty cohorts, the largest was medicine, with over 2.8 million admissions from 4407 hospitals. The smallest was the neurology cohort, with 411 375 admissions from 2594 hospitals. The observed patient-level, 30 day readmission rate was 16.0%. Specialty cohort readmission rates ranged from a low of 11.7% in the surgery/gynecology cohort to a high of 20.4% in the cardiorespiratory group.

Observed results

A scatter plot of the hospital-level, observed, unplanned, 30 day readmission rate is shown in figure 1, panel (a). Means and standard deviations are shown in Table 1. The hospital-level observed readmission rate

increased as hospital volume increased, ranging from a low of 13.4% in the smallest volume group to a high of 16.3% in the second largest volume group. Specialty cohorts exhibited a similar positive association of volume with observed readmission rates, with the exception of the cardiovascular cohort, in which observed readmission rates declined as hospital volume increased.

Standardized results

A scatter plot of the hospital-wide standardized, unplanned, 30 day readmission rate is shown in figure 1, panel (b). The mean and standard deviation of hospital-wide and specialty cohort standardized, unplanned, 30 day readmission rates are shown in box and whisker form in figure 2 and in Table 1. The hospital-wide mean standardized readmission rate was 14.7% (standard deviation 5.3) in the smallest volume group and 15.9% (1.7) in the highest volume group, an absolute difference of 1.2 percentage points (95% confidence interval 0.9 to 1.5) (Table 2). Among the specialty cohorts, we observed the same pattern of significantly lower standardized readmission rate in the lowest versus the highest volume hospitals in the medicine, cardiorespiratory, and neurology cohorts. The cardiorespiratory cohort showed the largest association, with hospitals in the lowest volume group having standardized readmission rates that were on average 2.0 percentage points lower than those in the highest volume group (95% CI 1.5 to 2.5). In the cardiovascular cohort, however, the lowest volume hospitals had significantly higher standardized readmission rates (0.9 percentage points (95% CI 0.4 to 1.3)). There was no significant association in the surgery/gynecology cohort. Using predicted-to-expected readmission ratios instead of observed-to-expected ratios yielded similar although much smaller differences (appendix A).

Adjustment for hospital characteristics

After adjustment for hospital safety net status, ownership, teaching status, cardiac procedure capability, nurse-to-bed ratio, urban/rural status, and geographic region, the differences between high and low volume hospitals were larger overall and in the medicine, cardiorespiratory, and neurology cohorts (Table 2). Hospitals in the lowest volume group had a hospital-wide mean, adjusted, standardized readmission rate 1.6 percentage points lower than hospitals in the highest volume group (95% CI 1.1 to 2.0). The largest difference was still in the cardiorespiratory cohort, in which the lowest volume fifth of hospitals had an adjusted standardized readmission rate 3.0 points lower than the highest volume group (95% CI 2.3 to 3.7). After adjustment for hospital characteristics, there was no longer an association between hospital volume and outcome in the cardiovascular cohort, but the smallest volume hospitals in the surgery/gynecology cohort had a significantly higher standardized readmission rate than the largest hospitals (difference 0.6 percentage points (95% CI 0.1 to 1.2)). Full model coefficients for all cohorts are shown in appendix B.

Table 1 | Hospital volume (hospitals divided by quintiles based on hospital's number of index discharges in 2010) and associated 30 day readmission rate (observed and standardized), by specialty cohort

Volume group (No of index discharges)	No of hospitals	No of index discharges	No of readmissions	Mean (SD) readmission rate (%)	
				Observed	Standardized
Hospital-wide					
Excluded (<25 per hospital)	158	1 823	205	N/A	N/A
A (25 to 173)	932	91 298	12 517	13.4 (5.5)	14.7 (5.3)
B (173 to 423)	930	266 303	39 465	14.8 (4.5)	15.6 (3.5)
C (423 to 1108)	929	649 751	102 357	15.7 (4.0)	15.8 (2.8)
D (1108 to 2595)	930	1 643 144	267 695	16.3 (3.1)	16.0 (2.1)
E (2595 to 25 002)	930	4 266 148	683 139	16.0 (2.4)	15.9 (1.7)
Total included	4 651	6 916 644	1 105 173	15.3 (4.2)	15.6 (3.4)
Medicine cohort					
Excluded (<25 per hospital)	347	3 673	456	N/A	N/A
A (25 to 99)	886	53 715	7 819	14.3 (5.9)	16.6 (6.3)
B (99 to 218)	883	134 386	20 708	15.3 (4.0)	17.1 (4.2)
C (218 to 534)	876	306 460	51 315	16.6 (3.6)	17.3 (3.2)
D (534 to 1124)	881	703 463	122 578	17.4 (2.9)	17.3 (2.4)
E (1124 to 11 380)	881	1 683 550	300 256	17.7 (2.4)	17.4 (1.9)
Total included	4 407	2 881 574	502 676	16.3 (4.1)	17.2 (3.9)
Surgery/gynecology cohort					
Excluded (<25 per hospital)	840	7 499	836	N/A	N/A
A (25 to 79)	666	32 088	3 408	10.5 (6.0)	11.3 (5.7)
B (79 to 186)	648	83 694	9 380	11.2 (4.9)	11.5 (3.7)
C (186 to 389)	660	184 435	21 043	11.4 (3.9)	11.5 (2.7)
D (389 to 792)	654	370 011	43 590	11.8 (3.2)	11.6 (2.1)
E (792 to 6389)	655	933 971	110 885	11.8 (2.5)	11.5 (1.7)
Total included	3 283	1 604 199	188 306	11.3 (4.3)	11.5 (3.5)
Cardiorespiratory cohort					
Excluded (<25 per hospital)	466	5 956	841	N/A	N/A
A (25 to 68)	844	37 723	6 064	15.9 (6.8)	18.5 (7.6)
B (68 to 133)	827	80 934	14 579	18.0 (5.3)	19.7 (5.3)
C (133 to 252)	832	155 497	30 919	19.8 (4.5)	20.5 (4.1)
D (252 to 458)	836	290 356	60 357	20.7 (3.9)	20.7 (3.4)
E (458 to 3068)	831	608 747	127 763	21.0 (3.1)	20.5 (2.5)
Total included	4 170	1 173 257	239 682	19.1 (5.2)	20.0 (5.0)
Cardiovascular cohort					
Excluded (<25 per hospital)	1 579	15 990	2 310	N/A	N/A
A (25 to 50)	593	20 962	3 117	14.9 (6.8)	14.6 (6.4)
B (50 to 120)	588	47 098	7 048	15.0 (5.0)	14.5 (4.5)
C (120 to 237)	587	102 434	14 835	14.6 (3.7)	14.1 (3.1)
D (237 to 441)	589	193 358	26 970	14.0 (2.9)	13.7 (2.4)
E (441 to 3361)	588	432 445	59 255	13.8 (2.3)	13.7 (1.9)
Total included	2 945	796 297	111 225	14.5 (4.5)	14.1 (4.0)
Neurology cohort					
Excluded (<25 per hospital)	1 917	18 647	2 239	N/A	N/A
A (25 to 44)	532	17 724	2 241	12.6 (6.7)	13.2 (6.9)
B (44 to 84)	508	31 903	4 251	13.3 (4.8)	13.6 (4.8)
C (84 to 141)	520	57 627	7 734	13.5 (4.0)	13.6 (3.8)
D (141 to 249)	518	98 675	13 431	13.6 (3.2)	13.6 (3.0)
E (249 to 1429)	516	205 446	29 150	14.1 (2.6)	14.0 (2.3)
Total included	2 594	411 375	56 807	13.4 (4.5)	13.6 (4.5)

Combined readmission and mortality outcome

The lowest volume and highest volume groups of hospitals were not significantly different in hospital-wide readmission or mortality (20.4% v 20.2%, $P = 0.19$), whereas the middle volume fifth of hospitals had significantly higher standardized mortality or readmission rates (range 20.6% to 20.8%) (see Table 3). Among the specialty cohorts, hospitals in the lowest volume group had significantly higher combined outcome rates in the medicine and cardiovascular cohorts, but significantly

lower combined outcome rates in the cardiorespiratory cohort. There was no significant difference between highest and lowest volume hospitals in the surgery/gynecology or neurology cohorts.

Discussion

Principal findings

We examined the association of hospital volume with standardized readmission rate and found that, overall, hospitals with the lowest volume had lower

Fig 1 | Scatter plots of hospital-wide unplanned, 30 day readmission rate by hospital volume: (a) observed rate, (b) standardized rate

standardized readmission rates than those with the highest volume. Within individual specialty cohorts, the only exception was the cardiovascular cohort, in which hospitals with the lowest volume had the highest standardized readmission rates. After accounting for hospital characteristics, hospitals with the lowest volume still had the lowest readmission rates and the inverse association in the cardiovascular cohort no longer existed, though a small inverse association developed in the surgery/gynecology cohort.

Our findings suggest that readmission does not perform in the same way as mortality or complications in its association with hospital volume. Readmissions are often precipitated by acute exacerbations of chronic disease, persistence of the initial problem, or increased frailty.²⁸ It is possible that the risk of these events may be reduced by more time and effort spent in educating patients, conducting high quality medication reconciliation, following up after discharge, and other activities that do not necessarily improve with greater patient volume and may even worsen if higher patient volume is associated with more turnover, more complicated team structure, or less time spent with each patient.

The competing risk of mortality also seems to play some role. Though the smallest hospitals still

*Hospitals divided by quintiles based on hospital's number of index discharges in 2010; group A lowest volume fifth, group E highest volume fifth

Fig 2 | Distribution of standardized readmission rate, by hospital volume group and specialty cohort

Table 2 | Bivariate and multivariate associations of hospital volume* with standardized readmission rate: absolute differences in readmission rates compared with highest volume fifth of hospitals by specialty cohort

Volume group*	Unadjusted difference in readmission rates		Adjusted difference in readmission rates†	
	Difference (95% CI)	P value	Difference (95% CI)*	P value
Hospital-wide				
A	−1.16 (−1.46 to −0.85)	<0.0001	−1.56 (−2.03 to −1.08)	<0.0001
B	−0.29 (−0.59 to 0.02)	0.07	−0.72 (−1.16 to −0.28)	0.001
C	−0.08 (−0.39 to 0.23)	0.61	−0.53 (−0.93 to −0.13)	0.01
D	0.14 (−0.17 to 0.44)	0.38	0.06 (−0.27 to 0.39)	0.73
E	Reference	—	Reference	—
Medicine cohort				
A	−0.76 (−1.13 to −0.39)	<0.0001	−1.41 (−1.96 to −0.85)	<0.0001
B	−0.28 (−0.65 to 0.08)	0.13	−0.99 (−1.51 to −0.47)	0.0002
C	−0.06 (−0.43 to 0.30)	0.73	−0.67 (−1.13 to −0.21)	0.004
D	−0.06 (−0.43 to 0.30)	0.74	−0.25 (−0.64 to 0.14)	0.22
E	Reference	—	Reference	—
Surgery/gynecology cohort				
A	−0.20 (−0.58 to 0.17)	0.29	0.63 (0.10 to 1.17)	0.02
B	−0.04 (−0.41 to 0.34)	0.86	0.66 (0.16 to 1.16)	0.01
C	−0.02 (−0.39 to 0.36)	0.93	0.49 (0.04 to 0.94)	0.03
D	0.03 (−0.35 to 0.41)	0.88	0.36 (−0.04 to 0.76)	0.08
E	Reference	—	Reference	—
Cardiorespiratory cohort				
A	−2.01 (−2.48 to −1.54)	<0.0001	−3.01 (−3.68 to −2.34)	<0.0001
B	−0.78 (−1.25 to −0.31)	0.001	−1.81 (−2.42 to −1.20)	<0.0001
C	0.01 (−0.46 to 0.49)	0.96	−0.84 (−1.39 to −0.29)	0.003
D	0.12 (−0.35 to 0.60)	0.61	−0.21 (−0.69 to 0.28)	0.40
E	Reference	—	Reference	—
Cardiovascular cohort				
A	0.86 (0.40 to 1.32)	0.0002	−0.57 (−1.21 to 0.07)	0.08
B	0.73 (0.27 to 1.18)	0.002	−0.13 (−0.70 to 0.44)	0.66
C	0.36 (−0.10 to 0.81)	0.13	0.03 (−0.49 to 0.54)	0.92
D	0.01 (−0.45 to 0.47)	0.97	−0.05 (−0.51 to 0.41)	0.82
E	Reference	—	Reference	—
Neurology cohort				
A	−0.73 (−1.27 to −0.19)	0.01	−0.87 (−1.59 to −0.16)	0.02
B	−0.33 (−0.88 to 0.21)	0.23	−0.35 (−0.99 to 0.29)	0.29
C	−0.41 (−0.96 to 0.13)	0.14	−0.23 (−0.82 to 0.35)	0.44
D	−0.34 (−0.88 to 0.21)	0.22	−0.15 (−0.70 to 0.39)	0.58
E	Reference	—	Reference	—

*Hospitals divided by quintiles based on hospital's number of index discharges in 2010; group A is lowest volume fifth, group E is highest volume fifth.
†Adjusted for hospital safety net status, ownership, teaching status, cardiac procedure capability, urban/rural status, geographic region, and nurse-to-bed ratio (see text for details).

performed as well overall as the largest hospitals in a combined outcome of mortality or readmission, the smallest hospitals did have the highest combined outcome rate in two specialty cohorts. Of note, the difference was not explained by hospital characteristics—such as teaching status, urban location, public ownership, or safety net status—that might be associated with hospital volume and with readmission rates. In fact, adjustment increased the size of the effect.

The findings that only the procedure-heavy cohorts demonstrated the typical association of higher volume with better outcomes may be a consequence of the causes of readmissions in these cohorts. Readmissions after major procedures are often related to procedural complications,⁴⁰ and higher volume centers produce fewer complications. Higher volume centers may also be more experienced at encouraging appropriate post-discharge care such as rehabilitation or home care services. It is notable that adjustment for hospital

characteristics such as presence of advanced cardiac capability eliminated the association in the cardiovascular cohort, suggesting there may be a causal relationship between structural hospital characteristics and readmission risk in the cardiovascular group.

Comparison with other studies

Our findings are similar to those from some studies of surgery volume and readmissions, which found no association of surgical volume and readmissions.^{22 25} Our results are also consistent with a recent study by Tsai et al of six surgical procedures, in which high volume centers had lower readmission rates after adjustment for hospital characteristics.²¹ Like Tsai et al, we found that high volume centers in our surgery/gynecology cohort had significantly lower readmission rates than lower volume centers after adjustment for hospital characteristics—though we did not find this association without adjusting for hospital characteristics. Our

Table 3 | Mean and median standardized mortality or readmission rate, hospital-wide and by specialty cohort, by hospital volume*

Volume group*	No of hospitals	Standardized mortality or readmission rate (%)		Absolute difference in readmission rates†	
		Mean (SD)	Median (IQR)	Parameter estimate (95% CI)	P value
Hospital-wide					
A	932	20.4 (6.1)	20.5 (16.7 to 24.1)	0.22 (−0.11 to 0.56)	0.19
B	930	20.8 (3.8)	20.7 (18.4 to 23.4)	0.61 (0.27 to 0.95)	0.0004
C	929	20.6 (2.9)	20.5 (18.7 to 22.3)	0.36 (0.02 to 0.70)	0.037
D	930	20.6 (2.2)	20.5 (19.2 to 22.0)	0.34 (0.00 to 0.68)	0.047
E	930	20.2 (1.7)	20.2 (19.1 to 21.3)	Reference	—
Overall	4651	20.5 (3.7)	20.4 (18.7 to 22.4)		
Medicine cohort					
A	886	23.6 (7.2)	23.5 (18.8 to 27.9)	0.88 (0.47 to 1.28)	<0.0001
B	883	23.6 (4.6)	23.4 (20.5 to 26.6)	0.83 (0.42 to 1.23)	<0.0001
C	876	23.2 (3.4)	23.0 (20.8 to 25.3)	0.40 (−0.01 to 0.80)	0.057
D	881	23.0 (2.5)	22.9 (21.3 to 24.6)	0.20 (−0.21 to 0.61)	0.33
E	881	22.8 (1.9)	22.7 (21.5 to 24.0)	Reference	—
Overall	4407	23.2 (4.4)	23.0 (20.9 to 25.3)		
Surgery/gynecology cohort					
A	666	13.5 (6.1)	13.1 (9.1 to 16.7)	0.11 (−0.29 to 0.51)	0.59
B	648	13.6 (3.9)	13.5 (10.8 to 16.2)	0.29 (−0.11 to 0.70)	0.15
C	660	13.5 (2.8)	13.4 (11.7 to 15.4)	0.18 (−0.22 to 0.58)	0.39
D	654	13.6 (2.3)	13.6 (12.1 to 15.1)	0.21 (−0.19 to 0.61)	0.31
E	655	13.3 (1.7)	13.3 (12.3 to 14.4)	Reference	—
Overall	3283	13.5 (3.7)	13.4 (11.5 to 15.4)		
Cardiorespiratory cohort					
A	844	25.6 (8.4)	25.0 (19.8 to 30.9)	−0.54 (−1.04 to −0.03)	0.037
B	827	26.3 (5.5)	25.9 (22.6 to 29.8)	0.19 (−0.31 to 0.70)	0.45
C	832	26.6 (4.2)	26.4 (23.8 to 29.1)	0.46 (−0.05 to 0.97)	0.076
D	836	26.4 (3.5)	26.1 (24.0 to 28.8)	0.23 (−0.28 to 0.74)	0.38
E	831	26.1 (2.6)	26.0 (24.3 to 27.8)	Reference	—
Overall	4170	26.2 (5.3)	26.0 (23.4 to 28.9)		
Cardiovascular cohort					
A	593	18.6 (6.9)	18.3 (14.0 to 22.7)	2.55 (2.07 to 3.02)	<0.0001
B	588	17.5 (4.6)	17.6 (14.4 to 20.6)	1.46 (0.98 to 1.94)	<0.0001
C	587	16.9 (3.1)	16.7 (14.6 to 19.0)	0.82 (0.34 to 1.30)	0.0008
D	589	16.2 (2.5)	16.1 (14.6 to 17.8)	0.12 (−0.36 to 0.60)	0.62
E	588	16.1 (2.0)	16.0 (14.7 to 17.4)	Reference	—
Overall	2945	17.1 (4.3)	16.6 (14.6 to 19.1)		
Neurology cohort					
A	532	21.4 (7.5)	21.0 (16.2 to 25.9)	0.27 (−0.33 to 0.87)	0.38
B	508	21.3 (5.6)	21.3 (17.8 to 24.9)	0.16 (−0.45 to 0.77)	0.61
C	520	20.9 (4.0)	20.6 (18.3 to 23.8)	−0.25 (−0.86 to 0.35)	0.42
D	518	21.0 (3.5)	20.7 (18.3 to 23.4)	−0.17 (−0.78 to 0.43)	0.58
E	516	21.1 (2.7)	21.0 (19.2 to 22.8)	Reference	—
Overall	2594	21.1 (5.0)	20.9 (18.2 to 23.9)		

*Hospitals divided by quintiles based on hospital's number of index discharges in 2010; group A is lowest volume fifth, group E is highest volume fifth.

†Difference in readmission rates (in percentage points) compared with highest volume fifth of hospitals.

study differs, however, in that it includes non-surgical patients. Indeed, we noted quite different associations of hospital volume and outcomes in other patient populations.

Strengths and limitations of study

A strength of this study is that we included only unplanned readmissions; this is particularly important given that larger centers are likely to conduct more planned readmissions for surgical procedures or chemotherapy. Moreover, this is the first study to examine all patients, rather than single diseases or specialties. None the less, our study has several limitations. We looked only at patients aged 65 years and over; results

may differ in younger populations. We used administrative data for risk adjustment, which might not fully capture acuity of illness at high volume centers. Moreover, although we accounted for safety net status, there may have been unmeasured non-clinical risk factors that are associated both with readmission risk and with hospital volume. It is notable, however, that the relationship between high volume and better outcome for mortality and complications has been repeatedly demonstrated in studies that use similar claims-based risk adjustment as in this study, suggesting our results are unlikely to be driven by unmeasured confounding. We include all admissions per patient, potentially creating a bias against hospitals with disproportionate numbers of

frequently admitted patients. Finally, we did not analyze the data on the level of individual procedures or diagnoses; results may differ for individual conditions.

Conclusions

Overall, we found that high volume centers have higher standardized unplanned readmission rates, except in procedure-heavy cohorts of patients. These effects were not explained by hospital characteristics and were only partially attenuated by considering both mortality and readmission as outcomes. As hospitals work to reduce readmissions, it may be helpful to explore reasons smaller hospitals have had more success at avoiding readmissions for non-procedural specialties than larger hospitals.

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