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

4651 US acute care hospitals.

STUDY DATA

6916444 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 network 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, as well as some non-surgical conditions. As a result, the Leapfrog Group has advocated that patients be steered towards institutions with higher volume for certain procedures, and the Agency for Healthcare Research and Quality has created seven metrics of facility volume for major surgical procedures. The Centers for Medicare and Medicaid Services publicly reports these volume measures for US acute care hospitals to inform consumer choice.

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, but several have not. One study of patients with heart failure found that low volume hospitals had slightly higher readmission rates. 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, patient care strategies that address increased patient frailty after hospitalization, and post-acute care coordination and follow-up. 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, 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. 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. 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.

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. 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 covari-
ates, identified from the 2010 American Hospital Asso-
ciation annual survey, that have been associated with 
readmission\textsuperscript{2}: safety net status (a public hospital or a
private hospital with a Medicaid caseload more than
one standard deviation above the state average for pri-
vate hospitals\textsuperscript{38}), 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 car-
diac bypass surgery, capable only of cardiac catheterization, not capable of either), urban status
(defined according to the National Center for Health
Statistics classification\textsuperscript{39}), and geographic region (US
Census Bureau division).

Statistical analysis
We calculated mean (standard deviation) and median
(interquartile range) by volume fifth for the hospi-
tal-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 vol-
ume 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
evaluate 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 Insti-
tute, 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 6,916,644 admissions to 4,651
hospitals. The number of unplanned readmissions and
admissions overall and in each specialty cohort, cate-
gorized by volume group, is shown in Table 1. Among
the specialty cohorts, the largest was medicine, with
over 2.8 million admissions from 4,407 hospitals. The
smallest was the neurology cohort, with 411,375 admis-
sions from 259 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 sur-
gery/gynecology cohort to a high of 20.4% in the cardio-
respiratory 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 vol-
ume with observed readmission rates, with the excep-
tion of the cardiovascular cohort, in which observed
readmission rates declined as hospital volume in-
creased.

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 hospit-
al-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 3.3) in the smallest volume group and 15.9%
(1.7) in the highest volume group, an absolute differ-
ence 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 stan-
dardized readmission rate in the lowest versus the high-
est 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 sur-
gery/gynecology cohort. Using predicted-to-expected
readmission ratios instead of observed-to-expected
ratios yielded similar although much smaller differ-
ences (appendix A).

Adjustment for hospital characteristics
After adjustment for hospital safety net status, owner-
ship, 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, car-
diorespiratory, and neurology cohorts (Table 2). Hospi-
tals in the lowest volume group had a hospital-wide
mean, adjusted, standardized readmission rate 1.6 per-
cent 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 stan-
dardized readmission rate 3.0 points lower than the highest
volume group (95% CI 2.3 to 3.7). After adjust-
ment 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 sig-
nificantly 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.
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% vs 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...
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. 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

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

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

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

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**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† | P value | P value |
|---------------|-------------------------------------------|----------------------------------------|---------|---------|
|               | Difference (95% CI)                        | Difference (95% CI)                    |         |         |
|               |                                       |                                       |         |         |
| Hospital-wide | -1.16 (-1.46 to -0.85)                    | <0.0001                               | -1.56 (-2.03 to -1.08) | <0.0001 |
|               | -0.29 (-0.59 to 0.02)                     | 0.07                                  | -0.72 (-1.16 to -0.28) | 0.001   |
|               | 0.08 (-0.39 to 0.23)                      | 0.61                                  | -0.53 (-0.93 to -0.13) | 0.01    |
|               | 0.14 (-0.17 to 0.44)                      | 0.38                                  | 0.06 (-0.27 to 0.39)  | 0.73    |
| E             | Reference                                 | Reference                             | Reference| Reference|

| Medicine cohort | -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                             | Reference| Reference|

| Surgery/gynecology cohort | -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                             | Reference| Reference|

| Cardiorespiratory cohort | -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                             | Reference| Reference|

| Cardiovascular cohort | 0.86 (0.60 to 1.12)                     | 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                             | Reference| Reference|

| Neurology cohort | -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                             | 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).
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† | Parameter estimate (95% CI) | P value |
|---------------|-----------------|---------------------------------------------|----------------------------------------|---------------------------|---------|
|               |                 | Mean (SD) | Median (IQR) |                                |                                |         |
| 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 (6.6) | 23.4 (20.5 to 26.6) | 0.83 (0.42 to 1.23) | <0.0001 |
| C             | 876             | 23.2 (5.4) | 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             | 668             | 13.6 (3.9) | 13.5 (10.8 to 16.2) | 0.29 (−0.11 to 0.70) | 0.15 |
| C             | 660             | 13.5 (2.6) | 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 (2.7) | 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 (3.0) | 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.

The 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 admissions.

Table 3 | Mean and median standardized mortality or readmission rate, hospital-wide and by specialty cohort, by hospital volume*
frequently admitted patients. Finally, we did not ana-
lyze 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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