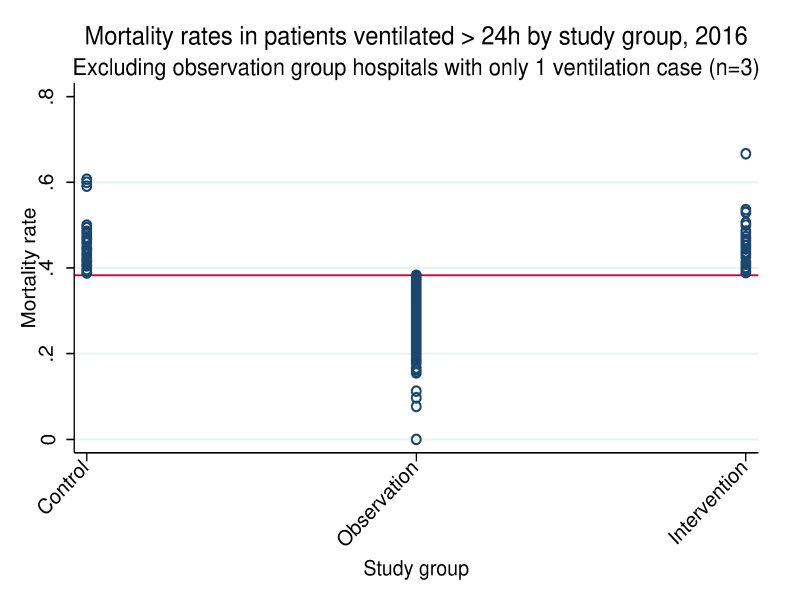
Effect of clinical peer review on mortality in patients ventilated >24h: cluster-randomized controlled trial

Descriptive statistics

The raw mortality rates in 2016 were used to select the hospitals allocated to the intervention and control group. As shown by the figure below, the 60 intervention and control group hospitals in our sample were characterized by the highest mortality rates in this period (3 observation group hospitals with only 1 patient ventilated for more than 24 hours in this period were excluded). Note that the red line indicates the highest observed mortality rate in the observation group. Minimum, maximum, and average mortality rates are shown in the table below.



Raw mortality rates by study group in 2016

Group	Mean	Min	Max
Control	45.37%	38.84%	60.71%
Observation	27.86%	0.00%	38.30%
Intervention	45.57%	38.92%	66.67%

Due to a merger of one control group hospital and an observation group hospital, the following analyses relied on data from 29 control and 30 intervention group hospitals. In total, the 59 intervention and control group hospitals recorded 25101 cases of patients ventilated for more than 24 hours during the observation period. The number of cases by group (intervention/control) and by study period (pre/post intervention) is shown in the table below.

Number of cases by study group and study period

Group	Pre intervention	Post intervention
Control	6586	6430
Intervention	6038	6047

As shown by the following tables, the age and sex distribution in the two study groups was similar.

Number and share of cases by sex and study group

Sex	n Control	Percent Control	n Intervention	Percent Intervention
male	7846	60.28%	7347	60.79%
female	5170	39.72%	4738	39.21%

Schmitt J, *et al. BMJ Qual Saf* 2022;0:1–9. doi: 10.1136/bmjqs-2021-013864

Number and share of cases by age group and study group

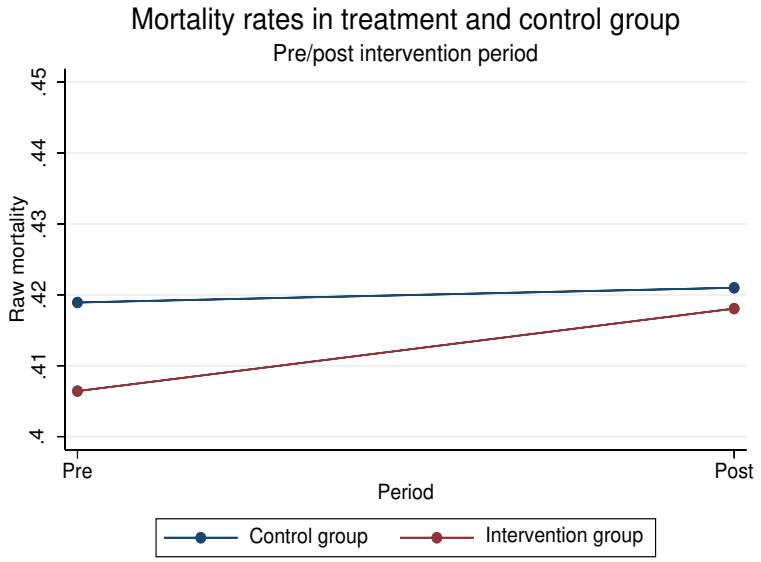
Age	n Control	Percent Control	n Intervention	Percent Intervention
< 1 years	150	1.15%	114	0.94%
1 to <= 5 years	127	0.98%	89	0.74%
5 to <= 10 years	56	0.43%	30	0.25%
10 to <= 15 years	63	0.48%	17	0.14%
15 to <= 20 years	72	0.55%	53	0.44%
20 to <= 25 years	70	0.54%	70	0.58%
25 to <= 30 years	93	0.71%	84	0.7%
30 to <= 35 years	172	1.32%	110	0.91%
35 to <= 40 years	191	1.47%	134	1.11%
40 to <= 45 years	223	1.71%	205	1.7%
45 to <= 50 years	407	3.13%	371	3.07%
50 to <= 55 years	805	6.18%	689	5.7%
55 to <= 60 years	1116	8.57%	998	8.26%
60 to <= 65 years	1394	10.71%	1245	10.3%
65 to <= 70 years	1504	11.56%	1549	12.82%
70 to <= 75 years	1592	12.23%	1502	12.43%
75 to <= 80 years	2173	16.69%	2160	17.87%
80 to <= 85 years	1715	13.18%	1717	14.21%
85 to <= 90 years	860	6.61%	754	6.24%
>= 90 years	233	1.79%	194	1.61%

The ventilation cases included in the confirmatory analysis were characterized by diverse main diagnoses. The table below shows the 10 most frequent ICD-3 codes and the number and share of cases for whom these codes were recorded.

Most frequent main diagnoses (ICD-3 codes)

ICD3	Description	n	Percent
J44	Other chronic obstructive pulmonary disease	1801	7.18%
A41	Other Sepsis	1380	5.50%
I50	Cardiac insufficiency	1294	5.16%
I21	Acute myocardial Infarction	1172	4.67%
J18	Pneumonia, pathogen not described in more detail	999	3.98%
I63	Cerebral infarction	905	3.61%
S06	Intracranial injury	742	2.96%
J15	Pneumonia caused by bacteria, not classified elsewhere	695	2.77%
I61	Intracerebral hemorrhage	670	2.67%
J96	Respiratory insufficiency, not classified elsewhere	468	1.86%

The following figure shows the raw mortality rates in the treatment and the control group before and after the intervention. The mortality rate was marginally higher in the control group prior to the intervention. While the mortality rate was higher in the post-treatment compared to the pre-treatment period in both groups, the increase was stronger in the intervention group. The absolute numbers of in-hospital deaths by study group and period are shown in the table below.



Number of in-hospital deaths and cases by study group and period

Group	Deaths pre	n pre	Deaths post	n post
Control	2759	6586	2707	6430
Intervention	2454	6038	2528	6047

Sensitivity analyses

Comparison of changes in raw mortality rates

Analogous to the WLS estimation based on SMRs, differences in the raw mortality rate changes between the groups were examined. The results are shown in the table below. Similar to the results obtained from the SMRs, there was a positive coefficient of the intervention group dummy, which was not significant at the 5% level. Hence, the raw mortality rates also did not indicate an effect of the IQM peer review.

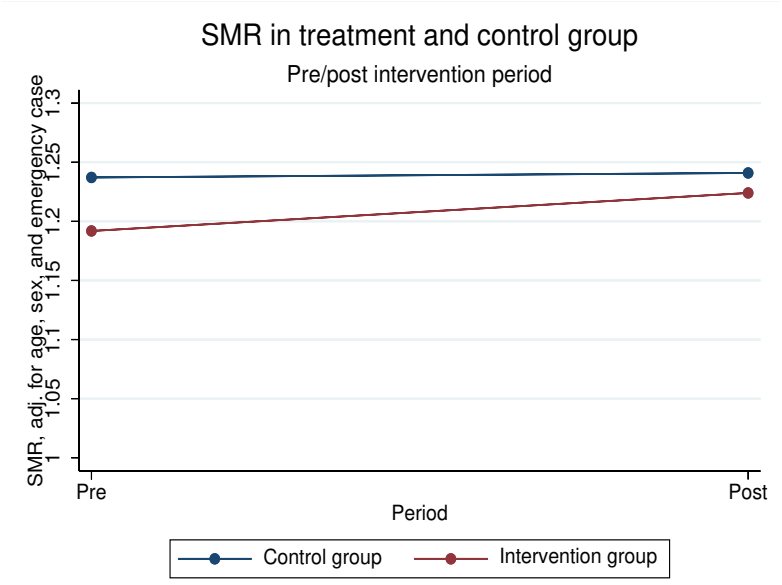
Results of WLS regression. Dependent variable: Change in raw mortality rate. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	1.310033	1.434328	0.91	0.365	-1.56216	4.182226

Number of hospitals = 59

Additional adjustment for admission as emergency case

Another sensitivity analysis used emergency case admission as an additional risk adjustment factor in the calculation of the SMRs. The following figure illustrates the SMRs based on age, sex, and emergency case admission. Results remained qualitatively unchanged.



The results of the WLS regression for the emergency case adjusted SMRs are shown in the table below. There was no significant difference between the study groups.

Results of WLS regression. Dependent variable: Change in SMR, adj. for age, sex, and admission as emergency case. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Interven-tion	.035658	.0440514	0.81	0.422	-.0525534	.1238694

Number of hospitals = 59

Alternative splitting date for the definition of pre and post-treatment period used for the control group

The table below shows that all peer reviews regarding ventilation were conducted after July 1, 2017 in the intervention group hospitals, which served as the date to split pre and post-treatment period for the control group hospitals. To test the robustness of the results with respect to the splitting date, the median review date of the intervention group (September 28, 2017) was used as alternative splitting date for the control group. The results of the WLS estimations using the age and sex adjusted SMRs are shown below. Qualitatively, results remained unchanged.

Number of conducted IQM peer reviews by date

Date	Number of conducted peer reviews
13Jul2017	1
02Aug2017	1
09Aug2017	1
17Aug2017	2
30Aug2017	2
31Aug2017	1
06Sep2017	1
07Sep2017	2
13Sep2017	1
20Sep2017	1
25Sep2017	1
26Sep2017	1
28Sep2017	1
29Sep2017	1
05Oct2017	1
10Oct2017	2
12Oct2017	1
13Oct2017	1
17Oct2017	1
18Oct2017	1
20Oct2017	2
26Oct2017	1
02Nov2017	1
09Nov2017	1
13Nov2017	1

Results of WLS regression with new splitting date for the control group. Dependent variable: Change in raw mortality rate. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	.0530898	.0453585	1.17	0.247	-.037739	.1439186

Number of hospitals = 59

Analysis by admission reason

The confirmatory analysis was also conducted for different admission reasons. For this purpose, patients admitted as emergency case, patients transferred from other hospitals and patients admitted for other reasons were considered separately.

The WLS results for emergency cases are shown in the table below. Since some hospitals did not record ventilations patients admitted as emergency case, this analysis included 27 hospitals of the control group and 23 hospitals of the intervention group. There was no evidence for an effect of the IQM peer review.

Results of WLS regression for emergency cases. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	.0497808	.049347	1.01	0.318	-.0494381	.1489997

Number of hospitals = 50

The WLS results for patients transferred from other hospitals are shown in the table below. Since some hospitals did not record ventilations patients transferred from other hospitals, this analysis included 25 hospitals of the control group and 28 hospitals of the intervention group. There was no evidence for an effect of the IQM peer review.

Results of WLS regression for patients transferred from other hospitals. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	.0362292	.0794554	0.46	0.650	-.1232843	.1957427

Number of hospitals = 53

The WLS results for patients transferred from other hospitals are shown in the table below. Since some hospitals did not record ventilations patients transferred from other hospitals, this analysis included 28 hospitals of the control group and 30 hospitals of the intervention group. There was no evidence for an effect of the IQM peer review.

Results of WLS regression for cases with other admission reasons. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	.0382487	.0665884	0.57	0.568	-.0951438	.1716412

Number of hospitals = 58

Analyses for ventilation patients with secondary outcomes

The confirmatory analysis was conducted separately for ventilation patients with one of the secondary outcomes of the IMPRESS study. The table below shows the number of ventilation cases with secondary outcome by study group.

Number of ventilation cases with secondary outcome by study group

Group	Myocardial infarction	Stroke	Pneumonia	COPD	Colorectal resection
Control	566	1123	987	792	133
Intervention	606	785	962	955	143

The mortality rates in ventilation patients with secondary outcome are shown in the following table.

Mortality rates in ventilation patients with secondary outcomes

Secondary outcome	Mortality	n
COPD	25.24%	1747
Pneumonia	34.74%	1949
Colorectal resection	36.96%	276
Myocardial infarction	44.97%	1172
Stroke	46.17%	1908

<u>Myocardial infarction</u>

The number of hospitals treating ventilation patients with myocardial infarction was 23 in the control group and 20 in the intervention group. The results of the WLS regressions are shown below. There was no evidence for an effect of the IQM peer review in this subpopulation.

Results of WLS regression for ventilation cases with myocardial infarction. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	.0210472	.177748	0.12	0.906	-.3379221	.3800166

Number of hospitals = 43

Stroke

The number of hospitals treating ventilation patients with stroke was 18 in the control group and 13 in the intervention group. The results of the WLS regressions are shown below. There was no evidence for an effect of the IQM peer review in this subpopulation.

Results of WLS regression for ventilation cases with stroke. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	-.0309109	.1354727	-0.23	0.821	-.3079838	.2461619

Number of hospitals = 31

Pneumonia

The number of hospitals treating ventilation patients with pneumonia was 29 in the control group and 29 in the intervention group. The results of the WLS regressions are shown below. There was no evidence for an effect of the IQM peer review in this subpopulation.

Results of WLS regression for ventilation cases with pneumonia. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	.067967	.1333949	0.51	0.612	-.1992551	.3351891

Number of hospitals = 58

COPD

The number of hospitals treating ventilation patients with COPD was 29 in the control group and 29 in the intervention group. The results of the WLS regressions are shown below. There was no evidence for an effect of the IQM peer review in this subpopulation.

Results of WLS regression for ventilation cases with COPD. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	.0236111	.1003098	0.24	0.815	-.1773336	.2245557

Number of hospitals = 58

Colorectal resection

The number of hospitals treating ventilation patients with colorectal resection was 19 in the control group and 20 in the intervention group. The results of the WLS regressions are shown below. There was no evidence for an effect of the IQM peer review in this subpopulation.

Results of WLS regression for ventilation cases with colorectal resection. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Interven-tion	.4295112	.3321328	1.29	0.204	-.2434539	1.102476

Number of hospitals = 39

Cardiac insufficiency

In addition to the secondary outcomes, we considered patients with the main diagnosis of cardiac insufficiency as a relatively large subgroup of ventilation patients (please refer to the most frequent ICD-codes shown above). The number of hospitals treating ventilation patients with cardiac insufficiency was 27 in the control group and 28 in the intervention group. The results of the WLS regressions are shown below. There was no evidence for an effect of the IQM peer review in this subpopulation.

Results of WLS regression for ventilation cases with cardiac insufficiency. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Interven-tion	.0731678	.1375791	0.53	0.597	-.2027809	.3491166

Number of hospitals = 55

Lag time of three months

Since the effect of the IQM peer review may not be observable immediately, the confirmatory analysis was conducted with a lag time of three months. For this purpose, patients admitted during the first three months after peer review were excluded. The post-treatment period thus comprised one year, starting three months after the initial splitting date. The same procedure was applied to the control group hospitals. Note that the lag time caused truncation of the observation period for 11 intervention group hospitals because data was available until December 31, 2018 only. The estimation results are shown in the table below. There was no evidence for an effect of the IQM peer review on the SMRs.

Results of WLS regression considering a lag time of three months. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Interven-tion	.0691577	.0515621	1.34	0.185	-.0340935	.172409

Number of hospitals = 59

Exclusion of university hospital

Exploratory analyses identified differences between university hospitals and other hospitals regarding relationships between mortality and risk factors in patients ventilated > 24h. Because of this evidence for statistical effect modification, the university hospital included in the control group was removed

from the sample for sensitivity analysis. Consequently, the reduced sample included 28 control group hospitals and 30 intervention group hospitals. The results of the confirmatory analysis using the age and sex adjusted SMRs are shown below. The estimated coefficient of the intervention study group dummy is positive and significant at the 10% level but insignificant at the 5% level. Hence, this analysis provides weak evidence for an adverse effect of the IQM peer review. However, the point estimate of the treatment effect changed only slightly from 0.04 to 0.08 compared to the main analysis. The reason for this shift in the estimate of the treatment effect is that the SMR of the university hospital increased from 1.22 in the pre-intervention phase to 1.36 in the post-intervention phase.

Results of WLS regression excluding university hospital. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	.0784034	.0393695	1.99	0.051	-.0004633	.15727

Number of hospitals = 58

Previous IQM peer reviews regarding ventilation > 24h

18 hospitals of the intervention group and 15 hospitals of the control group had an IQM peer review regarding ventilation > 24h prior to the IMPRESS study (i.e. in the period 2009-2016). Since previous reviews could confound or moderate the effect of review conducted during the IMPRESS study, we included a dummy variable indicating whether an IQM peer review regarding ventilation was conducted before 2017. A potential effect modification was examined by including an interaction term between the intervention group dummy and the variable indicating the existence of a previous peer review.

The results of the WLS regression considering previous peer reviews regarding ventilation > 24h are shown below. There was no significant effect of a previous peer review on the change in the SMRs. Likewise, the results did not indicate a significant effect of the IQM peer review conducted during the IMPRESS study.

Results of WLS regression controlling for previous IQM peer reviews. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	.0466272	.0473868	0.98	0.329	-.0483	.1415543
Previous peer review	-.0262301	.0470233	-0.56	0.579	-.1204291	.0679689

Number of hospitals = 59

The results of the interaction model are shown in the table below. The estimated coefficient of the interaction term was insignificant. Hence, there was no evidence that previous IQM peer reviews regarding ventilation > 24h altered the effect of the IQM peer reviews conducted during the IMPRESS study.

Results of WLS regression testing an interaction between the intervention during the IMPRESS study and previous IQM peer reviews regarding ventilation. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	.0267556	.0613263	0.44	0.664	-.0961451	.1496562
Previous peer review	-.0518523	.0858061	-0.60	0.548	-.2238115	.1201069
Intervention X Previous peer review	.0490361	.0974316	0.50	0.617	-.1462213	.2442934

Number of hospitals = 59

Possible anticipation effects

In the analyses presented above, the date of the IQM peer review in a specific hospital was considered as the treatment date. However, the decision on the IQM peer reviews conducted in 2017 was made on Mai 8, 2017. The decision was communicated to the IQM member hospitals on May 29, 2017. Since there may be anticipatory effects of pronounced IQM peer reviews regarding ventilation, the following analyses compared the one-year period before May 8, 2017 with the one-year period after May 29, 2017. Patients admitted in the intervention group hospitals between May 8, 2017 and May 29, 2017 were excluded. The same dates were used for the control group hospitals.

The results are shown below. The coefficient of the intervention group dummy is insignificant. Hence, there is no evidence for anticipatory effects of the IQM peer reviews on the age and sex adjusted SMRs.

Results of WLS regression using May 8, 2017 as the treatment date. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Interven-tion	-.0286916	.0399684	-0.72	0.476	-.1087269	.0513437

Number of hospitals = 59

Possible anticipation effects with lag time

Analogous to the analyses using the peer review date as the treatment date, a possible lag of the effect of the IQM peer review was considered when testing potential anticipation effects. The following table shows the estimated effect of the IQM peer review using May 29, 2017 as the treatment date and accounting for a three months lag time (as outlined above). There was no significant difference between intervention and control group with regard to changes in the age and sex adjusted SMRs.

Results of WLS regression using May 8, 2017 as the treatment date and accounting for a lag time of three months. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	.0302413	.0415484	0.73	0.470	-.0529581	.1134406

Number of hospitals = 59

Individual-level regression

While the analyses presented above were conducted at the hospital level, the following sensitivity analyses estimated the effect of the IQM peer review on the individual ventilation patient's risk to decease in hospital. The individual-level sample included 25101 ventilation cases observed in the treatment and control hospitals during the pre and post-treatment period. To obtain relative risk estimates, multilevel Poisson regression with standard errors clustered at the hospital level was applied. All models include an interaction term between the intervention group dummy and the study period dummy. The coefficient of this interaction term represents the estimate of the treatment effect.

The results of the model without covariates are shown in the table below. The coefficient of the interaction term between intervention group dummy and study period was positive but insignificant. Hence, there was no evidence for an effect of the IQM peer review.

Results of mixed effects Poisson regression. Dependent variable: In-hospital death. Weight: Number of patients treated in the hospitals during the study period

	RR	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Treatment effect	1.023548	.0339937	0.70	0.483	.959044	1.092391
Intervention	.9701781	.0369942	-0.79	0.427	.9003141	1.045464
Post treatment	1.004957	.0270374	0.18	0.854	.9533372	1.059371

N = 25 101

Individual-level regressions: Inclusion of potential confounders

According to the statistical analysis plan, several variables that may confound the effect of the IQM peer review were taken into account. Each of these variables was separately included as a covariate in the regression model. In line with the statistical analysis plan, a variable was considered as a confounder if the estimated treatment effect deviated from the raw effect estimate by at least 10%. The results are shown in the table below. In none of the models, the estimated treatment effect changed by at least 10% relative to the raw effect estimate. Hence, these analyses did not provide evidence for confounding.

Changes in the estimated treatment effect (relative risk from multilevel Poisson regression) due to inclusion of covariates

Covariate	Raw Effect	Adjusted Effect	Percentage change
Age	1.024	1.026	0.211%
Sex	1.024	1.024	0.002%
Secondary outcomes	1.024	1.028	0.426%
Elixhauser comorbidities	1.024	1.018	0.548%
Length of stay	1.024	1.006	1.696%
Admission reason	1.024	1.022	0.190%
Weekday of admission	1.024	1.024	0.070%
Number of visited hospital depart-ments	1.024	1.016	0.749%
Year of admission	1.024	1.006	1.713%
Hospital type	1.024	1.024	0.019%
Hospital ownership	1.024	1.024	0.049%
Number of beds	1.024	1.027	0.303%
Location (urban/rural)	1.024	1.024	0.051%
Number of ventilation cases	1.024	1.025	0.116%
Share of transfers to other hospitals	1.024	1.023	0.071%
Share of transfers from other hospitals	1.024	1.026	0.216%
Multiple locations	1.024	1.024	0.025%
Calendar months	1.024	1.024	0.089%
Previous peer review	1.024	1.022	0.113%

Individual-level regressions: Exclusion of potential confounders

In addition to the inclusion of covariates, the impact of exclusion of single covariates from the fully specified model was examined. For this purpose, the full model including all covariates was first estimated as the benchmark model. The results are shown in the table below. The estimation did not yield evidence for an effect of the IQM peer review.

Results of mixed effects Poisson regression. Dependent variable: In-hospital death.

	RR	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Treatment effect	.9961416	.0360213	-0.11	0.915	.927985	1.069304

N = 25101; the regression model includes the full set of covariates (not shown in the table). The full regression results are provided in the appendix.

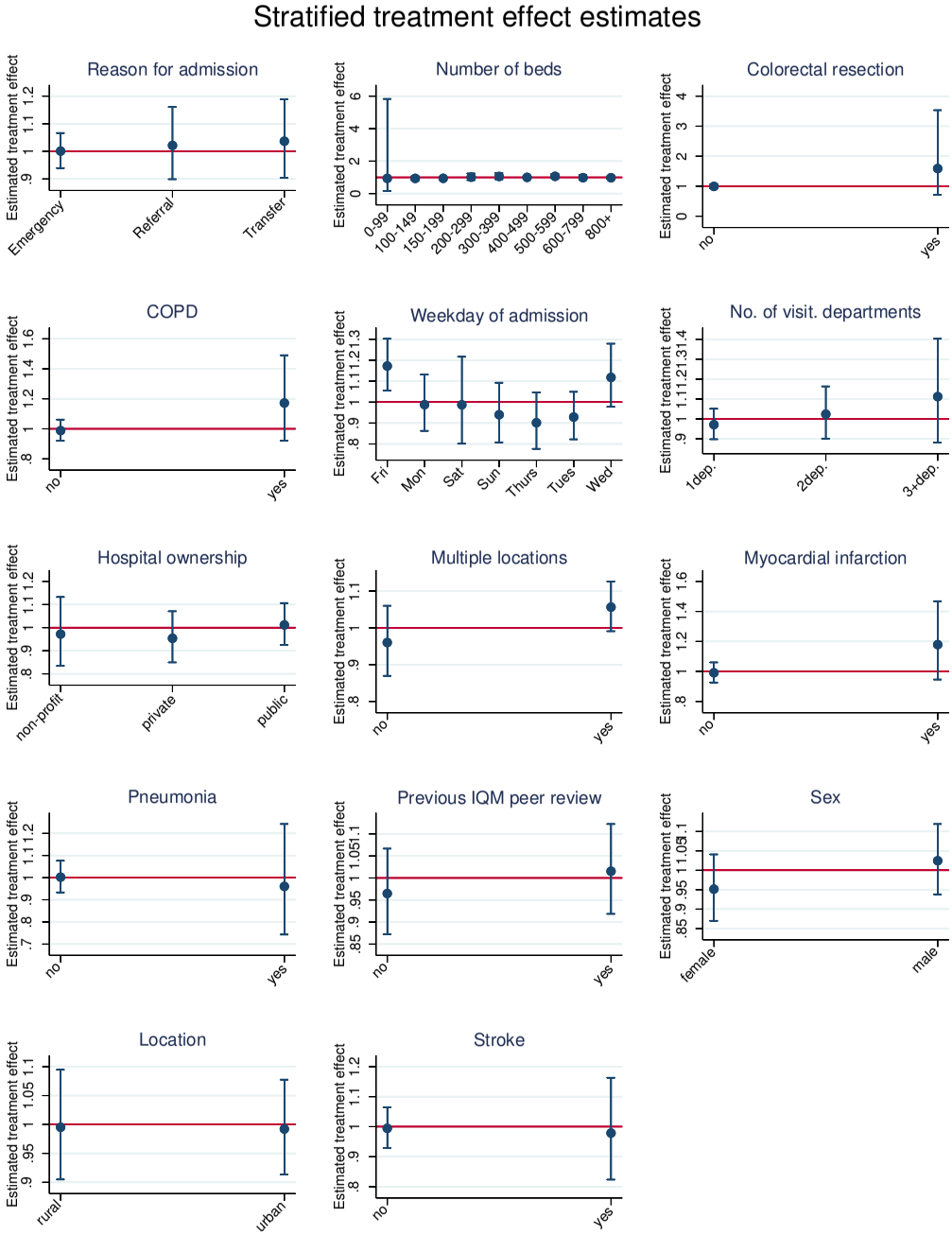
In the next step, single covariates were excluded from the model. The resulting percentage changes in the estimates of the treatment effect are shown below. There was no evidence for confounding as indicated by a change in the estimated treatment effect of at least 10%.

Changes in the estimated treatment effect (relative risk from multilevel Poisson regression) due to exclusion of covariates

Excluded Covariate	Raw Effect	Adjusted Effect	Percentage change
Age	0.996	1.001	0.534%
Sex	0.996	0.996	0.029%
Secondary outcomes	0.996	0.993	0.342%
Elixhauser comorbidities	0.996	0.997	0.068%
Length of stay	0.996	0.998	0.158%
Admission reason	0.996	0.997	0.085%
Weekday of admission	0.996	0.995	0.132%
Number of visited hospital departments	0.996	0.998	0.215%
Year of admission	0.996	1.009	1.322%
Hospital type	0.996	0.999	0.337%
Hospital ownership	0.996	0.996	0.013%
Number of beds	0.996	0.992	0.427%
Location (urban/rural)	0.996	0.995	0.104%
Number of ventilation cases	0.996	0.998	0.226%
Share of transfers to other hospitals	0.996	0.996	0.030%
Share of transfers from other hospitals	0.996	0.993	0.340%
Multiple locations	0.996	0.996	0.000%
Calendar months	0.996	0.995	0.121%
Previous peer review	0.996	0.998	0.153%

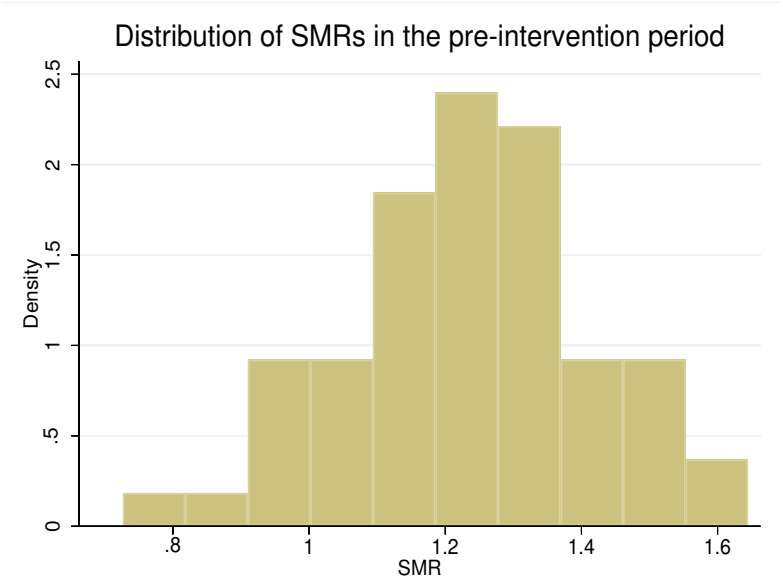
Stratified analysis to identify potential effect modifications

Following the statistical analysis plan, regression models for different strata were estimated to identify potential effect modifications. For this purpose, all available categorical variables were used for stratification if the number of observations in the strata was sufficiently high to estimate the regression. A variable was considered as an effect modifier if the confidence intervals for the strata did not overlap. The results are shown in the figure below. For reference, a horizontal line marking a relative risk estimate of 1 (i.e. no effect) is provided. Overall, there was no evidence for effect modification.


Stratified treatment effect estimates
Reason for admission
Estimated treatment effect
Emergency
Referral
Transfer
Number of beds
0-99
100-149
150-199
200-299
300-399
400-499
500-599
600-799
800+
Colorectal resection
no
yes
COPD
Weekday of admission
Fri
Mon
Sat
Sun
Thurs
Tues
Wed
No. of visit. departments
1dep.
2dep.
3+dep.
Hospital ownership
non-profit
private
public
Multiple locations
Myocardial infarction
Pneumonia
Previous IQM peer review
Sex
female
male
Location
rural
urban
Stroke

Estimations for different SMR thresholds

Although the 60 hospitals with the highest raw mortality rates in 2016 were randomized into treatment and control group, the SMRs of these hospitals varied considerably in the pre-intervention period. As shown in the figure below, there were even 7 hospitals (1 control and 6 intervention hospitals) with age and sex adjusted SMRs < 1. Since hospitals with relatively low SMRs may have less potential for improvement, the effect of the IQM peer review was estimated for hospitals reaching at least a certain threshold SMR. The results for threshold SMRs of 1.0, 1.1, 1.2, and 1.3 are reported below.



Threshold SMR of 1.0

Given the threshold SMR of 1.0, the estimation results shown in the table below were based on 24 intervention group hospitals and 28 control group hospitals. There was no evidence for an effect of the IQM peer review.

Results of WLS regression. Dependent variable: Change in SMR adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	.0361782	.047664	0.76	0.451	-.0595578	.1319142

Number of hospitals = 52

Threshold SMR of 1.1

Given the threshold SMR of 1.1, the estimation results shown in the table below were based on 20 intervention group hospitals and 25 control group hospitals. There was no evidence for an effect of the IQM peer review.

Results of WLS regression. Dependent variable: Change in SMR adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	.0415742	.050354	0.83	0.414	-.0599743	.1431226

Number of hospitals = 45

Threshold SMR of 1.2

Given the threshold SMR of 1.2, the estimation results shown in the table below were based on 14 intervention group hospitals and 21 control group hospitals. There was no evidence for an effect of the IQM peer review.

Results of WLS regression. Dependent variable: Change in SMR adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	-.0012043	.0541577	-0.02	0.982	-.1113889	.1089803

Number of hospitals = 35

Threshold SMR of 1.3

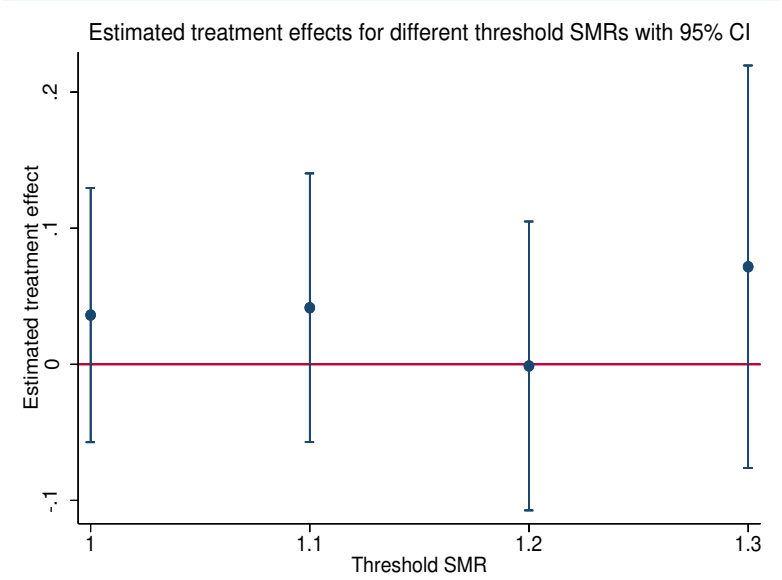
Given the threshold SMR of 1.3, the estimation results shown in the table below were based on 11 intervention group hospitals and 11 control group hospitals. There was no evidence for an effect of the IQM peer review.

Results of WLS regression. Dependent variable: Change in SMR adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intervention	.0716985	.0754473	0.95	0.353	-.0856819	.2290789

Number of hospitals = 22

The following figure provides a visualization of the results for all threshold SMRs.



Analysis by presence of OPS-5 codes

The effect of the IQM peer review was also separately estimated for ventilation cases with and without surgery. Surgery was identified by the presence of an OPS-5 code, excluding tracheostomy, and tube thoracostomy. The table below shows the number of ventilation cases with and without OPS-5 code by study group and period.

Number of cases by presence of OPS-5 code, study group, and study period

Group	Period	OPS-5: no	OPS-5: yes
Control	post	3140	3290
Control	pre	3347	3239
Intervention	post	3168	2879
Intervention	pre	3063	2975

The results of the confirmatory analysis for patients with and without OPS-5 code are shown in the tables below. In both groups, there was no evidence for an effect of the IQM peer review.

Results of WLS regression for patients without OPS-5 code. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Interven-tion	.035951	.0606851	0.59	0.556	-.0855688	.1574708

Number of hospitals = 59

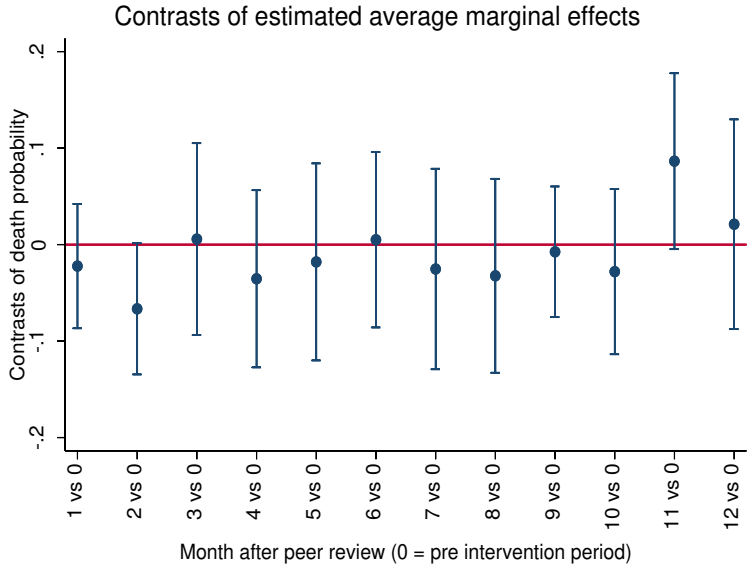
Results of WLS regression for patients with OPS-5 code. Dependent variable: Change in SMR, adj. for age and sex. Weight: Number of patients treated in the hospitals during the study period

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Interven-tion	.0199706	.0659045	0.30	0.763	-.1120009	.1519422

Number of hospitals = 59

Individual-level regressions with time varying effects

Since the effect of the IQM peer review may evolve over time, a logistic regression analysis at the individual level including interactions with the months after peer review was conducted. The regression model included the full set of covariates used in the previous analyses. The results are visualized in the figure below as contrasts of estimated average marginal effects (with 95% confidence intervals) for the intervention and control group relative to the pre-intervention period. To account for multiple testing, Bonferroni correction was applied. The results did not indicate significant differences between intervention and control group with regard to changes in the risk of mortality after IQM peer review.



Appendix

Summary statistics

Variable	Category	N/Median	Percent/IQR
Age; Median (IQR)		70	(59; 79)
Number of Elixhauser comorbidities; Median (IQR)		5	(3; 6)
Length of stay; N (Percent)		17.17	(8.70; 31)
Number of ventilation cases; Median (IQR)		302	(172; 616)
Share of transfers to other hospitals; Median (IQR)		0.16	(0.12; 0.22)
Share of transfers from other hospitals; Median (IQR)		0.07	(0.04; 0.15)
Death; N (Percent)	no	14653	(58.37%)
	yes	10448	(41.62%)
Study group; N (Percent)	Control	13016	(51.85%)
	Intervention	12085	(48.14%)
Period; N (Percent)	pre	12624	(50.29%)
	post	12477	(49.70%)
Sex; N (Percent)	male	15193	(60.52%)
	female	9908	(39.47%)
Myocardial infarction; N (Percent)	no	23929	(95.33%)
	yes	1172	(4.66%)
Stroke; N (Percent)	no	23193	(92.39%)
	yes	1908	(7.60%)
Pneumonia; N (Percent)	no	23152	(92.23%)
	yes	1949	(7.76%)
COPD; N (Percent)	no	23354	(93.04%)
	yes	1747	(6.95%)
Colorectal resection; N (Percent)	no	24825	(98.90%)
	yes	276	(1.09%)
Admission reason; N (Percent)	other	5827	(23.21%)
Admission reason; N (Percent)	Emergency case	16759	(66.76%)
	Tranfer from other hospital	2515	(10.01%)
Weekday of admission; N (Percent)	Sun	2966	(11.81%)
	Mon	4288	(17.08%)
	Tues	4035	(16.07%)
	Wed	3687	(14.68%)
	Thurs	3797	(15.12%)
	Fri	3566	(14.20%)
	Sat	2762	(11.00%)
Number of visited hospital departments; N (Percent)	1 department	13568	(54.05%)
	2 departments	8981	(35.77%)
	3 or more departments	2552	(10.16%)
Year of admission; N (Percent)	2016	3918	(15.60%)
	2017	12521	(49.88%)
	2018	8662	(34.50%)

Summary statistics

Variable	Category	N/Median	Percent/IQR
Hospital type; N (Percent)	University hospital	2677	(10.66%)
	H. of Germ. Hospital Plan	22424	(89.33%)
Hospital ownership; N (Percent)	public	18050	(71.90%)
	non-profit	4211	(16.77%)
	private	2840	(11.31%)
Number of beds; N (Percent)	0-99	215	(0.85%)
	100-149	428	(1.70%)
	150-199	1009	(4.01%)
	200-299	2044	(8.14%)
	300-399	2973	(11.84%)
	400-499	2972	(11.84%)
	500-599	3420	(13.62%)
	600-799	4069	(16.21%)
	800+	7971	(31.75%)
Location (urban/rural); N (Percent)	urban	18104	(72.12%)
	rural	6997	(27.87%)
Multiple locations; N (Percent)	no	16158	(64.37%)
	yes	8943	(35.62%)
Calendar months; N (Percent)	Jan	2541	(10.12%)
	Feb	2390	(9.52%)
	Mar	2319	(9.23%)
	Apr	2033	(8.09%)
	May	1982	(7.89%)
	Jun	1944	(7.74%)
	Jul	1958	(7.80%)
	Aug	1855	(7.39%)
	Sep	1890	(7.52%)
	Oct	2053	(8.17%)
	Nov	2020	(8.04%)
	Dec	2116	(8.42%)
Previous peer review; N (Percent)	no	14908	(59.39%)
	yes	10193	(40.60%)

Full results of mixed effects Poisson regression. Dependent variable: In-hospital death.

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Treatment effect	-.0038659	.0361608	-0.11	0.915	-.0747397	.067008
Intervention	-.0222336	.0332264	-0.67	0.503	-.0873562	.042889
Post treatment	.0291707	.0459207	0.64	0.525	-.0608322	.1191736
Age	.0217004	.0010022	21.65	0.000	.0197362	.0236646
Female	-.019258	.0112027	-1.72	0.086	-.0412148	.0026988
Myocardial infarction	-.0229479	.0296804	-0.77	0.439	-.0811205	.0352247
Stroke	.2284585	.0385976	5.92	0.000	.1528085	.3041085
Pneumonia	-.1383748	.0353601	-3.91	0.000	-.2076793	-.0690704
COPD	-.4049151	.0545934	-7.42	0.000	-.5119162	-.2979139
Colorectla resection	-.1496728	.0768839	-1.95	0.052	-.3003624	.0010169
Elixhauser com.						
Aids/HIV	.1909371	.1021411	1.87	0.062	-.0092558	.39113
Alcohol abuse	.0298573	.0214044	1.39	0.163	-.0120944	.0718091
Bloodloss anemia	-.1059961	.0889528	-1.19	0.233	-.2803405	.0683482
Cardiacar Rhythmias	.0625964	.0166322	3.76	0.000	.0299978	.095195
Chronic pulmonary disease	-.0446528	.0210777	-2.12	0.034	-.0859645	-.0033412
Coagulopathy	.3029491	.0226004	13.40	0.000	.2586533	.347245
Congestive heart failure	.0848457	.0178608	4.75	0.000	.0498391	.1198523
Deficiency anemia	.0056347	.0813383	0.07	0.945	-.1537854	.1650548
Depression	-.2324054	.0443255	-5.24	0.000	-.3192818	-.1455289
Diabetes complicated	.0201529	.0280067	0.72	0.472	-.0347392	.0750449
Diabetes uncomplicated	-.0223137	.0198464	-1.12	0.261	-.061212	.0165846
Drug abuse	-.3216267	.0736728	-4.37	0.000	-.4660227	-.1772307
Fluid and electrolyte disord.	.1261633	.0218905	5.76	0.000	.0832586	.1690679
Hypertension complicated	-.2919022	.0316319	-9.23	0.000	-.3538996	-.2299048
Hypertension uncomplicated	-.1765783	.0153455	-11.51	0.000	-.2066549	-.1465018
Hypothyroidism	-.0707771	.0332755	-2.13	0.033	-.1359959	-.0055584
Liver disease	.4299242	.0264778	16.24	0.000	.3780288	.4818197
Lymphoma	.4076434	.0375949	10.84	0.000	.3339588	.481328
Metastatic cancer	.2063116	.0449851	4.59	0.000	.1181424	.2944809
Obesity	-.0699902	.0391928	-1.79	0.074	-.1468067	.0068262
Other neurological disorder	.208432	.0262888	7.93	0.000	.1569069	.2599572
Paralysis	-.2745663	.0435411	-6.31	0.000	-.3599053	-.1892273
Pepticulcer disease	.1410005	.1465571	0.96	0.336	-.1462461	.428247
Peripheral vascular disorder	.1185782	.0176842	6.71	0.000	.0839179	.1532386
Psychoses	-.2948323	.0882655	-3.34	0.001	-.4678295	-.1218352
Pulmonary circulation disorer	.0663884	.0246899	2.69	0.007	.0179971	.1147798
Renal failure	.0799978	.0162363	4.93	0.000	.0481753	.1118203
Rheumatoid arthritis c.	.0769677	.0389047	1.98	0.048	.0007159	.1532195
Solid tumor without met.	.1393653	.0316501	4.40	0.000	.0773323	.2013983
Valvular disease	-.0415973	.0200596	-2.07	0.038	-.0809134	-.0022811
Weight loss	.0318067	.0373833	0.85	0.395	-.0414632	.1050767
Length of stay	-.0196276	.0017697	-11.09	0.000	-.0230962	-.016159

Full results of mixed effects Poisson regression. Dependent variable: In-hospital death.

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Admission reason						
Emergency case	.0593704	.0305105	1.95	0.052	-.000429	.1191698
Transfer from other hospital	.0860116	.0379976	2.26	0.024	.0115377	.1604856
Weekday of admission						
Mon	.0637571	.02502	2.55	0.011	.0147188	.1127955
Tues	.0605398	.0339265	1.78	0.074	-.0059548	.1270345
Wed	.0699087	.0249316	2.80	0.005	.0210438	.1187737
Thurs	.06887	.0256693	2.68	0.007	.018559	.119181
Fri	.0692571	.0325206	2.13	0.033	.0055179	.1329963
Sat	.0491883	.0319278	1.54	0.123	-.0133889	.1117656
Number of visited depart.						
2 departments	-.1613963	.0430697	-3.75	0.000	-.2458115	-.0769812
3 or more departments	-.0730367	.0421714	-1.73	0.083	-.1556912	.0096177
Admission year						
2017	-.0653916	.0242217	-2.70	0.007	-.1128653	-.0179178
2018	-.0681259	.0470844	-1.45	0.148	-.1604096	.0241579
Hospital type						
Hospital of Germ. Hospital Plan	.1736998	.0645493	2.69	0.007	.0471856	.300214
Hospital ownershkip						
non-profit	.0808806	.0621648	1.30	0.193	-.0409601	.2027214
private	-.0266098	.0456542	-0.58	0.560	-.1160903	.0628707
Number of beds						
100-149	-.1013225	.1202967	-0.84	0.400	-.3370996	.1344547
150-199	-.0336207	.0734762	-0.46	0.647	-.1776314	.11039
200-299	.0322726	.0821549	0.39	0.694	-.128748	.1932933
300-399	.1157099	.0784534	1.47	0.140	-.0380559	.2694758
400-499	.0833018	.0819989	1.02	0.310	-.0774131	.2440167
500-599	.0857701	.0862758	0.99	0.320	-.0833274	.2548676
600-799	.0785117	.0667454	1.18	0.239	-.0523068	.2093303
800+	.0360285	.0871465	0.41	0.679	-.1347755	.2068324
Location (urban/rural)						
rural	.0718045	.0385794	1.86	0.063	-.0038096	.1474187
Number of ventilation cases	.0002341	.0001154	2.03	0.043	7.90e-06	.0004603
Share of transfers to other h.	-.2896291	.1510427	-1.92	0.055	-.5856672	.0064091
Share of transfers from other h.	-.4855212	.274714	-1.77	0.077	-1.023951	.0529083
Multiple locations	-.012337	.0419022	-0.29	0.768	-.0944637	.0697898
Calendar month of admission						
Jan	.0960782	.0331129	2.90	0.004	.0311781	.1609782

Full results of mixed effects Poisson regression. Dependent variable: In-hospital death.

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Feb	.0347534	.0332331	1.05	0.296	-.0303823	.0998892
Mar	.0587575	.0242774	2.42	0.016	.0111747	.1063403
Apr	-.002932	.0426029	-0.07	0.945	-.0864321	.0805681
May	-.0265851	.0345708	-0.77	0.442	-.0943425	.0411724
Jun	-.0115402	.0479912	-0.24	0.810	-.1056013	.0825208
Aug	-.0133529	.0287506	-0.46	0.642	-.0697031	.0429973
Sep	-.0127233	.0298803	-0.43	0.670	-.0712876	.0458409
Oct	.0420287	.0315914	1.33	0.183	-.0198893	.1039467
Nov	-.0285475	.0314208	-0.91	0.364	-.0901311	.0330361
Dec	.0122923	.0334069	0.37	0.713	-.053184	.0777687
Previous peer review	.0718692	.0322712	2.23	0.026	.0086188	.1351196
_cons	-2.504904	.1482608	-16.90	0.000	-2.79549	-2.214318

N = 25 101