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Hospital volume and mortality for 25 types of inpatient treatment in German hospitals: observational study using complete national data from 2009 to 2014

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ABSTRACT

Objectives To explore the existence and strength of a relationship between hospital volume and mortality, to estimate minimum volume thresholds and to assess the potential benefit of centralisation of services.

Design Observational population-based study using complete German hospital discharge data (Diagnosis-Related Group Statistics (DRG Statistics)).

Setting All acute care hospitals in Germany.

Participants All adult patients hospitalised for 1 out of 25 common or medically important types of inpatient treatment from 2009 to 2014.

Main outcome measure Risk-adjusted inhospital mortality.

Results Lower inhospital mortality in association with higher hospital volume was observed in 20 out of the 25 studied types of treatment when volume was categorised in quintiles and persisted in 17 types of treatment when volume was analysed as a continuous variable. Such a relationship was found in some of the studied emergency conditions and low-risk procedures. It was more consistently present regarding complex surgical procedures. For example, about 22 000 patients receiving open repair of abdominal aortic aneurysm were analysed. In very high-volume hospitals, risk-adjusted mortality was 4.7% (95% CI 4.1 to 5.4) compared with 7.8% (7.1 to 8.7) in very low volume hospitals. The minimum volume above which risk of death would fall below the average mortality was estimated as 18 cases per year. If all hospitals providing this service would perform at least 18 cases per year, one death among 104 (76 to 166) patients could potentially be prevented.

Conclusions Based on complete national hospital discharge data, the results confirmed volume–outcome relationships for many complex surgical procedures, as well as for some emergency conditions and low-risk procedures. Following these findings, the study identified areas where centralisation would provide a benefit for patients undergoing the specific type of treatment in German hospitals and quantified the possible impact of centralisation efforts.

Strengths and limitations of this study

- ► The strength of this study is the use of current and complete national hospital discharge data, covering virtually every patient who underwent one out of the studied types of treatment during the study period.
- ► As hospital volumes vary widely among German acute care hospitals, this is a proper setting to study volume–outcome relationships.
- ► In contrast to most other volume–outcome studies, the present approach includes the calculation of minimum volume thresholds along with an assessment of the possible impact of centralisation efforts on the population.
- ► Within this observational retrospective study, the statistical association between volume and outcome was tested on administrative data.
- ► As information available from administrative data is limited, it is possible that unmeasured differences in disease severity, comorbidity or appropriateness of patient selection may partly explain the association between volume and outcome.
- ► This study did not consider hospital characteristics like teaching status, type of ownership or location.

INTRODUCTION

The relationship between hospital volume and patient outcomes has been widely studied. For many inpatient treatments, a higher volume was found to be associated with better outcomes, such as for high-risk surgical procedures, medical conditions or elective low-risk surgery.[1–10] Systematic reviews and meta-analyses were conducted to aggregate results into a broader frame of knowledge.[11–14] However, the heterogeneity of methods used impairs conclusions from meta-analyses. In particular, the categorisation of high-volume hospitals varies according to the geographical context.[15 16] Moreover, many studies include only samples of patients or are restricted to patients with a specific type of insurance or within a delimited geographic area. Therefore, it is often uncertain if the association of volume and outcome found in one study may be generalisable to the whole population affected or even to populations in other countries with different healthcare systems.

Finally, studies reporting better outcome in relation to higher volume often lack an assessment of the clinical and policy significance of their findings.[16]

To date, the volume–outcome relationship in Germany has been studied only for few inpatient services, such as pancreatic resection, abdominal aortic aneurysm repair, hip fracture or treatment of very low birth weight infants.[17–20] The German acute care hospital market is characterised by a relative overcapacity of hospital beds and high hospitalisation rates.[21] Volumes of inpatient treatments vary widely among about 1600 German acute care hospitals.[22] In 2004, minimum volume thresholds for specific types of inpatient treatment were established. However, it has been found that many hospitals did not adhere to this regulation, and the debate about the underlying evidence remains controversial.[23–25]

Efforts to improve quality of care by centralisation of services need to rely on evidence that higher volume is associated with better outcome. Therefore, this study aimed to explore the relation of hospital volume and outcome in the German hospital market by using complete national hospital discharge data. For a broad range of common or medically important inpatient services, the existence and strength of a relationship between volume and mortality were analysed. Where lower mortality in relation to higher volume was observed, minimum volume thresholds, above which mortality would be reduced, were estimated. Impact measures were calculated to assess the potential benefit of centralisation efforts.

METHODS

Data

German acute care hospitals are obliged to submit their inpatient discharge data annually to a nationwide database, which is available for research purposes. This database (Diagnosis-Related Group Statistics (DRG Statistics) provided by the Research Data Centres of the Federal Statistical Office and the statistical offices of the 'Länder') contains discharge information on every inpatient episode, covering patients of all types of insurance. Principal and secondary diagnoses are coded according to the German adaptation of the International Classification of Diseases (ICD-10-GM). Procedures are coded according to the German procedure coding system (OPS, Operationen- und Prozedurenschlüssel). Information on sex, age, source of admission, discharge disposition and length of stay is also included. Based on an anonymised hospital identifier, every inpatient episode can be assigned to the treating hospital.[26] The analyses included data of the years 2009–2014. Data were accessed via controlled remote data analysis.

Patient population

To study a broad range of hospital services, five groups of inpatient treatments comprising 25 single conditions or procedures were analysed:

- Common emergency conditions (6)
- Elective heart and thoracic surgery (4)
- Elective major visceral surgery (6)
- Elective vascular surgery (4)
- Elective low-risk surgery (5)

Each type of treatment was defined by specific inclusion and exclusion criteria in order to minimise confounding by differences in case-mix. Treatments for emergency conditions (eg, acute myocardial infarction) were restricted to direct admissions by excluding patients who had been transferred-in from another acute care hospital. Elective surgical treatments were defined by restriction to certain medical indications (eg, colorectal resection for carcinoma) or exclusion of complicated constellations (eg, aortic valve replacement excluding combined other heart surgery). All definitions refer to adult patients aged 20 years and older. Inclusion and exclusion criteria are listed in the online supplementary table 1 .

Hospital volume

Volume of patients treated by a hospital was calculated for each year of observation corresponding to the respective definition of a studied type of treatment. Aiming to compare results in the context of the current literature, hospitals were ranked into quintiles of approximately equal case numbers according to their annual volume. This ranking was done separately for each year for observation, allowing the rank of one hospital to change from 1 year to another, if volume changed over time. Additionally, annual hospital volume was analysed as a continuous variable.

Within a sensitivity analysis hospital volume was additionally determined on the basis of wider case definitions in order to fully consider all treatments which might enhance a hospital's experience regarding a specific condition or procedure (eg, all colorectal resections regardless from medical indication). This approach led to a higher estimation of annual volume per hospital in most cases and resulted in a slightly different ranking of hospitals. Within this analysis, restrictions in case definition, as described above, were subsequently applied for outcome measurement.

Outcome measure, risk adjustment and statistical analysis

Inhospital mortality, defined as death before discharge, was studied as outcome measure. Observed and risk-adjusted mortality were stratified by volume quintiles.

Risk-adjusted mortality for each volume quintile was calculated by using generalised estimating equations (GEE) with a logit link function, accounting for clustering of patients within hospitals. Using the pooled data of the entire observation period, one GEE model was fitted for each studied treatment. Depending on the type of treatment, models included comorbidities, which most likely have been present on admission (eg, diabetes, chronic liver disease), specific indicators of disease severity (eg, ST-elevation myocardial infarction) or extension of surgery (eg, concomitant resection of other visceral organs in patients with pancreatic resection). Five-year age groups, sex and calendar year of treatment were considered within each model. The definitions and treatment-specific applications of covariates for risk adjustment are displayed in the online supplementary tables 2 and 3.

In order to estimate the independent impact of hospital volume on inhospital mortality, hospital volume was subsequently entered into each model, taken as a categorically variable. ORs for inhospital death by hospital volume quintile were calculated.

To further explore the relationship between volume and outcome, GEE models with volume as a continuous variable were fitted for each treatment. In a first step, hospital volume was taken as the only predictor (simple model). In a second step, the treatment-specific covariates, as described above, were entered into the model (full model), and ORs for inhospital death according to an increment of one case, as well as of 50 cases per year, were calculated.

Where the regression coefficient of a one-case increment of hospital volume remained statistically significant after consideration of covariates, minimum volume thresholds were estimated from the simple model using Bender's Value of Acceptable Risk Limit.[27] This value is calculated from the function of the logistic regression coefficient of hospital volume. It denotes the threshold where mortality is expected to fall below a predefined acceptable risk. The acceptable risk was set to the average mortality of the respective treatment during the observation period.

The clinical relevance of thresholds was assessed by the population impact number (PIN). The PIN was calculated as reciprocal of the difference between the average mortality risk in the entire patient population and the adjusted risk among patients treated by hospitals with volumes above the threshold (population-based risk difference (PRD)).[28] In the context of this study, the PIN can be interpreted as average number of patients within a treatment group among whom one death is attributable to treatment by a below-threshold volume hospital, due to excess risk of mortality in these hospitals. In other words, among this number of patients, one death could hypothetically be prevented if all hospitals providing the respective inpatient service had annual volumes equal or higher than the threshold.

The level of statistical significance was set to 0.05. The analyses were conducted using SAS V.9.3 (SAS Institute, Cary, North Carolina, USA).

Reporting guideline

Reporting of this analysis adheres to the REporting of studies Conducted using Observational Routinely-collected health Data statement.[29]

RESULTS

Common emergency conditions

Lower inhospital mortality in association with higher hospital volume was observed in four out of the six studied types of common emergency treatment when volume was categorised in quintiles and persisted in two types of treatment when volume was analysed as a continuous variable.

From 2009 to 2014, nearly 1.1 million patients were treated for acute myocardial infarction (table 1). Risk-adjusted mortality was 8.9% (95% CI 8.8 to 9.0) in the very high volume quintile versus 11.4% (11.3 to 11.6) in the very low volume quintile (figure 1). Adjusted ORs of inhospital death were significantly reduced in the low to very high volume quintiles when compared with the very low volume quintile (table 2). A statistically significant effect of volume on mortality was also observed when volume was analysed as a continuous variable. An increment of 50 cases per year was associated with reduced odds of death (figure 2). The minimum hospital volume where risk of mortality would fall below the average mortality of 9.8% was calculated as 309 cases per year. Stratification by this threshold resulted in a PRD of 0.7% (0.7 to 0.8) and a PIN of 137 (127 to 149, table 3). This means that, out of 137 patients hospitalised for acute myocardial infarction, one death would be prevented if annual volumes in treating hospitals were at least 309.

In total, 2.3 million patients treated for heart failure were studied. Risk-adjusted mortality was 8.5% (95% CI 8.4 to 8.6) in the very high volume quintile versus 9.2% (9.1 to 9.3) in the very low volume quintile (figure 1). For volume as a continuous variable, no association was found after consideration of covariates (table 3).

During the observation period, 1.2 million patients were hospitalised for ischaemic stroke (table 1). Adjusted mortality in the very high volume quintile was 6.9% (95% CI 6.8 to 7.0) versus 7.3% (7.2 to 7.4) in the very low volume quintile (figure 1). After consideration of covariates no measurable effect of hospital volume as a continuous variable was observed (table 3).

Among the 1.3 million patients treated for pneumonia (table 1), higher hospital volume was associated with higher inhospital mortality. Adjusted mortality was 11.5% (95% CI 11.3 to 11.6) in the very high volume quintile, 12.3% (12.2 to 12.5) in the medium volume quintile and 10.8% (10.7 to 10.9) in the very low volume quintile (figure 1), and the ORs were higher in the low to very high volume quintiles when compared with the very low volume quintile (table 2). When considered as a continuous variable, hospital volume was not associated with mortality (table 3).

For the more than 1.15 million patients with chronic obstructive pulmonary disease (COPD, table 1), adjusted mortality was 3.1% (95% CI 3.0 to 3.2) in the very high volume quintile and 4.3% (4.2 to 4.4) in the very low volume quintile (figure 1). Hospital volume as a continuous variable had an independent effect on mortality (figure 2), and the minimum volume to achieve a lower-than-average risk of death was calculated as 271 patients per year. This threshold was estimated to prevent one death among 170 (158 to 185) COPD patients (table 3).

The analysis of 711 000 patients hospitalised for hip fracture (table 1) revealed slightly higher mortality in

Table 1 Number of patients and hospitals by volume quintile

		Hospital volume quintile									
		Very low		Low		Medium		High		Very high	
Common emergency conditions											
Acute myocardial infarction	No of patients		219178		219291		219189		219778		220805
	No of hospitals		763		198		121		88		54
	Median annual volume (IQR)	43	(20–71)	184	(154–215)	303	(274–331)	412	(387–450)	594	(534–732)
Heart failure	No of patients		463352		463883		463283		464586		465401
	No of hospitals		608		263		184		136		87
	Median annual volume (IQR)	139	(63–189)	290	(260–321)	418	(374–461)	570	(518–613)	804	(703–950)
Ischaemic stroke	No of patients		244125		244272		244299		243725		246858
	No of hospitals		915		155		96		70		42
	Median annual volume (IQR)	28	(10–62)	259	(213–310)	427	(383–471)	577	(542–625)	865	(766–1028)
Pneumonia	No of patients		258016		257688		258010		258051		259391
	No of hospitals		630		255		186		140		84
	Median annual volume (IQR)	73	(25–107)	167	(150–183)	229	(211–249)	304	(279–331)	447	(396–523)
Chronic obstructive pulmonary disease	No of patients		230629		230793		231093		230258		232476
	No of hospitals		612		264		182		125		61
	Median annual volume (IQR)	67	(33–92)	144	(126–163)	209	(187–233)	299	(262–337)	546	(455–702)
Hip fracture	No of patients		142041		142082		141910		141658		143271
	No of hospitals		609		232		172		133		88
	Median annual volume (IQR)	43	(6–64)	101	(93–110)	137	(128–146)	176	(164–190)	244	(221–283)
Elective heart and thoracic surgery											
Isolated surgical aortic valve replacement	No of patients		10275		10238		10627		10066		11397
	No of hospitals		33		17		14		10		7
	Median annual volume (IQR)	54	(37–71)	101	(93–108)	132	(124–138)	172	(159–188)	246	(227–283)
Transcatheter aortic valve replacement	No of patients		9915		10009		9926		9935		10980
	No of hospitals		48		17		12		9		6
	Median annual volume (IQR)	31	(12–50)	98	(69–123)	141	(99–161)	169	(142–228)	286	(233–328)
Isolated coronary artery bypass graft	No of patients		35648		36967		36047		37221		37807
	No of hospitals		48		18		14		11		8
	Median annual volume (IQR)	120	(1–230)	353	(318–375)	436	(407–465)	561	(518–585)	729	(669–824)
Partial lung resection for carcinoma	No of patients		14655		14766		14626		14872		15064
	No of hospitals		260		48		27		17		9
	Median annual volume (IQR)	5	(2–14)	49	(43–59)	89	(79–98)	137	(122–160)	272	(208–313)
Elective major visceral surgery											

Continued

Table 1 Continued

		Hospital volume quintile									
		Very low		Low		Medium		High		Very high	
Colorectal resection for carcinoma	No of patients		66058		66089		66119		66185		66451
	No of hospitals		492		218		153		112		71
	Median annual volume (IQR)	23	(14–32)	50	(45–55)	72	(66–78)	97	(91–105)	141	(126–165)
Colorectal resection for diverticulosis	No of patients		35828		35821		35810		35872		36032
	No of hospitals		487		215		154		114		73
	Median annual volume (IQR)	13	(7–18)	28	(25–30)	39	(36–42)	52	(48–56)	74	(68–86)
Total nephrectomy for carcinoma	No of patients		13582		13569		13570		13600		13766
	No of hospitals		307		90		65		47		31
	Median annual volume (IQR)	5	(2–13)	25	(23–27)	35	(33–37)	48	(45–52)	67	(60–76)
Cystectomy for carcinoma	No of patients		8706		8702		8761		8734		8832
	No of hospitals		177		78		56		39		24
	Median annual volume (IQR)	9	(5–12)	18	(17–20)	26	(24–28)	36	(34–40)	57	(51–68)
Complex oesophageal surgery for carcinoma	No of patients		3625		3625		3639		3550		3769
	No of hospitals		228		71		43		23		10
	Median annual volume (IQR)	2	(1–4)	8	(7–10)	14	(12–16)	25	(21–29)	54	(42–67)
Pancreatic resection for carcinoma	No of patients		6886		6915		6880		6854		7020
	No of hospitals		322		117		71		41		17
	Median annual volume (IQR)	3	(2–5)	10	(9–11)	16	(14–18)	27	(23–33)	57	(46–72)
Elective vascular surgery											
Surgical lower extremity revascularisation for atherosclerosis	No of patients		49239		49385		49467		49086		49997
	No of hospitals		348		113		79		57		37
	Median annual volume (IQR)	21	(7–39)	72	(65–80)	102	(95–112)	143	(131–158)	210	(185–243)
Open repair of abdominal aortic aneurysm	No of patients		4422		4425		4430		4420		4530
	No of hospitals		239		81		50		33		18
	Median annual volume (IQR)	3	(1–4)	9	(7–10)	15	(13–17)	21	(19–25)	39	(33–46)
Endovascular repair of abdominal aortic aneurysm	No of patients		8281		8338		8288		8309		8462
	No of hospitals		219		81		52		34		20
	Median annual volume (IQR)	6	(3–9)	17	(15–19)	26	(24–30)	40	(36–45)	64	(57–75)
Carotid endarterectomy	No of patients		32345		32267		32460		32017		33081
	No of hospitals		317		101		67		47		30
	Median annual volume (IQR)	16	(6–27)	52	(46–59)	80	(73–87)	113	(104–123)	165	(148–195)
Elective low-risk surgery											

Continued

Table 1 Continued

		Hospital volume quintile									
		Very low		Low		Medium		High		Very high	
Cholecystectomy for cholelithiasis	No of patients		177 346		177 411		177 835		177 199		178 752
	No of hospitals		450		232		178		140		94
	Median annual volume (IQR)	71	(44–91)	128	(118–137)	166	(157–176)	210	(196–224)	286	(264–331)
Inguinal or femoral hernia repair	No of patients		178 992		179 169		179 285		179 338		179 911
	No of hospitals		471		247		186		142		84
	Median annual volume (IQR)	68	(45–86)	120	(111–129)	160	(150–171)	208	(194–224)	312	(274–377)
Primary hip replacement for arthrosis or arthritis	No of patients		175 918		175 797		176 313		175 834		177 287
	No of hospitals		608		226		135		82		42
	Median annual volume (IQR)	49	(25–71)	128	(111–146)	213	(190–242)	351	(314–388)	619	(522–768)
Primary knee replacement for arthrosis or arthritis	No of patients		168 312		168 479		168 415		168 015		169 623
	No of hospitals		517		222		143		94		51
	Median annual volume (IQR)	56	(36–75)	125	(112–140)	195	(176–215)	291.5292	(267–324)	477	(421–632)
Transurethral resection of prostate	No of patients		86 404		86 934		86 199		86 967		87 412
	No of hospitals		247		104		77		59		40
	Median annual volume (IQR)	60	(23–92)	139	(128–150)	186	(172–199)	243	(227–262)	331	(303–380)

No of hospitals: mean number of hospitals in quintile per year providing the respective inpatient service; IQR, IQR within the quintile (due to data protection regulations the minimum and maximum values cannot be displayed).

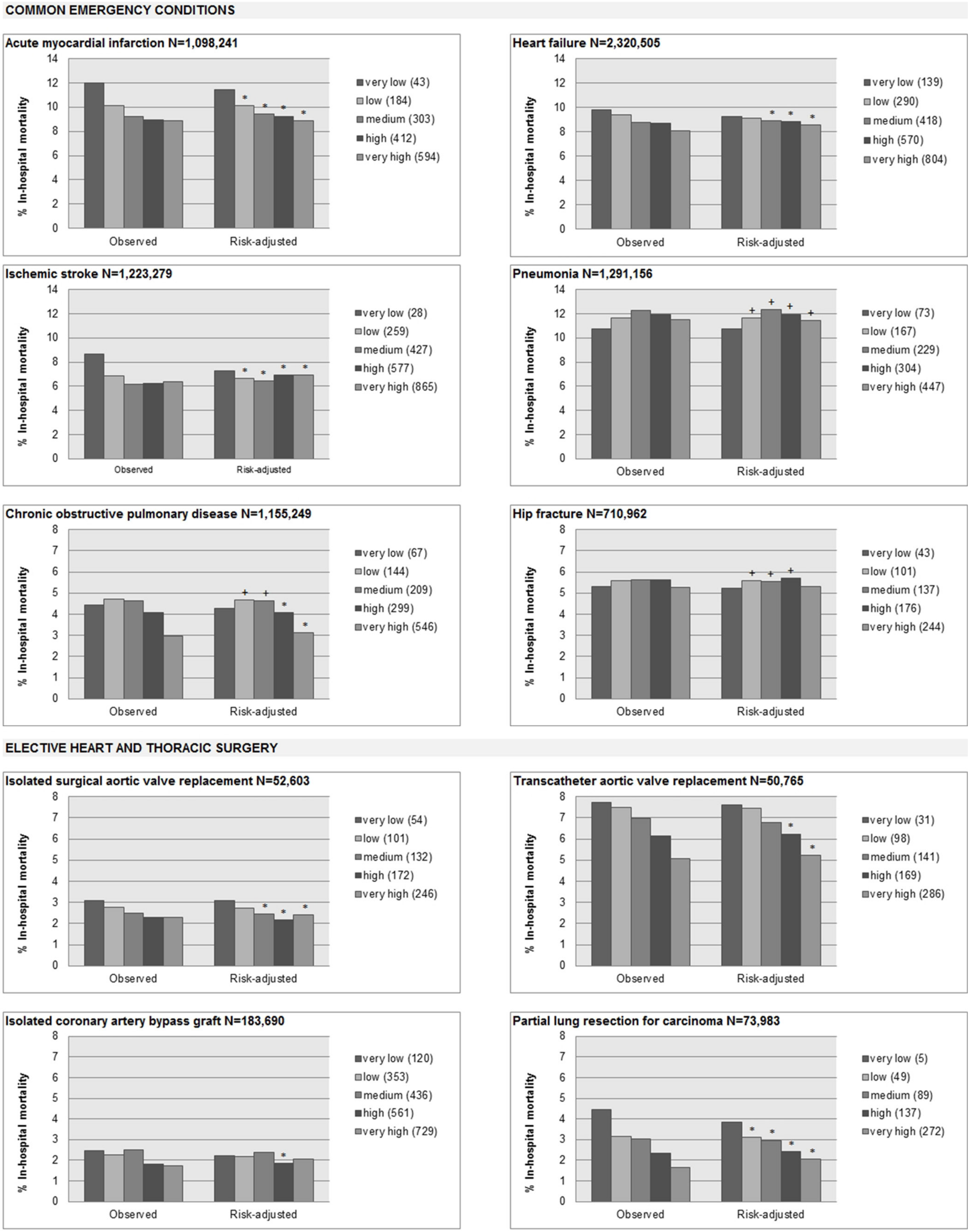

Figure 1 Continued

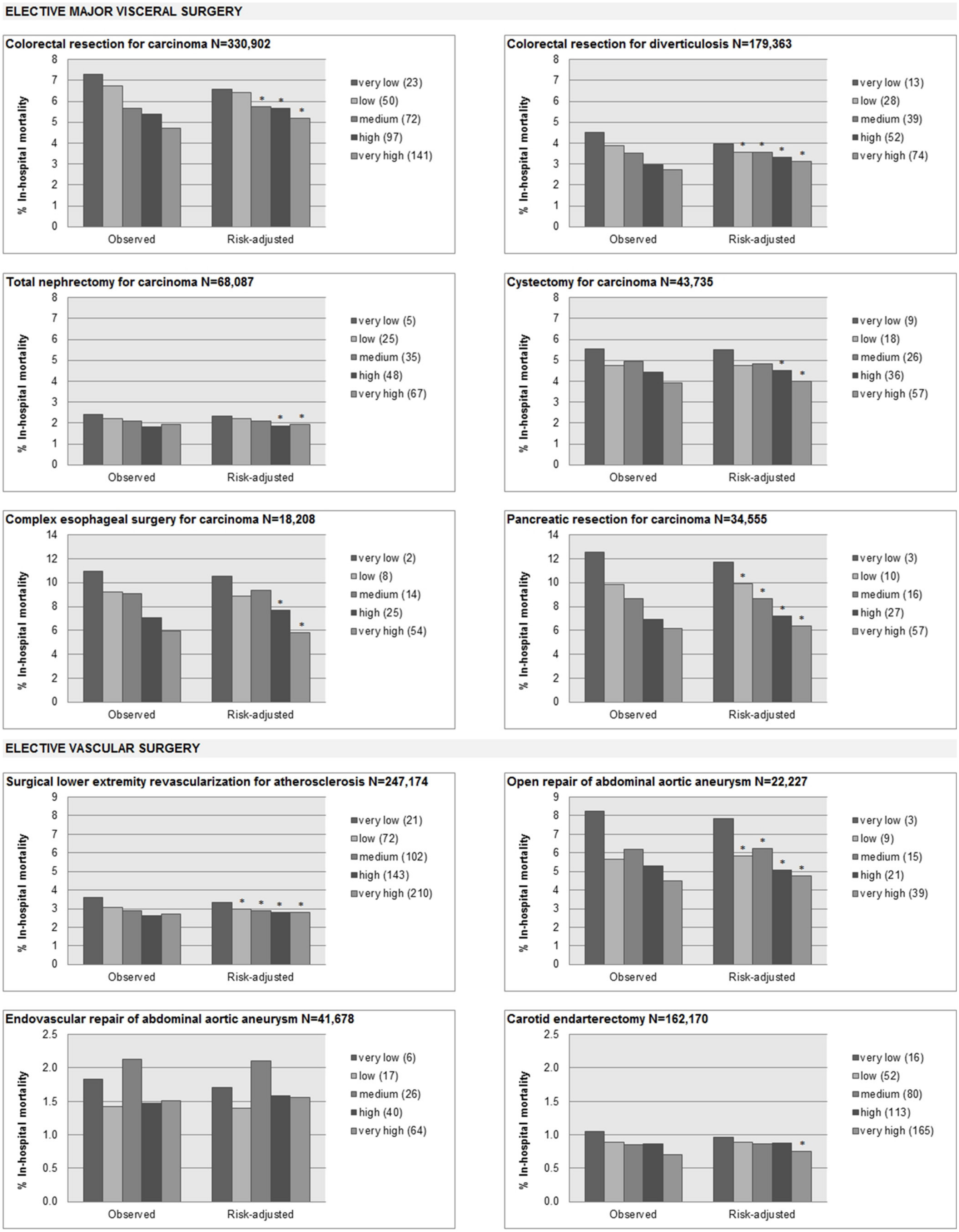

Figure 1 Continued

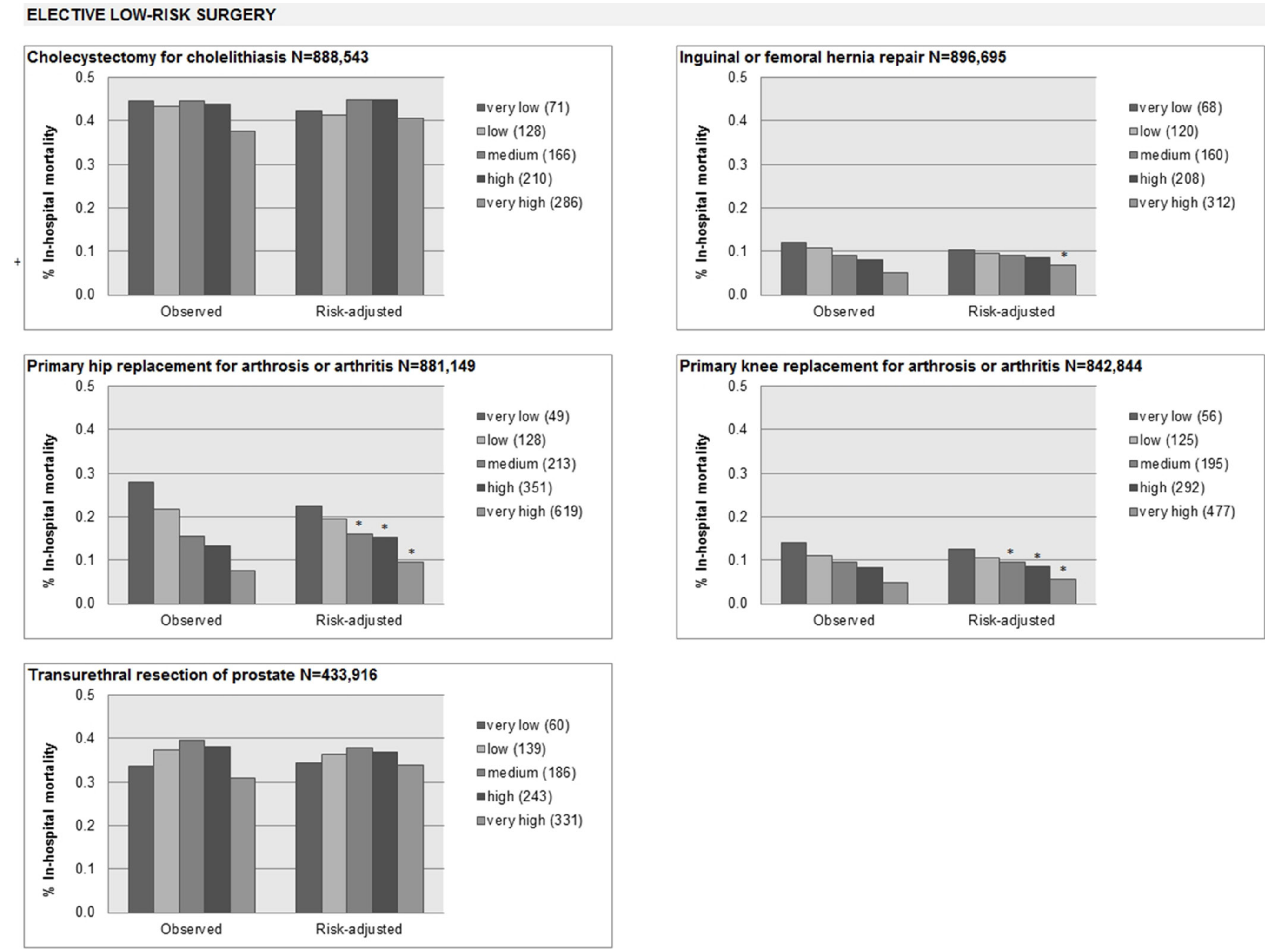

Figure 1 Observed and risk-adjusted inhospital mortality by hospital volume quintile. *Statistically significant lower than very low volume quintile. +Statistically significant higher than very low volume quintile. Numbers displayed in the legend of each graph denote the median annual hospital volume within the respective volume quintile. Covariates used for risk adjustment are displayed in the online supplementary table 3.

low to high volume quintiles when compared with the very low volume quintile (figure 1). Hospital volume as a continuous variable had no effect on mortality (table 3).

Elective heart and thoracic surgery

For each out of the four studied types of heart and thoracic surgery, lower inhospital mortality in association with higher hospital volume was observed.

From 2009 to 2014, about 52 600 patients were treated with isolated surgical aortic valve replacement (table 1). Adjusted mortality was 2.4% (95% CI 2.1 to 2.7) in the very high volume quintile versus 3.1% (2.8 to 3.4%)%) in the very low volume quintile (figure 1). Reduced odds of death were found in the medium to very high volume quintiles when compared with the very low volume quintile (table 2). As a continuous variable, hospital volume demonstrated an independent effect on mortality (figure 2). The minimum volume to achieve a lower-than-average risk of death was calculated as 147 annual treatments. This threshold resulted in a non-significant PRD of 0.2% (−0.02 to 0.3) and a PIN of 516 (288 to 2589, table 3).

Inhospital mortality of the 50 800 patients treated with transcatheter aortic valve replacement (table 1) was 5.2% (95% CI 4.8 to 5.7) in the very high volume quintile versus 7.6% (7.1 to 8.2) in the very low volume quintile (figure 1). Hospital volume as a continuous variable revealed an independent effect on mortality (figure 2), and the minimum volume to fall below the average mortality of 6.6% was calculated as 157 cases per year. Application of this threshold was estimated to prevent one death among 133 (101 to 193) patients (table 3). This means that among 133 patients with transcatheter aortic valve replacement, one death would be prevented if all providing hospitals would perform this treatment at least 157 times per year.

A total of 184 000 patients were treated with an isolated coronary artery bypass graft (table 1). According to hospital quintiles, no constant association of volume and mortality was found (figure 1, table 2). However, an

Table 2 ORs of inhospital death according to volume quintile

		Hospital volume quintile				
		Very low	Low	Medium	High	Very high
Common emergency conditions						
Acute myocardial infarction	Crude OR	1.00	0.82	0.74	0.72	0.71
	Adjusted OR (95% CI)	1.00	0.84* (0.81 to 0.87)	0.75* (0.72 to 0.78)	0.73* (0.7 to 0.76)	0.69* (0.66 to 0.72)
Heart failure	Crude OR	1.00	0.95	0.89	0.87	0.81
	Adjusted OR (95% CI)	1.00	0.99 (0.96 to 1.01)	0.96* (0.93 to 0.99)	0.95* (0.92 to 0.98)	0.91* (0.88 to 0.94)
Ischaemic stroke	Crude OR	1.00	0.77	0.70	0.70	0.72
	Adjusted OR (95% CI)	1.00	0.90* (0.87 to 0.94)	0.87* (0.83 to 0.9)	0.94* (0.91 to 0.98)	0.94* (0.91 to 0.98)
Pneumonia	Crude OR	1.00	1.09	1.16	1.12	1.08
	Adjusted OR (95% CI)	1.00	1.10 (1.07 to 1.13)	1.17 (1.14 to 1.21)	1.13 (1.09 to 1.16)	1.08 (1.04 to 1.11)
Chronic obstructive pulmonary disease	Crude OR	1.00	1.06	1.04	0.91	0.66
	Adjusted OR (95% CI)	1.00	1.09 (1.06 to 1.14)	1.08 (1.04 to 1.12)	0.94* (0.90 to 0.98)	0.70* (0.65 to 0.75)
Hip fracture	Crude OR	1.00	1.06	1.06	1.07	1.00
	Adjusted OR (95% CI)	1.00	1.07 (1.03 to 1.12)	1.07 (1.03 to 1.11)	1.10 (1.06 to 1.15)	1.01 (0.97 to 1.06)
Elective heart and thoracic surgery						
Isolated surgical aortic valve replacement	Crude OR	1.00	0.90	0.80	0.74	0.74
	Adjusted OR (95% CI)	1.00	0.87 (0.69 to 1.10)	0.78* (0.62 to 0.99)	0.69* (0.54 to 0.87)	0.77* (0.61 to 0.97)
Transcatheter aortic valve replacement	Crude OR	1.00	0.97	0.90	0.78	0.64
	Adjusted OR (95% CI)	1.00	0.98 (0.69 to 1.1)	0.87* (0.62 to 0.99)	0.79* (0.54 to 0.87)	0.65* (0.61 to 0.97)
Isolated coronary artery bypass graft	Crude OR	1.00	0.93	1.03	0.73	0.70
	Adjusted OR (95% CI)	1.00	0.98 (0.81 to 1.17)	1.08 (0.90 to 1.28)	0.82* (0.68 to 0.99)	0.92 (0.76 to 1.11)
Partial lung resection for carcinoma	Crude OR	1.00	0.71	0.68	0.52	0.37
	Adjusted OR (95% CI)	1.00	0.77* (0.67 to 0.90)	0.73* (0.63 to 0.85)	0.58* (0.50 to 0.69)	0.49* (0.41 to 0.58)
Elective major visceral surgery						
Complex oesophageal surgery for carcinoma	Crude OR	1.00	0.83	0.81	0.62	0.51
	Adjusted OR (95% CI)	1.00	0.81* (0.68 to 0.96)	0.85 (0.72 to 1.01)	0.67* (0.56 to 0.82)	0.47* (0.38 to 0.58)

Continued

Table 2 Continued

		Hospital volume quintile				
		Very low	Low	Medium	High	Very high
Pancreatic resection for carcinoma	Crude OR	1.00	0.76	0.66	0.52	0.46
	Adjusted OR (95% CI)	1.00	0.80* (0.71 to 0.92)	0.68* (0.59 to 0.77)	0.54* (0.46 to 0.62)	0.46* (0.39 to 0.54)
Colorectal resection for carcinoma	Crude OR	1.00	0.92	0.77	0.72	0.63
	Adjusted OR (95% CI)	1.00	0.97 (0.91 to 1.02)	0.85* (0.80 to 0.90)	0.83* (0.78 to 0.88)	0.75* (0.70 to 0.80)
Colorectal resection for diverticulosis	Crude OR	1.00	0.86	0.77	0.65	0.60
	Adjusted OR (95% CI)	1.00	0.87* (0.80 to 0.95)	0.87* (0.79 to 0.95)	0.80* (0.72 to 0.88)	0.74* (0.67 to 0.82)
Total nephrectomy for carcinoma	Crude OR	1.00	0.92	0.87	0.75	0.80
	Adjusted OR (95% CI)	1.00	0.95 (0.79 to 1.13)	0.89 (0.75 to 1.06)	0.78* (0.64 to 0.94)	0.80* (0.67 to 0.97)
Cystectomy for carcinoma	Crude OR	1.00	0.85	0.89	0.80	0.70
	Adjusted OR (95% CI)	1.00	0.85* (0.73 to 0.98)	0.86 (0.74 to 1.00)	0.80* (0.69 to 0.93)	0.69* (0.58 to 0.82)
Elective vascular surgery						
Surgical lower extremity revascularisation for atherosclerosis	Crude OR	1.00	0.86	0.80	0.73	0.75
	Adjusted OR (95% CI)	1.00	0.88* (0.81 to 0.96)	0.85* (0.78 to 0.94)	0.82* (0.75 to 0.90)	0.82* (0.75 to 0.91)
Open repair of abdominal aortic aneurysm	Crude OR	1.00	0.67	0.73	0.62	0.52
	Adjusted OR (95% CI)	1.00	0.71* (0.59 to 0.84)	0.76* (0.63 to 0.91)	0.60* (0.50 to 0.72)	0.55* (0.45 to 0.68)
Endovascular repair of abdominal aortic aneurysm	Crude OR	1.00	0.77	1.17	0.80	0.82
	Adjusted OR (95% CI)	1.00	0.81 (0.63 to 1.04)	1.26 (1.00 to 1.59)	0.93 (0.72 to 1.19)	0.91 (0.68 to 1.21)
Carotid endarterectomy	Crude OR	1.00	0.85	0.81	0.82	0.66
	Adjusted OR (95% CI)	1.00	0.92 (0.77 to 1.09)	0.89 (0.75 to 1.05)	0.90 (0.76 to 1.06)	0.77* (0.64 to 0.93)
Elective low-risk surgery						
Cholecystectomy for cholelithiasis	Crude OR	1.00	0.97	1.00	0.98	0.84
	Adjusted OR (95% CI)	1.00	0.98 (0.87 to 1.09)	1.06 (0.95 to 1.19)	1.07 (0.95 to 1.19)	0.95 (0.85 to 1.08)
Inguinal or femoral hernia repair	Crude OR	1.00	0.88	0.75	0.66	0.43
	Adjusted OR (95% CI)	1.00	0.94 (0.77 to 1.14)	0.90 (0.72 to 1.11)	0.83 (0.66 to 1.04)	0.66* (0.51 to 0.86)

Continued

Table 2 Continued

		Hospital volume quintile				
		Very low	Low	Medium	High	Very high
Transurethral resection of prostate	Crude OR	1.00	1.11	1.18	1.13	0.92
	Adjusted OR (95% CI)	1.00	1.06 (0.89 to 1.25)	1.11 (0.93 to 1.32)	1.08 (0.90 to 1.28)	0.98 (0.82 to 1.18)
Primary hip replacement for arthrosis or arthritis	Crude OR	1.00	0.78	0.56	0.48	0.27
	Adjusted OR (95% CI)	1.00	0.87* (0.75 to 1.00)	0.70* (0.60 to 0.82)	0.67* (0.56 to 0.79)	0.41* (0.33 to 0.51)
Primary knee replacement for arthrosis or arthritis	Crude OR	1.00	0.79	0.68	0.59	0.35
	Adjusted OR (95% CI)	1.00	0.84 (0.69 to 1.02)	0.76* (0.62 to 0.94)	0.68* (0.54 to 0.85)	0.45* (0.34 to 0.58)

Covariates used for risk adjustment are displayed in the online supplementary table 3.
*Statistically significantly lower than reference category (very low volume).

independent effect of hospital volume on mortality was observed when volume was analysed as a continuous variable (figure 2), and the minimum volume to achieve a risk of death below the average of 2.1% was calculated as 475 cases per year. This threshold led to a PIN of 658 (445 to 1271, table 3).

In total, 74000 patients with partial lung resection for carcinoma were studied (table 1). In the very high volume quintile, adjusted mortality was 2.0% (95% CI 1.8 to 2.3) versus 3.8% (3.6 to 4.1) in the very low volume quintile (figure 1). The observed independent effect of hospital volume when analysed continuously resulted in a minimum volume of 108 cases per year. This threshold was estimated to prevent one death among 168 (137 to 217) patients (table 3).

Elective major visceral surgery

Lower mortality associated with higher hospital volume was found for all six studied types of elective visceral surgery.

During the observation period, 331000 colorectal resections for carcinoma were performed in German hospitals (table 1). Mortality was 5.2% (95% CI 5.0 to 5.4) in the very high volume quintile and 6.6% (6.4 to 6.8) in the very low volume quintile (figure 1). In comparison to the very low volume quintile, odds of death were statistically significantly reduced in the medium to very high volume quintiles (table 2). Hospital volume as a continuous variable had an independent effect on mortality (figure 2). The minimum volume to achieve a risk of death below the average of 6.0% was calculated as 82 annual treatments, associated with a PIN of 197 (167 to 241, table 3).

A total of 179000 colorectal resections were performed for diverticulosis (table 1). Adjusted mortality was 3.1% (95% CI 2.9 to 3.3) in the very high volume quintile versus 3.9% (3.8 to 4.1) in the very low volume quintile (figure 1). Hospital volume as a continuous variable had an independent effect on mortality, and a minimum volume of 44 was calculated to achieve a risk of death below the average of 3.5%. This threshold was associated with a PIN of 364 (269 to 564, table 3).

During the observation period, 68000 patients with total nephrectomy for carcinoma were identified (table 1). In the very high volume quintile, adjusted mortality was 1.9% (95% CI 1.7 to 2.2) and in the very low volume quintile 2.3% (2.1 to 2.6). The independent effect of hospital volume as a continuous variable demonstrated borderline statistical significance (figure 2), and the minimum volume to achieve lower-than-average mortality was calculated as 40 cases per year. Application of this threshold would prevent one death among 459 (295 to 1056) nephrectomy patients (table 3).

Adjusted mortality among the 44000 patients receiving cystectomy for carcinoma (table 1) was 4.0% (95% CI 3.6 to 4.4) in the very high volume quintile versus 5.5% (5.0 to 6.0) in the very low volume quintile (figure 1). Continuous increment of hospital volume was independently associated with lower mortality (figure 2). This relation

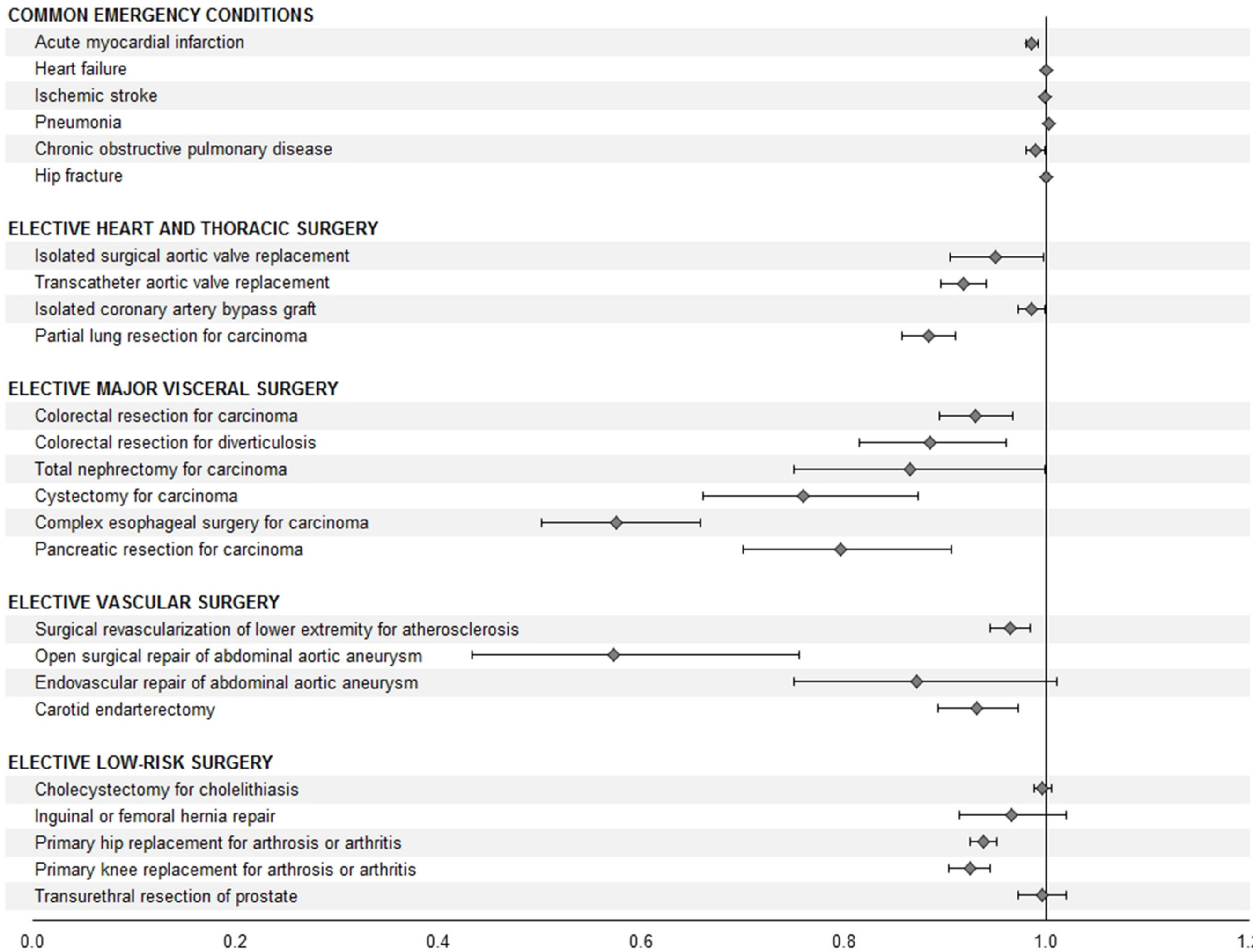

Figure 2 Adjusted odds ratios of inhospital death according to an increment of hospital volume of 50 cases per year. Whiskers indicate 95% CI. Covariates used for risk-adjustment are displayed in the online supplementary appendixe table 3.

of volume and outcome resulted in a minimum volume of 31 cases per year to fall below the average mortality of 4.7%. Application of this threshold was associated a PIN of 227 (150 to 480, table 3).

Among the 18 000 patients with complex oesophageal surgery for carcinoma, adjusted mortality was 5.8% (95% CI 5.1 to 6.6) in the very high volume quintile versus 10.5% (9.5 to 11.6) in the very low volume quintile. As a continuous variable, hospital volume had an independent effect on mortality, and the minimum volume to fall below the average mortality of 8.5% was calculated as 22 cases per year. If all hospitals would perform at least 22 complex oesophageal surgeries per year, one death among 47 (38 to 62) patients could be prevented (table 3).

A pancreatic resection for carcinoma was performed in 35 000 patients in total (table 1). Adjusted mortality was 6.4% (95% CI 5.8 to 7.0) in the very high volume quintile versus 11.7% (10.9 to 12.5) in the very low volume quintile (figure 1). Continuous increment of hospital volume was associated with lower mortality, and the minimum volume where risk of death would fall below the average mortality of 8.8% was calculated as 29 cases per year. This threshold resulted in a PIN of 46 (39 to 58, table 3).

Elective vascular surgery

In three out of the four studied types of elective vascular surgery, higher hospital volume was associated with lower inhospital mortality.

During the observation period, 247 000 patients were treated with surgical revascularisation of lower extremities for atherosclerosis (table 1). Risk-adjusted mortality was 2.8% (95% CI 2.7 to 3.0) in the very high volume quintile versus 3.3% (3.2 to 3.5) in the very low volume quintile (figure 1). Odds of death were reduced in all other quintiles when compared with the very low volume quintile (table 2). The association of volume and outcome persisted when volume was analysed as continuous variable (figure 2), and the minimum volume to achieve a mortality risk below the average of 3.0% was calculated as 123 cases per year. This led to the estimation that among 561 (387 to 1024) patients, one additional death was attributable to treatment by a hospital performing less than 123 of such operations (table 3).

In total, more than 22 000 patients receiving open repair of abdominal aortic aneurysm were analysed (table 1). In the very high volume quintile, risk-adjusted mortality was 4.7% (95% CI 4.1 to 5.4) versus 7.8% (7.1

Table 3 Minimum volume threshold estimation and assessment of population impact

	Logistic regression coefficients of hospital volume				VARL Minimum volume threshold (95% CI)	Average mortality in population	Adjusted mortality if volume ≥ VARL (95% CI)	Population-based risk difference (95% CI)	PIN Population impact number (95% CI)
	Simple model		Full model						
	β	p	β	p					
Common emergency conditions									
Acute myocardial infarction	−0.0003	<0.001	−0.0003	<0.001	309 (288 to 330)	9.8%	9.1% (9.0 to 9.2)	0.7% (0.7 to 0.8)	137 (127 to 149)
Heart failure	−0.0001	0.001	0.0000	0.358	–	8.9%			
Ischaemic stroke	−0.0002	0.000	0.0000	0.025	–	6.9%			
Pneumonia	0.0000	0.003	0.0000	<0.001	–	11.6%			
Chronic obstructive pulmonary disease	−0.0003	0.039	−0.0002	0.026	271 (240 to 301)	4.2%	3.6% (3.5 to 3.6)	0.6% (0.5 to 0.6)	170 (158 to 185)
Hip fracture	0.0000	0.138	0.0000	0.828	–	5.5%			
Elective heart and thoracic surgery									
Isolated surgical aortic valve replacement	−0.0014	0.001	−0.0010	0.039	147 (111 to 182)	2.6%	2.4% (2.2 to 2.6)	0.2% (0.0 to 0.3)	516 (288 to 2589)
Transcatheter aortic valve replacement	−0.0024	<0.001	−0.0017	<0.001	157 (142 to 171)	6.6%	5.8% (5.5 to 6.2)	0.8% (0.5 to 1.0)	133 (101 to 193)
Isolated coronary artery bypass graft	−0.0007	<0.001	−0.0003	0.024	475 (430 to 521)	2.1%	2.0% (1.9 to 2.1)	0.2% (0.1 to 0.2)	658 (445 to 1271)
Partial lung resection for carcinoma	−0.0034	<0.001	−0.0025	<0.001	108 (95 to 120)	2.9%	2.3% (2.1 to 2.5)	0.6% (0.5 to 0.7)	168 (137 to 217)
Elective major visceral surgery									
Colorectal resection for carcinoma	−0.0023	<0.001	−0.0014	<0.001	82 (76 to 88)	6.0%	5.4% (5.3 to 5.5)	0.5% (0.4 to 0.6)	197 (167 to 241)
Colorectal resection for diverticulosis	−0.0049	<0.001	−0.0025	0.003	44 (38 to 49)	3.5%	3.2% (3.1 to 3.4)	0.3% (0.2 to 0.4)	364 (269 to 564)
Total nephrectomy for carcinoma	−0.0032	0.012	−0.0029	0.047	40 (24 to 56)	2.1%	1.9% (1.7 to 2.0)	0.2% (0.1 to 0.3)	459 (295 to 1056)
Cystectomy for carcinoma	−0.0054	<0.001	−0.0055	<0.001	31 (23 to 39)	4.7%	4.3% (4.0 to 4.6)	0.4% (0.2 to 0.7)	227 (150 to 480)
Complex oesophageal surgery for carcinoma	−0.0105	<0.001	−0.0111	<0.001	22 (17 to 28)	8.5%	6.3% (5.7 to 6.9)	2.1% (1.6 to 2.6)	47 (38 to 62)
Pancreatic resection for carcinoma	−0.0049	<0.001	−0.0045	0.001	29 (21 to 37)	8.8%	6.6% (6.2 to 7.2)	2.2% (1.7 to 2.6)	46 (39 to 58)
Elective vascular surgery									
Surgical lower extremity revascularisation for atherosclerosis	−0.0011	<0.001	−0.0007	<0.001	123 (102 to 144)	3.0%	2.8% (2.7 to 2.9)	0.2% (0.1 to 0.3)	561 (387 to 1024)
Open repair of abdominal aortic aneurysm	−0.0129	<0.001	−0.0112	<0.001	18 (14 to 23)	6.0%	5.0% (4.6 to 5.5)	1.0% (0.6 to 1.3)	104 (76 to 166)
Endovascular repair of abdominal aortic aneurysm	−0.0031	0.014	−0.0028	0.069	–	1.7%			
Carotid endarterectomy	−0.0021	<0.001	−0.0014	<0.001	93 (69 to 116)	0.87%	0.81% (0.74 to 0.88)	0.06% (0.01 to 0.11)	1646 (886 to 12661)
Elective low-risk surgery									

Continued

Table 3 Continued

	Logistic regression coefficients of hospital volume				VARL Minimum volume threshold (95% CI)	Average mortality in population	Adjusted mortality if volume ≥ VARL (95% CI)	Population-based risk difference (95% CI)	PIN Population impact number (95% CI)
	Simple model		Full model						
	β	p	β	p					
Cholecystectomy for cholelithiasis	−0.0003	0.008	−0.0001	0.425	–	0.43%			
Inguinal or femoral hernia repair	−0.0019	0.009	−0.0007	0.212	–	0.09%			
Primary hip replacement for arthrosis or arthritis	−0.0020	<0.001	−0.0013	<0.001	252 (227 to 278)	0.17%	0.13% (0.12 to 0.14)	0.04% (0.03 to 0.05)	2747 (2186 to 3701)
Primary knee replacement for arthrosis or arthritis	−0.0020	<0.001	−0.0016	<0.001	228 (190 to 265)	0.10%	0.07% (0.07 to 0.08)	0.02% (0.01 to 0.03)	4729 (3513 to 7269)
Transurethral resection of prostate	−0.0003	0.130	−0.0001	0.740	–	0.36%			

Logistic regression coefficients of hospital volume relate to an increment of 1 case per year.
VARL, value of acceptable risk limit,[27] calculated from the logistic regression coefficient of the simple model. It estimates a minimum volume threshold to achieve a risk of inhospital mortality which is lower than a predefined acceptable risk. The acceptable risk for each treatment was set to the average mortality in the respective patient population during the observation period. The population impact number PIN is the reciprocal of the difference between the average mortality in the patient population and the adjusted mortality in those patients treated by hospitals with volumes above the threshold (population-based risk difference). It can be interpreted as average number of the entire patient population among whom one death is attributable to treatment by a below-threshold volume hospital. Covariates used for risk adjustment are displayed in the online supplementary table 3.

to 8.7) in the very low volume quintile (figure 1). When analysed continuously, higher volume was independently associated with lower mortality (figure 2). The calculated minimum volume where risk would fall below the average of 6.0% was 18 cases per year. The resulting PIN was 104 (76 to 166, table 3).

Among the 42 000 patients treated with endovascular repair of abdominal aortic aneurysm (table 1), risk-adjusted mortality was 1.6% (95% CI 1.3 to 1.9) in the very high volume quintile versus 1.7% (1.4 to 2.0) in the very low volume quintile. Highest mortality was observed in the medium volume quintile (2.1%, 1.8 to 2.4, figure 1). Odds of death were not significantly different between volume quintiles (table 2). Analysed as continuous variable, no statistically significant effect of hospital volume on mortality was observed (figure 2, table 3).

From 2009 to 2014, about 162 000 patients with carotid endarterectomy were identified (table 1). Risk-adjusted inhospital mortality was 0.75% (95% CI 0.66 to 0.86) in the very high volume quintile and 0.97% (0.87 to 1.07) in the very low volume quintile (figure 1). Continuous increment of hospital volume was independently associated with lower inhospital mortality (figure 2). A lower-than-average risk of mortality is expected if hospitals perform at least 93 carotid endarterectomies per year. Under this threshold, the estimated PIN was 1646 (886 to 12661, table 3).

Elective low-risk surgery

In three out of the five studied types of elective low-risk surgery, higher hospital volume was found to be associated with lower mortality when volume was categorised in quintiles. In two types of elective low-risk surgery, this relation persisted when volume was analysed as a continuous variable.

From 2009 to 2014, nearly 889 000 inpatient cholecystectomies for cholelithiasis were performed in German hospitals (table 1). Risk-adjusted mortality differed not significantly between volume quintiles (figure 1), as well as risk-adjusted odds of death (table 2). Continuous increment of hospital volume was not associated with mortality (table 3).

Among the 897 000 inpatient inguinal or femoral hernia repairs (table 1), mortality in the very high volume quintile was lower (0.07%, 95% CI 0.06 to 0.08) than in the very low volume quintile (0.10%, 0.09 to 0.12, figure 1). Yet, the independent effect of continuous increment of hospital volume was not statistically significant (table 3).

The analysis of more than 881 000 primary hip replacements for arthrosis or arthritis (table 1) revealed a constant association of hospital volume and mortality when patients were stratified by volume quintiles. Risk-adjusted inhospital mortality was 0.10% (95% CI 0.08 to 0.11) in the very high volume quintile versus 0.23% (0.21 to 0.25) in the very low volume quintile (figure 1). In comparison to the very low volume quintile, odds of death were significantly reduced in all other volume quintiles (table 2). Within the analysis of continuous increment of hospital volume, an independent effect on mortality was observed (figure 2). A minimum volume of 252 cases per year was calculated to achieve a risk of mortality below the average of 0.17%. The PIN resulting from this threshold was 2747 (2186 to 3701, table 3).

Overall, 843 000 patients with primary knee replacement for arthrosis or arthritis were identified (table 1). Risk-adjusted mortality was 0.06% (95% CI 0.05 to 0.07) in the very high volume quintile versus 0.13% (0.11 to 0.14) in the very low volume quintile (figure 1). Continuous increment of hospital volume was independently associated with lower mortality (figure 2), and 228 annual cases were calculated as the minimum volume where risk of mortality would fall below the average of 0.10%. This minimum volume threshold resulted in an estimation of one preventable death among 4729 (3513 to 7269) primary knee replacement patients if all hospitals would perform at least 228 such operations per year (table 3).

In total, 434 000 patients with transurethral resection of prostate were studied (table 1). No statistically significant differences in inhospital mortality were found when patients were stratified by hospital volume quintiles (figure 1, table 2), and there was no significant association of hospital volume and mortality when volume was analysed continuously (table 3).

Sensitivity analysis

Within the sensitivity analysis, hospital volume was determined more widely by considering all those treatments or procedures, which could be regarded as technically similar to the specific treatment for which outcome was measured. The specific restrictions for the purpose of outcome measurement were applied after determining volume. Using this divergent volume definition, results remained substantially unchanged in 23 out of the 25 studied types of treatments.

Different findings were observed regarding isolated coronary artery bypass graft, where the relation of volume and mortality was more pronounced when all related procedures (ie, coronary bypass grafts in patients with acute myocardial infarction or combined with other heart surgery instead of elective isolated coronary operations only) were considered for determination of hospital volume. Different from the findings in the main analysis, higher volume was constantly associated with lower mortality when patients were stratified by these volume quintiles.

The volume–outcome association in colorectal resections for diverticulosis diminished when hospital volume was determined by considering all colorectal resections, regardless from medical indication. In contrast to the results of the main analysis, no statistically significant relation between volume and outcome was observed under this approach.

DISCUSSION

Lower inhospital mortality in association with higher hospital volume was observed in 20 out of the 25 studied types of treatment when volume was categorised in quintiles and persisted in 17 types of treatment when volume was analysed as a continuous variable. While a volume–outcome relationship was not found in all studied emergency conditions and low-risk procedures, it was more consistently present regarding complex surgical procedures. The potential benefit of a centralisation according to the calculated minimum volume thresholds varied depending on the treatment-specific risk of death and the strength of the association between volume and mortality.

The analysis included every patient who underwent one of the studied types of inpatient treatment in a German acute care hospital during the observation period. Limitations occur from the limited information available in administrative data, including lack of information on appropriateness of patient selection for procedures. Although types of treatment and covariates for risk adjustment were defined in a sophisticated way, it is possible that unmeasured differences in disease severity, comorbidity or appropriateness may partly explain the association between volume and outcome. However, it should be considered that the more severe patients should intentionally not be treated by low-volume hospitals. Elective types of treatment were either defined by exclusion of patients with diagnoses pointing to an emergency admission or potential emergency diagnoses were considered within the risk adjustment models. However, this approach might not have fully separated elective admissions. The analyses could focus hospital volume only because physician volumes are not available in German administrative data. Regarding the determination of hospital volume, a possible misclassification of multicampus hospitals as high-volume providers must be taken into account, resulting in a possible underestimation of the association between hospital volume and mortality.[30] Finally, this study did not consider hospital characteristics like teaching status, type of ownership or location.

Inpatient treatments for emergency conditions revealed mixed results. Associations between higher hospital volume and lower mortality were found for treatment of acute myocardial infarction, heart failure, ischaemic stroke and COPD. These results are similar to findings of previous studies from other countries.[6 7 31–36] Regarding the treatment of patients with pneumonia, the analysis revealed higher mortality in hospitals with higher volumes. A similar finding has been reported by one previous US study,[37] while another more recent US study found higher hospital volume being associated with lower mortality.[6] No constant relation between volume and outcome was observed in hip fracture patients, similar to findings from a recent US study.[38] However, a previous German study, which was based on national discharge data as well, but focused an earlier time period and surgically treated hip fracture patients only, found lower mortality related to higher hospital volumes.[19] An Italian study observed a volume–outcome relation in hip fracture patients, too.[36]

An association of lower mortality and higher hospital volume was observed for each studied type of elective heart and thoracic surgery. These findings correspond to those from several European and US studies.[3 5 14 36 39–41] In the present study, a more pronounced volume–outcome association was found for lung resection than for the studied types of heart surgery. This might be explained by an already quite high degree of centralisation of heart surgery services in Germany.

The analysis of major visceral surgery treatments revealed the most pronounced associations between volume and mortality, for example, regarding oesophageal surgery, cystectomy or pancreatic resection for carcinoma. These results are well supported by international evidence of a strong volume–outcome association in complex visceral surgery.[3 11 12 17 18 42–46]

In the case of vascular surgery, the analyses demonstrated lower mortality in association with higher hospital volume for lower extremity revascularisation, carotid endarterectomy and open repair of abdominal aortic aneurysm, in accordance to findings from the international literature.[3 5 36 47 48] A volume–outcome relation for abdominal aortic aneurysm repair (open, endovascular or totally percutaneous) had been demonstrated by a previous German study based on national discharge data.[19] In the present study, however, endovascular repair of abdominal aortic aneurysm was analysed separately, and no significant relationship between volume and mortality was observed. This finding is in contrast to one study from the US,[49] while a more recent US study found no significant association.[50]

Among the studied types of elective low-risk surgery, lower mortality associated with higher volume was found for primary knee and hip replacements, supported by international findings.[8 51–54] However, no such relation was observed for cholecystectomy, similar to one study from England,[55] but in contrast to studies from Italy and Scotland, which found a modest association between volume and outcome in cholecystectomy patients.[10 36] The effect of volume on mortality observed in patients undergoing inguinal or femoral hernia repair was small. Studies from the USA and Sweden reported a volume–outcome relation for hernia repair but focused different outcomes (hernia recurrence or reoperation rates) and determined volume rather on the surgeon level.[56 57] Regarding transurethral resection of prostate, no association between hospital volume and mortality was found. This confirms the findings of a Japanese study which found an association regarding complication and blood transfusion rates, but not regarding mortality.[58]

Overall, the results of the present study seem plausible in view of the current literature. Discrepancies to findings from other studies might be caused by differences in completeness of data or alternative methodological approaches, for example, regarding case definitions or volume determination. However, it is also possible that an association between volume and outcome is more or less existent in different countries, depending on characteristics of a healthcare system and hospital market structures.[39]

Minimum volume thresholds were calculated for those treatments, in which the association of volume and mortality persisted when volume was analysed as a continuous variable, which provides a strong indication that such an association truly exists. The highest population impact of centralisation according to the calculated thresholds was estimated for oesophageal surgery and pancreatic resection for carcinoma. Compared with this, the potential for improvement might appear small in the case of treatments with a basically low risk of mortality. However, one should consider that risk of mortality is likely correlated with the occurrence of non-lethal adverse events, in particular with regard to low-risk procedures. Thus, possible improvements of patient safety by centralisation might reach beyond effects on mortality.

When interpreting the findings of this study, one should note that observational studies cannot proof a causal volume–outcome relation. In consequence, this retrospective observational study cannot provide evidence that an application of the calculated thresholds as minimum volumes would actually improve quality of care. Therefore, the threshold values are meant to serve as basic orientation points for policy decisions in Germany and as hypothesis-generating landmarks for further research. Although estimated rather conservatively, roughly 80%–90% of hospitals providing a specific treatment performed annual volumes below the respective threshold and between 50% (acute myocardial infarction) and 70% (pancreatic resection for carcinoma) of patients were treated by those hospitals. Policy decisions on centralisation of services cannot rely on testing a statistical association on observational data, alone. As well, the regional availability and accessibility of inpatient services must be considered, in particular regarding emergency treatments. Centralisation should be pushed primarily in oversupplied geographical regions. However, experiences from the Netherlands have demonstrated that centralisation of inpatient services improved national outcome.[59]

A previous German study concluded that full implementation of the existing minimum volume regulation could improve the quality of hospital care in Germany.[24] In addition to this, the present study identified further areas where centralisation could provide a benefit for patients and quantified the possible impact of centralisation efforts by using complete national hospital discharge data. These findings might support future policy decisions in Germany.

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Contributors UN designed the study, conducted the analysis, interpreted the data and drafted the manuscript. TM contributed to the study design, to the interpretation of data and to revising the manuscript critically for important intellectual content. Both authors gave final approval of the version to be published and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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