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The association of hospital volume with outcomes in patients with abdominal aorta aneurysms

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Illonzo 2014	USA	Hospitals, number of hospitals unclear	295851 patients	Abdominal aorta aneurysm (codes not reported)	Open (procedure codes not reported)	Low <3, medium 4 to 7, high 8 to 257	Mortality (30 day mortality after complications associated with procedure)	High volume hospitals had a higher success rate of rescue compared to low volume hospitals (p<0.001). Trend in failure to rescue 2.73% for high volume vs 5.66% for low volume. In the multivariate regression, the OR for failure to rescue in medium volume compared to low was 0.68 (95% CI 0.64 to 0.73), in high OR 0.30 (95%CI 0.28 to 0.32) (data from the multivariate analysis included for both open and endovascular).	Multivariate logistic regression analysis adj for age, gender, race, comorbidities, hospital annual volume, and year of the surgery.
Amundsen 1990	Norway	26 surgical units	279 patients	Abdominal aorta aneurysm (code not reported)	Open (procedure codes not reported)	Volume categories were 1: <9, 2: 10 to 29, 3: 30 to 39, 4:	Mortality (30-day mortality)	Hospital mortality for elective surgery: 1-9 surgeries: 8/58 (13.8%), 10-29 surgeries: 6/82	Cross tabulation and chi-square. A model consisting of the significant variables (log likelihood ratio

						>40		(7.3%), 30-39 surgeries 4/67 (6%), >40 surgeries 1/45 (2.2%). The odds of mortality was OR 2.7 (p=0.04).	tests, p<0.05) predicts the probability of dying. The odds ratio- the ratio between the odds for dying in two groups of patients as given by the levels of a prognostic variable, indicate the strength of that variable and can be found by exponentian of its regression coefficient.
Kantonen 1997 (and 1999)	Finland	23 hospitals	929 patients	Abdominal aorta aneurysm (codes not reported)	Open (procedure codes not reported)	>15 high	Mortality (30-day mortality)	There was no association according to the authors between volume and mortality. Numbers not reported, only plotted in figure.	Correlation between volume and mortality was tested using linear regression analysis.
Khuri 1999	USA	107 hospitals	3767 cases	Department of Veterans Affairs (VA) National Surgical Quality Improvement Program (NSQIP) database 1991 to 1999	Open (CPT-4 code 35081)	Quartiles, 1: 0 to 3, 2: 4 to 6, 3: 7 to 10, and 4: 11 to 32	Mortality (30-day mortality)	Lower volume was not found to be a strong predictor of mortality (in logistic regression -0.02844 (SE 0.02), p=0.10)	A mixed effects hierarchical logistic regression analysis adj for patient risk factors.
Landon 2010	USA	Hospitals, numbers unlcear	78257 cases	Abdominal aorta aneurysm (ICD-9 code 441.4)	Open (ICD-9 codes 38.44 or 39.25)	1: <9, 2: 10 to 17, 3: 18 to 29, 4: 30 to 49, 5: >50.	Mortality (30-day mortality)	Mortality decreases with higher volume, with an absolute difference of >3 percentage points between the highest- and lowest	All models were adjusted for baseline clinical and demographic characteristics. Observed mortality in each

								volume hospitals	quintile was compared with predicted adjusted mortality computed under the counterfactual assumption that all procedures occurred at a hospital in the lowest-volume quintile.
Brooke 2008	USA (California)	140 hospitals of 337 hospitals included	6406 cases	Abdominal aorta aneurysm (codes not reported)	Open (ICD-9 codes 38.34, 38.36, 38.44, 38.64, 39.25, 39.52)	>50 high	Mortality (in-hospital mortality)	The average rates of mortality at time-point 1 (2000-2003): high volume 69 (3.96%)/ low volume 74 (3.85%) Time-point 2 (2003-2005): high volume 55 (4.39%)/ low volume 75 (5.05%). In the adj regression model, the effect of volume on mortality was uncertain. The RR 0.80 (95% CI 0.44 to 1.45)	Rate of rate ratio for two periods (relative risk) was calculated. The effect of Leapfrog standards on hospital LOS was analysed using a linear regression model and fit using a random intercept for each hospital and a log-normal distribution. Adj for age, sex, comorbidities, type of admissions
Dardik 1998	USA, Maryland	47 hospitals	3293 patients	Abdominal aorta aneurysm (codes not reported)	Open (ICD-9 codes 38.34, 38.44, 38.64, 38.84, 39.54)	Low <50, medium 50 to 99, and high >100	Mortality (in-hospital mortality)	There association is uncertain. Low 54 % (6.3), medium 46% (3.6), high 46.9% (3.0), p=0.53. The association of hospital volume with mortality was not evaluated in the multivariate analysis.	Categoricalal variables were analysed by Pearson's test or Fisher's Exact Test. Continuous variables were analysed by analysis of variance for parametric variables and the Mann-Whitney U test or Kruskal-Wallis test for nonparametric variables. Multiple logistic regression

									was used for multivariate analysis and controlled for age, sex, race, hypertension, diabetes, comorbidities, and health beaviours.
Dimick 2002b	USA	507 in 1996 and 536 1997 hospitals	7980 patients	Abdominal aorta aneurysm (code not reported)	Open (ICD-9 code 38.44)	>30 high	Mortality (in-hospital mortality)	The mortality rate in high was 3.1% and 4.7% in low. In the multiple regression analysis, having surgery at a low volume hospital predicted increased in-hospital death (OR 1.71; 95% CI, 1.37–2.14)	Multiple logistic regression of the in hospital death rate was used to test its association with hospital volume after adjusting for age, sex, comorbidities, admission type and race. LOS was not normally distributed and was skewed to the left, so multiple linear regression of log-transformed LOS was used for the multivariate analysis. The Shapiro-Wilk test was used to ensure normality of the log-transformed data.
Dimick 2003	USA	536 hospitals	3912 patients	Abdominal aorta aneurysm (code not reported)	Open (ICD-9 codes 38.44 and 39.25)	>35 high	Mortality (in-hospital mortality)	Patients undergoing surgery at an high volume hospital had 30% reduction in risk for death (95% CI, 2% to 51%; $p<0.05$)	Univariate analysis and multiple regression with hospital clustering, adj for age, race, gender, nature of admission, comorbidity, and hospital specialty.
Dua 2014	USA	Hospitals, numbers unlcear	Unclear	Abdominal aorta aneurysm	Open (ICD-9 codes 38.34,	No-cut off, this is explored as	Mortality (in-hospital mortality)	Hospitals with mortality higher than 40% complete fewer	Statistical analysis was completed using analysis of

				(ICD-9 code 441.4 and 441.9)	38.44, 38.64 and 39.52)	part of the analysis, threshold set at <5		than five procedures. These hospitals have a mortality of up to 100% (OR 2.5 to 10.6) when compared to the mean 6 two standard deviations of all hospitals or the middle 95% of all hospitals; 0.20 to 0.84; p <0 .001.	variance for continuous variables (number of cases) and x2 for categorical variables (i.e., hospital covariates, inpatient mortality). The Mann-Whitney U test was used for LOS and median total costs. Mann-Kendall trend analysis was completed to determine if trends outside the 95% CI were statistically significant; s values and P values are reported in conjunction with odds ratios (ORs).
Eckstein 2007	Germany	131 hospitals	10163 patients	Abdominal aorta aneurysm (codes not reported)	Open (procedure codes not reported)	1: <9, 2: 10 to 19. 3: 20 to 29, 4: 30 to 39, 5: 40 to 49 and 6: >50	Mortality (in-hospital mortality)	The mortality rate was 5.2% for low-volume hospitals and 2.6% for high volume hospitals. In the stepwise regression analysis, OR for annual volume as predictor of mortality was 1.003 (95% CI 1 to 1.006; p=0.075). Hospitals with >50 procedures had lower mortality rate than the other thresholds, with the largest difference for hospitals with 1-9 procedures (OR 1.90,	Stepwise regression of thresholds. To identify a relationship between annual volume and preoperative and/or intraoperative parameters and further outcome parameters we analysed the different volume groups descriptively. Statistics were performed by use of the chi-sqare-test and Odds-Ratios (OR) with a confidence interval (CI) of 95%.

								95% CI 1.12 to 3.22)	Conspicuous parameters in the descriptive analysis of volume groups were subjected to a tatistical trend analysis (Cochran Armitage Trend Test).
Holt 2007	UK	Hospitals, numbers unlcear	15515 procedures	Abdominal aortic aneurysm (ICD 10 codes I171.4)	Open (OPCS-4 codes L194-L199, L222-L229, L258-L259, L491-L499, L652)	1: <7.2, 2: 7.3 to 12.6, 3: 12.7 to 19.4, 4: 19.5 to 32, 5:>32	Mortality (in-hospital mortality)	Death rate by quintile was, 1: 8.5%, 2: 7.6%, 3: 7.2%, 4: 7.7%, 5: 5.9%. In the multivariate analysis, increasing annual hospital volume was associated with a reduction in the mortality rate for elective (OR 0.92, 95% CI 0.88 to 0.96, p<0.001)	Odds ratios, with the lowest volume-quintile in each group set at an odds ratio of 1.0, and the odds of the other four quintiles calculated against this fixed value. Multiple regression. Maximum likelihood estimates were generated tested by X2 analysis. Volume was quantified in terms of proportional odds ratios with 95% Wald confidence limits. Adj for age, sex.
Holt 2009	UK, England	134 Hospitals (trusts)	5668 patients	Abdominal aorta aneurysm (ICD-10 codes I173 or I174)	Open (procedure codes not reported)	Unclear, divided into five quintiles.	Mortality (in-hospital mortality)	In the multivariate analysis, higher volume was associated with a lower rate of mortality: OR 0.99; 95% CI 0.989 to 0.999, p=0.0216	The effect of volume on outcome was evaluated using both crude data and after risk-adjustment. The samples were the same for both crude and adjusted analyses. Multiple logistic regression model, controlled for gender, comorbidities and age.
Manheim	USA,	Hospitals,	Unclear	Abdominal	Open (ICD-	Low <20,	Mortality (in-	The OR for dying in	Multiple logistic

1998	California	numbers unlcear		aorta aneurysm (codes not reported)	9 codes 38.34, 38.44 and 38.64)	moderate 20 to 49, and high 50 to 99	hospital mortality)	medium volume hospitals was 0.78 (p<0.001), OR in high was 0.84 (p<0.001) compared to low volume	regression adj for age, gender, year of surgery, admission type and comorbidities
McPhee 2011	USA	Hospitals, numbers unclear	Unclear	Abdominal aorta aneurysm (ICD-9 code 441.4)	Open (ICD-9 38.44 and 39.25)	Low <7, medium 7 to 30, and high >30	Mortality (in-hospital mortality)	The high-volume institutions had lower in-hospital mortality rate (3.3%) than the medium- (4.9%) and low-volume (5.9%) institutions; p<0.01. In the multivariate analysis, low volume compared to high volume and medium volume compared to high volume was associated with increased mortality, but these associations were uncertain (OR 1.6 (95% CI 0.98 to 2.7) and OR 1.6 (95% CI 1.0 to 2.4).	Multivariable logistic regression models, adj for patient level factors such as age, gender, comorbidity and hospital level characteristics.
Vogel 2011	USA	Hospitals , range from 1335 to 1116	17210 procedures	Abdominal aorta aneurysm (ICD-9 code 441.4)	Open (ICD-9 codes 38.34,38.44 and 38.64)	Top ten % volume was categorized as high-volume, all remaining hospitals placed in the low-group	Mortality (in-hospital mortality)	Patients in low-volume hospitals were more likely to die after surgery; OR 1.22, 95% CI 1.04 to 1.44.	Multivariable analysis with forward step-wise regressions, adj for age, sex, race, comorbidities and hospital procedure.
Wen 1996	Canada, Ontario	All Ontario hospitals, numbers unclear	5492 patients	Abdominal aorta aneurysm (ICD-9 code 441.4)	Open (CC code 5034 or 5024 or 5125)	1: <10, 2: 10 to 20, 3: 21 to 40, and 4: >40	Mortality (in-hospital mortality)	The % mortality rate per quintile; 1: 4.6, 2: 4.0, 3: 3.8, 4: 3.5 (p=0.59). In the linear regression	Stepwise multiple logistic regression analysis was used to examine the volume-mortality

								analysis, each 10 case per year increase in hospital volume was related to a 6% reduction in adj. odds of death OR 0.94, 95% CI 0.88 to 0.99).	relationship, and stepwise multiple linear regression was used to examine the volume-postoperative LHS relationship at the individual patient level. Adj for bed size and teaching status of the admitting hospital, patient's sex and age, comorbidity index, and whether the patient had been transferred from another hospital.
Rutledge 1996	USA, North Carolina	Hospitals, numbers unlcear	12658 patients	Abdominal aorta aneurysm (ICD-9 code 441.4)	Open (codes not reported)	Unclear	Mortality (in-hospital survival)	Hospital experience with elective AAAs was analysed, and although there was a trend toward improved survival in hospitals with a greater case load of AAAs, this did not achieve statistical significance (p = 0.59). Numbers not reported.	Very little described, no apparent adjustments. Logistic regression.
Pearce 1999	USA, Florida	Hospitals, range over time 156 to 165	13415 patients	Abdominal aorta aneurysm (ICD-9 code 441.4)	Open (ICD-9 38.34 and 38.44)	Unclear	Mortality and complications (hospital mortality, myocardial infarction or cerebrovascular accident)	The relative reduction in risk for doubling of hospital volume was (Coefficient Relative risk) 0.88, p=0.0003	Multiple logistic regression, adj for age, sex, emergency admission status, hospital characteristics, year of discharge.

Table 1. Mortality in patients undergoing elective admissions for open surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Amundsen 1990	Norway	26 surgical units	155 patients	Ruptured or acute abdominal aorta aneurysm (code not reported)	Open (procedure codes not reported)	Volume categories were 1: <9, 2: 10 to 29, 3: 30 to 39, 4: >40	Mortality (30-day mortality)	Hospital mortality for acute surgery by category: 1: 36/50 (72%), 2: 14/22 (63.6%), 3: 7/13 (53.8%), 4: 8/15 (53.3%). The chance of dying was almost twice as high (OR 1.9) in low volume compared to units with >10 surgeries, although there was high uncertainty associated with this outcome p=0.14)	Cross tabulation and chi-square. A model consisting of the significant variables (log likelihood ratio tests, p<0.05) predicts the probability of dying. The odds ratio- the ratio between the odds for dying in two groups of patients as given by the levels of a prognostic variable, indicate the strength of that variable and can be found by exponentian of its regression coefficient.
Kantonen 1997 (and 1999)	Finland	26 hospitals	610 patients	Ruptured or acute abdominal aorta aneurysm (code not reported)	Open (procedure codes not reported)	>10 high	Mortality (30-day mortality)	There was no association according to the authors. Numbers not reported, only plotted in figure.	Correlation between volume and mortality was tested using linear regression analysis.
Dardik 1998	USA, Maryland	45 hospitals	527 patients	Ruptured or acute abdominal aorta aneurysm (ICD-9 code 441.02 and 441.3)	Open (ICD-9 codes 38.34, 38.44, 38.64, 38.84 and 39.54)	Low <10, medium 10 to 19, and high >20	Mortality (in hospital mortality)	There association is uncertain. Low 45.6% (4.1), medium 49.2% (3.6), high 47.1% (3.6), p=0.8. The association of hospital volume	Categoricalal variables were analysed by Pearson's test or Fisher's Exact Test. Continuous variables were analysed by analysis of variance for parametric

								with mortality was not evaluated in the multivariate analysis.	variables and the Mann-Whitney U test or Kruskal-Wallis test for nonparametric variables. Multiple logistic regression was used for multivariate analysis and controlled for age, sex, race, hypertension, diabetes, comorbidities, and health beaviours.
Dua 2014	USA	Hospitals, numbers unclear	Unclear	Ruptured or acute abdominal aorta aneurysm (ICD-9 code 441.3)	Open (ICD-9 codes 38.34,38.44, 38.64 and 39.52)	No-cut off, this is explored as part of the analysis, threshold set at <10	Mortality (in hospital mortality)	Hospitals have a 95% CI of 0% to 100% for mortality, indicative of the high mortality risk associated with rupture. Most hospitals complete one to 10 OARs and one to eight EVARs for ruptured AAA. Hospitals that complete >10 surgeries have a mortality between 20% and 40%.	Statistical analysis was completed using analysis of variance for continuous variables (number of cases) and x2 for categorical variables (ie, hospital covariates, inpatient mortality). The Mann-Whitney U test was used for LOS and median total costs. Mann-Kendall trend analysis was completed to determine if trends outside the 95% CI were statistically significant; s values and P values are reported in conjunction with odds ratios (ORs).
Holt 2007	UK	Hospitals, numbers unclear	6462 patients	Abdominal aortic aneurysm (ICD 10 codes I171.3)	Open (OPCS-4 codes L184-L189, L194-L199, L222-L229, L258-L259, L481-L489, L652)	1: <7.2, 2: 7.3 to 12.6, 3: 12.7 to 19.4, 4: 19.5 to 32, 5:>32	Mortality (in hospital mortality)	Death rate by quintile was, 1: 4.1%, 2: 42.9%, 3: 43.7%, 4: 39.0%, 5: 42.4%. In the multivariate analysis, increasing annual hospital volume	Odds ratios, with the lowest volume-quintile in each group set at an odds ratio of 1.0, and the odds of the other four quintiles calculated against this fixed value. Multiple regression. Maximum

								had a weak or no association with mortality rate for ruptured (OR 0.98, 95% CI 0.95 to 1.02, p=0.302)	likelihood estimates were generated tested by X2 analysis. Volume was quantified in terms of proportional odds ratios with 95% Wald confidence limits. Adj for age, sex.
Holt 2007	UK	26 hospitals	4845 patients	Abdominal aortic aneurysm (ICD 10 codes I171.3)	Open (OPCS-4 codes L184-L189, L194-L199, L222-L229, L258-L259, L481-L489, L652)	1: <2. 2: 2.1-4.2, 3: 4.3-6.6, 4: 6.7-12.2, 5:>12.2	Mortality (in hospital mortality)	Death rate by quintile was, 1: 27%, 2: 24.1%, 3: 21.8%, 4: 21.2%, 5: 23.6%. In the multivariate analysis, increasing annual hospital was associated with a reduction in the mortality rate for urgent (OR 0.94, 95% CI 0.90 to 0.99, p<0.017)	Odds ratios, with the lowest volume-quintile in each group set at an odds ratio of 1.0, and the odds of the other four quintiles calculated against this fixed value. Multiple regression. Maximum likelihood estimates were generated tested by X2 analysis. Volume was quantified in terms of proportional odds ratios with 95% Wald confidence limits. Adj for age, sex.
McPhee 2009	USA	Hospitals, numbers unclear	Unclear	Ruptured or acute abdominal aorta aneurysm (ICD-9 code 441.3)	Open (ICD-9 codes 38.44 and 39.25)	Low <13, medium 13 to 29, high >29	Mortality (in hospital mortality)	In the multivariate analysis, low compared to high volume was associated with higher mortality (OR 1.24; 95% CI 1.01 to 1.52). The difference in mortality between moderate and high volume categories were uncertain (OR 1.09; 95% CI 0.91	Multivariable logistic regression models, controlled for age, sex, comorbidities, insurance type, year of procedure, hospital characteristics

								to 1.32)	
Wen 1996	Canada, Ontario	All Ontario hospitals, numbers unclear	1203 patients	Ruptured or acute abdominal aorta aneurysm (ICD-9 code 441.3)	Open (CC code 5125)	1: <2, 2: 2 to 4, 3: 4 to 8, 4: >8	Mortality (in hospital mortality)	% mortality rate per quintile; 1: 44.7, 2: 40.6, 3: 38.6, 4: 39.0 (p= 0.82). There was little or no association between hospital volume and mortality in ruptured cases. Adj OR from the linear regression analysis was 0.97 (95% Ci 0.91 to 1.03)	Stepwise multiple logistic regression analysis was used to examine the volume-mortality relationship, and stepwise multiple linear regression was used to examine the volume-postoperative LHS relationship at the individual patient level. Adj for bed size and teaching status of the admitting hospital, patient's sex and age, comorbidity index, and whether the patient had been transferred from another hospital.
Cowan 2003	USA	Hospitals	Unclear	Ruptured or acute abdominal aorta aneurysm (ICD-9 441.3, 441.5)	Open (ICD-9 codes 38.44 and 38.45)	Low 1 to 4 procedures, medium 5 to 15 and high 16 to 191	Mortality (in-hospital mortality)	No statistical significant relationship between hospital volume and mortality in the univariate analysis (p=0.375). Numbers not reported.	Student's t-test and logistical multivariate regressions.
Dimick 2002b	USA	507 in 1996 and 536 1997 hospitals	5907 patients	Ruptured or acute abdominal aorta aneurysm (ICD-9 code 441.3)	Open (ICD-9 code 38.44)	Unclear	Mortality (in-hospital mortality)	The mortality rate in high was 42.4% and 49.6% in low. In the multiple regression analysis, having surgery at a low volume hospital predicted	Multiple logistic regression of the in hospital death rate was used to test its association with hospital volume after adjusting for age, sex, comorbidities, admission type and

								increased in-hospital death (OR 1.43; 95% CI, 1.15–1.78)	race. LOS was not normally distributed and was skewed to the left, so multiple linear regression of log-transformed LOS was used for the multivariate analysis. The Shapiro-Wilk test was used to ensure normality of the log-transformed data.
Manheim 1998	USA, California	Hospitals, numbers unclear	Unclear	Ruptured or acute abdominal aorta aneurysm (code not reported)	Open (ICD-9 codes 38.34, 38.44 and 38.64)	Low <20, moderate 20 to 49, and high 50 to 99	Mortality (in-hospital mortality)	The OR for dying in medium volume hospitals was 0.74 ($p<0.001$), OR in high was 0.49 ($p<0.001$) compared to low volume	Multiple logistic regression, adj for age, gender, year of surgery, admission type and comorbidities
Rutledge 1996	USA, North Carolina	Hospitals, numbers unclear	1480 patients	Ruptured or acute abdominal aorta aneurysm (ICD-9 code 441.3)	Open (codes not reported)	Unclear	Mortality (in-hospital survival)	Although there appears to be a trend to improved survival with increased hospital caseload, this did not reach statistical significance ($p = 0.23$).	Logistic regression was used to assess the association between hospital AAA caseload and patient survival after RAAA.

Table 2. Mortality in patients undergoing acute/ ruptured admissions for open surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Illonzo 2014	USA, Medicare files	Hospitals, number of hospitals	295851 patients	Abdominal aorta aneurysm	Open repair (procedure codes not	Low <3, medium 4 to 7, high 8 to	Complications (cardiac arrest, vascular device	Hospitals of high volume had fewer complications after	Multivariate logistic regression analysis adj for age, gender, race,

		unclear		(codes not reported)	reported)	257	implant and graft complications, amputation and wound complications)	open repair than low-volume did: pulmonary embolism (0.51% vs 0.62%; p<0.02), sepsis (2.11% vs 3.36%; p<.001), septic shock (0.13% vs 0.44%; p<0.001), perioperative stroke (0.05% vs 0.11%; p< 0.001), acute dialysis (0.43% vs 0.68%; p<0 .001), arterial reintervention (1.08% vs 1.68%; p<0.001), and prolonged ventilation (3.73% vs 5.63%; p<0.001).	comorbidities, hospital annual volume, and year of the surgery.
Holt 2007	UK	Hospitals, number of hospitals unclear	15515 procedures	Abdominal aortic aneurysm (ICD 10 codes I171.4)	Open (OPCS-4 codes L194-L199, L222-L229, L258-L259, L491-L499, L652)	1: <7.2, 2: 7.3 to 12.6, 3: 12.7 to 19.4, 4: 19.5 to 32, 5:>32	Complications (renal, respiratory, system infection, shock, local infection, local complications (graft failure and hemorrhage, hematoma, seroma), thrombotic or embolic, cardiac, disseminated intravascular coagulation, ischemic stroke and transfusion)	Complication rate by quintile was, 1: 23%, 2: 24%, 3: 23%, 4: 23%, 5: 22%. In the multivariate analysis, increasing annual hospital volume had a weak or no association with complication rate for elective (p=ns). Numbers from multivariate analysis not reported.	Odds ratios, with the lowest volume-quintile in each group set at an odds ratio of 1.0, and the odds of the other four quintiles calculated against this fixed value. Multiple regression. Maximum likelihood estimates were generated tested by X2 analysis. Volume was quantified in terms of proportional odds ratios with 95% Wald confidence limits. Adj for age, sex.
Eckstein 2007	Germany	131 hospitals	10163 patients	Abdominal aorta aneurysm (codes not reported)	Open (procedure codes not reported)	1: <9, 2: 10 to 19. 3: 20 to 29, 4: 30 to 39, 5: 40 to 49 and 6: >50	Complications (secondary bleeding, intestinal ischemia, peripheral arterial thrombosis/ embolism)	General and specific complications occurred equally across volume groups according to the authors. Association with volume not tested in the multivariate	Stepwise regression of thresholds. To identify a relationship between annual volume and preoperative and/or intraoperative parameters and further

								analysis.	outcome parameters we analysed the different volume groups descriptively. Statistics were performed by us of the chi-sqare-test and Odds-Ratios (OR) with a confidence interval (CI) of 95%. Conspicuous parameters in the descriptive analysis of volume groups were subjected to a statistical trend analysis (Cochran Armitage Trend Test).
Vogel 2011	USA	Hospitals , range from 1335 to 1116	17210 procedures	Abdominal aorta aneurysm (ICD-9 code 441.4)	Open (ICD-9 codes 38.34, 38.44 and 38.64)	Top ten % volume was categorized as high-volume, all remaining hospitals placed in the low-group	Complications (pneumonia, urinary tract infection, sepsis and surgical site infection)	Mean frequency of any complications were: high volume mean 810 (12.1%) and 1346 for (12.8%) low-volume. For pneumonia, high volume 374 (5.59%) complications and 712 (6.77%) for low-volume. For sepsis high volume had 134 (2%) and low-volume had 285 (2.71%) for UTI high volume had 255 (3.81%) and low-volume had 343 (3.26%). For SSI high volume had 146 (2.18%) and low-volume had 185 (1.76%). In the logistic regression analysis, patients in low volume were more likely to develop pneumonia (OR 1.23; 95% CI 1.08 to 1.40) or sepsis (OR 1.36; 95% CI	Multivariable analysis with forward step-wise regressions, adj for age, sex, race, comorbidities and hospital procedure.

								1.11 to 1.68).	

Table 3. Complications in patients undergoing elective admissions for open surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Holt 2007	UK	Hospitals, numbers unclear	6462 patients	Ruptured or acute abdominal aorta aneurysm (ICD-10 code 71.3)	Open (OPCS-4 codes L184- L189, L194-L199, L222-L229, L258-L259, L481-L489, L652)	1: <2.8, 2: 2.9-5.6, 3: 5.7-9.2, 4: 9.3-13.2, 5:>13.2	Complications (renal, respiratory, system infection, shock, local infection, local complications (graft failure and hemorrhage, hematoma, seroma), thrombotic or embolic, cardiac, dessiminated intravascular coagulation, ischemic stroke and transfusion)	Complication rate by quintile was, 1: 39%, 2: 40%, 3: 39%, 4: 44%, 5: 37%. In the multivariate analysis, increasing annual hospital volume had a weak or no association with complication rate for ruptured (p=ns).	Odds ratios, with the lowest volume-quintile in each group set at an odds ratio of 1.0, and the odds of the other four quintiles calculated against this fixed value. Multiple regression. Maximum likelihood estimates were generated tested by X2 analysis. Volume was quantified in terms of proportional odds ratios with 95% Wald confidence limits. Adj for age, sex.
Holt 2007	UK	26 hospitals	4845 patients	Urgent abdominal aortic aneurysm (ICD-10 code 71.3)	Open (OPCS-4 codes L184- L189, L194-L199, L222-L229, L258-L259, L481-L489, L652)	1: <7.2, 2: 7.3 to 12.6, 3: 12.7 to 19.4, 4: 19.5 to 32, 5:>32	Complications (renal, respiratory, system infection, shock, local infection, local complications (graft failure and hemorrhage, hematoma, seroma), thrombotic or embolic, cardiac, dessiminated intravascular coagulation, ischemic stroke and transfusion)	Complication rate by quintile was, 1: 35%, 2: 38%, 3: 32%, 4: 36%, 5: 35%. In the multivariate analysis, increasing annual hospital volume had a weak or no association with complication rate for urgent (p=ns).	Odds ratios, with the lowest volume-quintile in each group set at an odds ratio of 1.0, and the odds of the other four quintiles calculated against this fixed value. Multiple regression. Maximum likelihood estimates were generated tested by X2 analysis. Volume was quantified in terms of proportional odds ratios with 95% Wald confidence limits. Adj for age, sex.
Kantonen	Finland	26 hospitals	610 patients	Ruptured or	Open (codes	>10 high	Complications (shock)	There was no	Correlation between

1997 (and 1999)				acute abdominal aorta aneurysm (codes not reported)	not reported)			association according to the authors. Numbers not reported.	volume and mortality was tested using linear regression analysis.

Table 4. Complications in patients undergoing acute/ ruptured admissions for open surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Brooke 2008	USA (California)	140 hospitals of 337 hospitals included	6406 cases	Abdominal aorta aneurysm (codes not reported)	Open (ICD-9 codes 38.34, 38.36, 38.44, 38.64, 39.25 and 39.52)	>50 high	Length of hospital stay (hospital days)	The average rates of length of stay at time-point 1 (2000-2003): high volume 6.92 days (SD 1.2)/ low volume 7.09 days (SD 1.7) Time-point 2 (2003-2005): high volume 6.94 days (SD 1.0)/ low volume 7.48 days (SD 3.0). In the adj regression model, the effect of volume on length of stay was not statistically significant. Figures not reported.	Rate of rate ratio for two periods (relative risk) was calculated. The effect of Leapfrog standards on hospital LOS was analysed using a linear regression model and fit using a random intercept for each hospital and a log-normal distribution. Adj for age, sex, comorbidities, type of admissions.
Dimick 2002b	USA	507 in 1996 and 536 1997 hospitals	7980 patients	Abdominal aorta aneurysm (code not reported)	Open (ICD-9 code 38.44)	>30 high	Length of hospital stay (hospital days)	In the univariate analysis, high volume had a median 1 day shorter stay than low (7 days [IQR 6-10] versus 8 days [IQR 6 to 10], p<0.02. Little or no association between volume and length of stay was found in the multivariate analysis, figures not reported.	Multiple logistic regression of the in hospital death rate was used to test its association with hospital volume after adjusting for age, sex, comorbidities, admission type and race. LOS was not normally distributed and was skewed to the left, so multiple linear regression of log-transformed LOS was used for the multivariate analysis. The Shapiro-Wilk test was used to ensure normality of the log-transformed data.
Eckstein 2007	Germany	131 hospitals	10163 patients	Abdominal aorta aneurysm (codes not	Open (procedure codes not reported)	1: <9, 2: 10 to 19. 3: 20 to 29, 4: 30 to 39, 5: 40 to 49	Length of hospital stay (hospital	Higher median hospital stay in low versus high volume hospitals (p<0.001). Range from	Stepwise regression of thresholds. To identify a relationship between annual volume and preoperative

				reported)		and 6: >50	days)	19 (low-volume) to 15 (in high volume). Association with volume not tested in the multivariate analysis.	and/or intraoperative parameters and further outcome parameters we analysed the different volume groups descriptively. Statistics were performed by use of the chi-sqare-test and Odds-Ratios (OR) with a confidence interval (CI) of 95%. Conspicuous parameters in the descriptive analysis of volume groups were subjected to a statistical trend analysis (Cochran Armitage Trend Test).
Holt 2007	UK	Hospitals	15515 elective procedures	Abdominal aortic aneurysm (ICD 10 code 71.4)	Open (OPCS-4 codes L194- L199, L222-L229, L258-L259, L491-L499, L652)	1: <7.2, 2: 7.3 to 12.6, 3: 12.7 to 19.4, 4: 19.5 to 32, 5:>32	Length of hospital stay (hospital days)	Length of stay days by quintile was, 1: 16.19, 2: 14.55, 3: 14.51, 4: 15.49, 5: 17-02. In the multivariate analysis, the duration of stay was longer at lower volume hospitals (p<0.001)	Odds ratios, with the lowest volume-quintile in each group set at an odds ratio of 1.0, and the odds of the other four quintiles calculated against this fixed value. This allowed the calculation of the number of excess deaths per 1000 procedures. Multiple regression. Maximum likelihood estimates were generated tested by X2 analysis. Volume as an independent variable was quantified in terms of proportional odds ratios with 95% Wald confidence limits. Adj for age, sex.
Vogel 2011	USA	Hospitals , range from 1335 to 1116	17210 procedures	Abdominal aorta aneurysm (ICD-9 code 441.4)	Open (ICD-9 codes 38.34, 38.44 and 38.64)	Top ten % volume was categorized as high-volume, all remaining hospitals placed in the	Length of stay (hospital days)	Hospital days were lower in high-volume hospitals. Mean hospital days in high volume 8.94 (SD 7.59) and low-volume 9.28 (SD 8.01), p<0.004.	Multivariable analysis with forward step-wise reressions, adj for age, sex, race, comorbidities and hospital procedure.

						low-group			
Wen 1996	Canada, Ontario	All Ontario hospitals, numbers unclear	5492 patients	Abdominal aorta aneurysm (ICD-9 code 441.4)	Open (CC code 5034 or 5024 or 5125)	1: <10, 2: 10 to 20, 3: 21 to 40, and 4: >40	Length of stay (hospital days)	Mean days per quintile; 1: 11.5, 2: 11.2, 3: 11.0, 4: 11.1 (p<0.06). 10 case per year increase in hospital volume was related to a 0.29 day reduction in postoperative length of stay in unruptured cases, adj OR in the linear regression was: 0.29 (95% CI 0.22 to 0.35).	Stepwise multiple logistic regression analysis was used to examine the volume-mortality relationship, and stepwise multiple linear regression was used to examine the volume-postoperative LHS relationship at the individual patient level. Adj for bed size and teaching status of the admitting hospital, patient's sex and age, comorbidity index, and whether the patient had been transferred from another hospital.
Eckstein 2007	Germany	131 hospitals	10163 patients	Abdominal aorta aneurysm (codes not reported)	Open (procedure codes not reported)	1: <9, 2: 10 to 19. 3: 20 to 29, 4: 30 to 39, 5: 40 to 49 and 6: >50	Length of stay (intensive care days)	Higher median inpatient intensive days in low versus high volume hospitals (p<0.001). Range from 4 (low-volume) to 2 (in high volume) days of stay. Association with volume not tested in the multivariate analysis.	Stepwise regression of thresholds. To identify a relationship between annual volume and preoperative and/or intraoperative parameters and further outcome parameters we analysed the different volume groups descriptively. Statistics were performed by use of the chi-sqare-test and Odds-Ratios (OR) with a confidence interval (CI) of 95%. Conspicuous parameters in the descriptive analysis of volume groups were subjected to a statistical trend analysis (Cochran Armitage Trend Test).
Vogel 2011	USA	Hospitals , range from 1335 to 1116	17210 procedures	Abdominal aorta aneurysm (ICD-9 code	Open (ICD-9 codes 38.34, 38.44 and 38.64)	Top ten % volume was categorized as high-volume,	Length of stay (intensive unit days)	Intensive unit days were lower in high-volume hospitals. Mean hospital days in high volume days	Multivariable analysis with forward step-wise regressions, adj for age, sex, race, comorbidities and

				441.4)		all remaining hospitals placed in the low-group		4.41 (SD 6.66) and low-volume 4.64 (SD 6.69), p<0.3.	hospital procedure.

Table 5. Length of stay in patients undergoing elective admissions for open surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Dimick 2002b	USA	507 in 1996 and 536 1997 hospitals	5907 patients	Ruptured or acute abdominal aorta aneurysm (ICD-9 code 441.3)	Open (ICD-9 code 38.44)	Unclear	Length of stay (hospital days)	In the univariate and multivariate analysis, there was no statistical significant association between volume and length of stay. Numbers not reported.	LOS was not normally distributed and was skewed to the left, so multiple linear regression of log-transformed LOS was used for the multivariate analysis. The Shapiro-Wilk test was used to ensure normality of the log-transformed data.
Holt 2007	UK	26 hospitals	4845 procedures	Urgent abdominal aortic aneurysm (ICD-10 code 71.3)	Open (OPCS-4 codes L184-L189, L194-L199, L222-L229, L258-L259, L481-L489, L652)	1: <7.2, 2: 7.3 to 12.6, 3: 12.7 to 19.4, 4: 19.5 to 32, 5:>32	Length of stay (hospital days)	Length of stay days by quintile was, 1: 23.27, 2: 21.86, 3: 20.60, 4: 21.56, 5: 22.37%. In the multivariate analysis, the duration of stay was longer for the urgent repair at higher volume hospitals (p<0.041). The increased survival rate may explain this.	Odds ratios, with the lowest volume-quintile in each group set at an odds ratio of 1.0, and the odds of the other four quintiles calculated against this fixed value. This allowed the calculation of the number of excess deaths per 1000 procedures. Multiple regression. Maximum likelihood estimates were generated tested by X2 analysis. Volume as an independent variable was quantified in terms of proportional odds ratios with 95% Wald confidence limits. Adj for age, sex.
Holt 2007	UK	Hospitals, numbers unclear	6462 procedures	Ruptured or acute abdominal aorta aneurysm (ICD-10 code 71.3)	Open (OPCS-4 codes L184-L189, L194-L199, L222-L229, L258-L259, L481-L489, L652)	1: <2.8, 2: 2.9-5.6, 3: 5.7-9.2, 4: 9.3-13.2, 5:>13.2	Length of stay (hospital days)	Length of stay days by quintile was, 1:15.85 2: 15.89, 3:16.99, 4: 16:15, 5: 21.93. In the multivariate analysis, no relationship was found between volume and length of stay for ruptured (p=0.806)	Odds ratios, with the lowest volume-quintile in each group set at an odds ratio of 1.0, and the odds of the other four quintiles calculated against this fixed value. This allowed the calculation of the number of excess deaths per 1000 procedures. Multiple regression. Maximum likelihood estimates were generated tested by X2 analysis. Volume as an independent variable was

									quantified in terms of proportional odds ratios with 95% Wald confidence limits. Adj for age, sex.
Wen 1996	Canada, Ontario	All Ontario hospitals, numbers unclear	1203 patients	Ruptured or acute abdominal aorta aneurysm (ICD-9 code 441.3)	Open (CC code 5125)	1: <2, 2: 2 to 4, 3: 4 to 8, 4: >8	Length of stay (hospital days)	Mean days per quintile; 1: 17.4, 2: 17.7, 3: 19.7, 4: 18.6 (p=0.33). There was little or no association between hospital volume and length of stay in ruptured cases. Adj OR in the linear regression was -0.12 (95% CI -0.46 to 0.22)	Stepwise multiple logistic regression analysis was used to examine the volume-mortality relationship, and stepwise multiple linear regression was used to examine the volume-postoperative LHS relationship at the individual patient level. Adj for bed size and teaching status of the admitting hospital, patient's sex and age, comorbidity index, and whether the patient had been transferred from another hospital.
Dardik 1998	USA, Maryland	45 hospitals	527 procedures	Ruptured or acute abdominal aorta aneurysm (ICD-9 codes 441.02 and) 441.3)	Open (ICD-9 codes 38.34, 38.44, 38.64, 38.84, 39.54)	Low <10, medium 10 to 19, and high >20	Length of stay (hospital days)	The association was uncertain (days). Low 14.0 (1.3), medium 10.4 (1.0), high 11.6 (0.9), p=0.15. The association of volume with length of stay was not evaluated in the multivariate analysis.	Categoricalal variables were analysed by Pearson's c2 test or Fisher's Exact Test. Continuous variables were analysed by analysis of variance for parametric variables and the Mann-Whitney U test or Kruskal-Wallis test for nonparametric variables. Multiple logistic regression was used for multivariate analysis and controlled for age, sex, race, hypertension, diabetes, comorbidities, and health behaviours.

Table 6. Length of stay in patients undergoing acute/ ruptured admissions for open surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Vogel 2011	USA	Hospitals , range from 1335 to 1116	17210 procedures	Abdominal aorta aneurysm (ICD-9 code 441.4)	Open (ICD-9 codes 38.34,38.44, 38.64)	Top ten % volume was categorized as high-volume, all remaining hospitals placed in the low-group	Costs (hospital resource utilisation, charges and supplies)	Costs were lower in high-volume hospitals Mean USD hospital charges in high volume 72524 (SD 71955) and low-volume 82292 (SD91185), and for med/sur supplies 9073 (SD9971) and low-volume 11110 (SD12416), p-values for the difference in both outcomes <0.0001	Multivariable analysis with forward step-wise regressions, adj for age, sex, race, comorbidities and hospital procedure.

Table 7. Costs in patients undergoing elective admissions for open surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Dardik 1998	USA, Maryland	45 hospitals	527 procedures	Ruptured or acute abdominal aorta aneurysm (ICD-9 codes 441.02 and) 441.3)	Open surgery (38.34, 38.44, 38.64, 38.84, 39.54)	Low <10, medium 10 to 19, and high >20	Costs (total hospital charges)	There association was uncertain. Low USD 31105 (2154), medium USD 25243 (1471), high USD 25624 (1427, p=0.10. The association of volume with charges was not evaluated in the multivariate analysis.	Categoricalal variables were analysed by Pearson's test or Fisher's Exact Test. Continuous variables were analysed by analysis of variance for parametric variables and the Mann-Whitney U test or Kruskal-Wallis test for nonparametric variables. Multiple logistic regression was used for multivariate analysis and controlled for age, sex, race, hypertension, diabetes, comorbidities, and health behaviours.

Table 8. Costs in patients undergoing acute/ ruptured admissions for open surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Eckstein 2007	Germany	131 hospitals	10163 patients	Abdominal aorta aneurysm (ICD-10 codes I173 or I174)	Open (procedure codes not reported)	1: <9, 2: 10 to 19. 3: 20 to 29, 4: 30 to 39, 5: 40 to 49 and 6: >50	Process measures (intraoperative variables)	Higher frequency of blood transfusions (%) and longer duration of procedure (min, median) in low versus high volume hospitals (p<0.001). Range from 81.2% (low-volume) to 65.6% (in high volume) transfusions. Range from 170% (low-volume) to 143% (in high volume) in median minutes in duration of procedure. Association with volume not tested in the multivariate analysis.	Stepwise regression of thresholds. To identify a relationship between annual volume and preoperative and/or intraoperative parameters and further outcome parameters we analysed the different volume groups descriptively. Statistics were performed by use of the chi-sqare-test and Odds-Ratios (OR) with a confidence interval (CI) of 95%. Conspicuous parameters in the descriptive analysis of volume groups were subjected to a statistical trend analysis (Cochran Armitage Trend Test).

Table 9. Process outcomes in patients undergoing elective admissions for open surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Reames 2014	USA	Hospitals, ranged from 2301 to 1888	National sample, ranged from 62327 to 46105	Abdominal aorta aneurysm (code not reported)	Open and endovascular (codes not reported)	Hospital volume was defined as total volume of operations performed in Medicare beneficiaries during each 2-year period: low <18 procedures, high >70. The cut-off varied for each year.	Mortality (30- day mortality)	Odds of mortality was higher in low-volume hospitals for all years: Adj. OR (95% CI) year 1: 1.39 (1.19–1.62) Year 2: 1.59 (1.35–1.88) year 3: 1.28 (1.07–1.52) year 4: 1.48 (1.21–1.81) year 5: 1.48 (1.27–1.72).	Multivariable logistic regression during the 10-year study period, after adjusting for patient characteristics (age, sex, race (black or nonblack) and their interactions, urgency or emergency of the admission, the presence of coexisting conditions, and socioeconomic status), year of the procedure, and surgical approach.
Massarweh 2011	USA, Washington	Hospitals, numbers unlcear	7724 patients	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (codes not reported)	>50 high	Mortality (30-day and 90-day)	Adjusted mortality, were generally similar for patients at high volume compared to low volume. Year 1, 30 day mortality: low volume 4.4%, high volume 4.9%, p-	Multilevel binomial generalized estimating equation regression models with an exchangeable correlation

								value= 0.58. Year 1, 90-day mortality: low-volume 5.2%, high volume 5.3%, p-value= 0.93. Year 2, 30 day mortality: low volume 3.7%, high volume 2.5%, p-value= 0.12. Year 2, 90-day mortality: low-volume 4.7%, high volume 3.1%, p-value= 0.07	structure and robust standard errors were used to calculate risk-adjusted outcome rates. Adj for age, sex, type of insurance, length of stay, comorbidity, type of procedure, leapfrog era.
Birkmeyer 2002	USA	2819 hospitals	140577 patients	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (codes not reported)	1: <17, 2: 17 to 30, 3: 31 to 49, 4: 50 to 79, 5:>79	Mortality (30-day mortality)	The mortality rate by category was: low 5.9%, medium 5.2%, high 5.3% and very high 4.4%. In the multivariate analysis, higher volume was associated with lower mortality rates. Compared to lowest volume quintile, the odds for operative mortality was by quintile; 2: OR 0.79 (95% CI 0.73 to 0.86), 3: OR 0.70 (95% CI 0.64 to 0.76), 4: OR 0.71 (95% CI 0.65 to 0.78), 5. OR 0.58 (95%CI 0.53 to 0.65).	Multiple logistic regression with adjustment for characteristics of the patients (age, gender, comorbidities, race, year of procedure, type of admission, and mean income)
Bush 2003	USA	123 hospitals	1904 patients of which 717 were endovascular and 1187 were open	Abdominal aorta aneurysm (ICD-9 codes 441.4)	Both (Open CPT codes 35081 and 35102 and EVAR CPT codes 34800, 34802, and 34804.	Low <10 procedures	Mortality (30-day mortality)	There was higher mortality in lower volume, low compared to high: OR 1.89, 95% CI 1.19 to 2.98, p< 0.006)	Multivariate logistic regression analysis, adj for procedure type, personal and system characteristics.
Dueck 2004	Canada,	Hospitals,	13701	Abdominal	Open and	Continuous	Mortality (30-day	An association was	Univariate

	Ontario	number unclear	patients	aortic aneurysm (fee code R802, R816, and R817)	endovascular (codes not reported)	variable analysed as annual volume per 10 cases	mortality)	found in the univariate model (hazard ratio 1.01 (95% CI 1.00 to 1.01), but this effect diminished when explored in the multi-regression model suggesting that this relationship could be explained by other covariates- such as surgeon volume. Numbers for hospital volume in multivariate analysis not reported.	proportional hazards survival analysis was performed for each variable, a multivariate model was constructed. Adj for the following variables in the analysis; age, gender, income, hospital factors, year of operations.
Finks 2011	USA	Hospitals, range from 1860 to 2339	Patients, range from 56333 to 71170	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (ICD-9 codes 38.34, 38.44, 38.64, 39.25 and 39.71)	Not defined, analysed as the proportion of the effect of hospital volume that could be attributed to volume	Mortality (30-day mortality)	Proportion of the difference in mortality explained by increased hospital volume over time was 11% Measures of uncertainty was not reported.	Stepwise logistic-regression model, adj for age, sex, race, admission type, comorbidities and socio-economic status.
Goodney 2003	USA	Hospitals, number unclear	12573 patients	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (codes not reported)	Hospitals were divided into five quintiles, the analysis includes a comparison of the lowest volume quintile (<17 procedures), and the highest volume (>79	Mortality (30-day mortality)	The relative risk of mortality was lower in high versus low volume hospitals, with 0.51 (95% CI 0.49 to 0.53) at high volume hospitals compared to 0.54 (95% CI 0.52 to 0.56) in low volume hospitals.	The results are reported unadjusted because the authors had already stratified the samples. Adj for patient characteristics. Risks of in-hospital mortality was compared in high and low volume.

						procedures).			
Regenbogen 2012	USA	1939 hospitals	69141 patients	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (codes not reported)	1: <34. 2 : 35-60, 3: 61- 95, 4: 96-155, 5: >155	Mortality (30-day mortality)	The % mortality was higher in low volume, by quintiles, 1: 3.6%, 2: 3.1%, 3: 3.0%, 4: 2.9%, 5: 3.0%. The association between volume and mortality had a p-value of <0.0001.	Mantel-Haenszel chi-square tests for dichotomous outcomes variables
Urbach 2004	Canada, Ontario	57 hospitals	6279 patients	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (codes not reported)	>42 high	Mortality (30-day mortality)	The Adj OR for the association between volume and mortality was 0.62 (95% CI 0.46 to 0.83). Higher volume was associated with lower mortality.	Binary logistic regression with risk-adjustment for age, sex, and comorbidity index.
Allareddy 2010	USA	1207 hospitals	35104 procedures	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (ICD-9 codes 38.34, 38.44, 38.64, 39.71 and 39.25)	>50 high	Mortality (in-hospital mortality)	The rates of mortality in high was 2.63% and in low 3.47%. In the multivariable analysis, the OR for mortality lower in high volume (adj OR 0.83 (0.69 to 0.99).	Multivariable logistic regression models were used to examine the association between hospital volume and complications, adj for age, sex, admission type, type of procedure, year of procedure, hospital characteristics, and comorbidity
Hill 2008	USA	Aprox. 555 hospitals	46901 patients	Abdominal aortic aneurysm (ICD-9 code 441.4)	Open and endovascular (ICD-9 codes 38.34, 38.44 and 39.71)	<17 low, medium 18 to 49, >50 high	Mortality (in-hospital mortality)	High volume compared to low volume had a reduced risk of mortality of adjusted OR 0.6, 95% CI 0.5 to 0.7. Medium volume compared to low-	Multivariate Cox proportional hazards model

								volume was reduced, adjusted OR 0.7, 95% CI 0.6 to 0.8. Numbers for time trend is not reported, only in figure, this confirms the results from the multivariate analysis.	
Bush 2003	USA	123 hospitals	1904 patients of which 717 were endovascular and 1187 were open	Abdominal aorta aneurysm (ICD-9 codes 441.4)	Both (Open CPT codes 35081 and 35102 and EVAR CPT codes 34800, 34802, and 34804.	Low <10 procedures	Mortality (one year mortality)	Patients at low volume sites were also at increased risk for 1-year mortality, however results for this outcome was not reported and the association had a p-value of 0.17.	Multivariate logistic regression analysis, adj for procedure type, personal and system characteristics.
Mell 2012	USA	Hospitals, numbers unclear	2616 patients	Abdominal aortic aneurysm (ICD-9 code 441.4 and 441.9)	Open and endovascular (ICD-9 Codes 38.34, 38.44, 38.64, 39.52 and 39.71)	1: <17, 2: 17 to 30, 3: 31 to 49, 4: 50 to 79, 5:>79	Mortality and rehospitalisation (30-day mortality or reshospitalisation)	Volume did not independently predict mortality or rehospitalisation. Compared to the highest volume quintile, the Odds per quintile was, 1: OR 1.09 (95% CI 0.77 to 1.56), 2: 1.17 (95% CI 0.80 to 1.71), 3: OR 1.36 (95% CI 0.954 to 1.94), 4: 1.36 (95% CI 0.953 to 1.95).	Variables were compared with x2, Fisher exact test, t-test, analysis of variance, or Wilcoxon rank-sum test when indicated. Multivariable hierarchical mixed-effects regression models controlling for age, gender, area of residence, race, comorbidities, procedure type (open or endo), surgeon type were then used to determine

									independent correlates for treatment and outcome variables and to adjust for clustering at the hospital level.

Table 10. Mortality in patients undergoing elective admissions for open and endovascular surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Dueck 2004	Canada, Ontario	Hospitals, number unclear	2601 patients	Ruptured or acute abdominal aorta aneurysm (fee code E627)	Open and endovascular (procedure codes not reported)	Continuous variable analysed as annual volume per 5 cases	Mortality (30-day mortality)	An association was found in the univariate model (hazard ratio 0.93 (95% CI 0.91 to 0.97), but this effect diminished in the multi-regression model suggesting that this relationship could be explained by other covariates- such as surgeon volume. Numbers for hospital volume in multivariate analysis not reported.	Univariate proportional hazards survival analysis was performed for each variable, a multivariate model was constructed. Adj for the following variables in the analysis; age, gender, income, hospital factors, year of operations.
Karthikesalingam 2014	UK	Hospitals, numbers unlcear	11 799 patients	Ruptured or acute abdominal aorta aneurysm	Open and endovascular (OPCS-4 codes L194-199, L231, L236, L238-239, L254, L258, L259, L49, L271, L275,	Unclear	Mortality (in hospital mortality)	Numbers not reported, only p-value for the association of hospital volume with in-hospital mortality: <0.0001	Binary logistic regression with risk-adjustment for age, sex, social deprivation, and comorbidity

					L276, L281, L285, L286, L289)				index.
Karthikesalingam 2014	USA	Hospitals, numbers unlcear	23838 patients	Ruptured or acute abdominal aorta aneurysm	Open and endovascular (ICD-9 38.44, 38.34, 39.25 and 39.71)	Unclear	Mortality (in hospital mortality)	Numbers not reported, only p-value for the association of hospital volume with in-hospital mortality <0.0001	Binary logistic regression with risk-adjustment for age, sex, social deprivation, and comorbidity index.
Karthikesalingam 2014	UK	Hospitals, numbers unlcear	11 799 patients	Ruptured or acute abdominal aorta aneurysm	Open and endovascular (OPCS-4 codes L194-199, L231, L236, L238-239, L254, L258, L259, L49, L271, L275, L276, L281, L285, L286, L289)	Unclear	Operative mortality, not further described	Numbers not reported, only p-value for the association of hospital volume with operative mortality (p<0.0371)	Binary logistic regression with risk-adjustment for age, sex, social deprivation, and comorbidity index.
Karthikesalingam 2014	USA	Hospitals, numbers unlcear	23838 patients	Ruptured or acute abdominal aorta aneurysm	Open and endovascular (ICD-9 38.44, 38.34, 39.25 and 39.71)	Unclear	Operative mortality, not further described	Numbers not reported, only p-value for the association of hospital volume with operative mortality (p <0.0001)	Binary logistic regression with risk-adjustment for age, sex, social deprivation, and comorbidity index.

Table 11. Mortality in patients undergoing acute/ ruptured admissions for open and endovascular surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Allareddy 2010 (and Allareddy 2007)	USA	1207 hospitals	35104 procedures	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (ICD-9 codes 38.34, 38.44, 38.64, 39.71 and 39.25)	>50 high	Complications (cardiac, nervous system, respiratory, digestive, urinary, latrogenic induced complications, hemorrhage/ hematoma/ seroma complicating a procedure, septicemia and other complications)	The risk of any complications was lower in high volume compared to low volume. The adj OR for any complications was 0.89 (95% CI 0.81 to 0.98). Cardiac adj OR 0.87 (95% CI 0.75 to 1.01), nervous system 1.31 (95% CI 0.93 to 1.84), respiratory 0.73 (95% CI 0.61 to 0.88), digestive 0.85 (95% CI 0.71 to 1.01), urinary 1.07 (95% CI 0.89 to 1.28), latrogenic induced complications 1.03 (95% CI 0.87 to 1.21), hemorrhage/ hematoma/ seroma complicating a procedure 0.91 (95% CI 0.77 to 1.07), septicemia 0.91 (95% CI 0.73 to 1.13), and other	Multivariable logistic regression models were used to examine the association between hospital volume and complications, adj for age, sex, admission type, type of procedure, year of procedure, hospital characteristics, and comorbidity

								complications 0.76 (95% CI 0.61 to 0.99)	
Bush 2003	USA	123 hospitals	1904 patients of which 717 were endovascular and 1187 were open	Abdominal aorta aneurysm (ICD-9 codes 441.4)	Both (Open CPT codes 35081 and 35102 and EVAR CPT codes 34800, 34802, and 34804.	Low <10 procedures	Complications (30-day complications)	The association was reported as not statistical significant (p=0.17)	Multivariate logistic regression analysis, adj for procedure type, personal and system characteristics.
Massarweh 2011	USA, Washington	Hospitals, numbers unlcear	7724 patients	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (procedure codes not reported)	>50 high	Complications (occurrence of a postoperative complication within 30 days of the index operation)	Adjusted complication rates were generally similar for patients who underwent AAA repair at high volume compared to low volume. Year 1, 30 day complications: low volume 29.3%, high volume 26.2%, p-value= 0.93. Year 2, 30-day complications: low-volume 26.2%, high volume 20.0%, p-value= 0.03. The only statewide difference in outcomes was a lower rate of complications (28.8% vs 25.1%, p 0.001) in the post-LF era	Multilevel binomial generalized estimating equation regression models with an exchangeable correlation structure and robust standard errors were used to calculate risk-adjusted outcome rates. Adj for age, sex, type of insurance, length of stay, comorbidity, type of procedure, leapfrog era.
Regenbogen 2012	USA	1939 hospitals	69141 patients	Abdominal aorta aneurysm	Open and endovascular (procedure	1: <34. 2 : 35-60, 3: 61- 95, 4:	Complications (pulmonary failure; pneumonia;	The % complications was higher in low	Multiple logistic regression, age, gender, race,

				(codes not reported)	codes not reported)	96-155, 5: >155	myocardial infarction; deep venous thrombosis/pulmonary embolism; acute renal failure; postoperative hemorrhage; surgical site infection; and gastrointestinal bleeding)	volume, by quintiles, 1: 18.5%, 2: 16%, 3: 15.9%, 4: 15%, 5: 15.5%. The association between volume and complications ad a p-value of <0.0001.	admission type, length of stay

Table 12. Complications in patients undergoing elective admissions for open and endovascular surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Massarweh 2011	USA, Washington	Hospitals, numbers unclear	7724 patients	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (procedure codes not reported)	>50 high	Readmissions (30- and 90-days)	Adjusted readmission were generally similar for patients who underwent AAA repair at high volume compared to low volume. Year 1, 30 day readmission: low volume 10.4%, high volume 8.3%, p-value= 0.93. Year 1, 90-day readmission: low-volume 15.6%, high volume 15.6%, p-value= 0.96. Year 2, 30 day readmission: low volume 10.5%, high volume 10.4%, p-value= 0.82. Year 2, 90-day readmission: low-volume 16.6%, high volume 17.7%, p-value= 0.28	Multilevel binomial generalized estimating equation regression models with an exchangeable correlation structure and robust standard errors were used to calculate risk-adjusted outcome rates. Adj for age, sex, type of insurance, length of stay, comorbidity, type of procedure, leapfrog era.

Table 13. Length of stay in patients undergoing elective admissions for open and endovascular surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Regenbogen 2012	USA	1939 hospitals	69141 patients	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (procedure codes not reported)	1: <34. 2 : 35-60, 3: 61- 95, 4: 96-155, 5: >155	Costs (home health, USD per patient)	Total payments in USD by quintiles, 1: 402, 2: 325, 3: 346, 4: 297, 5: 318. USD associated with home health for low was 84 (20.59%) higher compared with high	Multiple logistic regression, adj for age, gender, race, admission type, length of stay
Regenbogen 2012	USA	1939 hospitals	69141 patients	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (procedure codes not reported)	1: <34. 2 : 35-60, 3: 61- 95, 4: 96-155, 5: >155	Costs (outpatient care, USD per patient)	Total payments in USD by quintiles, 1: 150, 2: 169, 3: 182, 4: 205, 5: 177. USD associated with outpatient care for low was 27 (18%) lower compared with high	Multiple logistic regression, adj for age, gender, race, admission type, length of stay
Regenbogen 2012	USA	1939 hospitals	69141 patients	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (procedure codes not reported)	1: <34. 2 : 35-60, 3: 61- 95, 4: 96-155, 5: >155	Costs (physician services, USD per patient)	Total payments in USD by quintiles, 1: 4059, 2: 3769, 3: 3754, 4: 3523, 5: 3446. USD associated with physician services for low was 613 (15.1%) higher compared with high	Multiple logistic regression, adj for age, gender, race, admission type, length of stay
Regenbogen 2012	USA	1939 hospitals	69141 patients	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (procedure codes not reported)	1: <34. 2 : 35-60, 3: 61- 95, 4: 96-155, 5: >155	Costs (post-discharge ancillary care, USD per patient)	Total payments in USD by quintiles, 1: 2366, 2: 1943, 3: 1880, 4: 1687, 5: 1667. USD associated with ancillary care for low was 699 (29.5%) higher compared with high	Multiple logistic regression, adj for age, gender, race, admission type, length of stay
Regenbogen 2012	USA	1939 hospitals	69141 patients	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (procedure codes not reported)	1: <34. 2 : 35-60, 3: 61- 95, 4: 96-155, 5: >155	Costs (readmissions, USD per patient)	Total payments in USD by quintiles, 1: 1617, 2: 1370, 3: 1425, 4: 1413, 5: 1448. USD associated with readmissions for low was 169 (10.5%) higher compared with high	Multiple logistic regression, adj for age, gender, race, admission type, length of stay

Regenbogen 2012	USA	1939 hospitals	69141 patients	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (procedure codes not reported)	1: <34. 2 : 35-60, 3: 61- 95, 4: 96-155, 5: >155	Costs (skilled nursing, USD per patient)	Total payments in USD by quintiles, 1: 686, 2: 584, 3: 507, 4: 504, 5: 472. USD associated with skilled nursing for low was 214 (31.2%) higher compared with high	Multiple logistic regression, adj for age, gender, race, admission type, length of stay

Table 14. Costs in patients undergoing elective admissions for open and endovascular surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Dimick 2008	USA	2301 hospitals	54203 patients	Abdominal aortic aneurysm (ICD-9 code 441.4) and ruptured (ICD-9 code 441.3)	Open surgery (ICD-9 code 38.44)	Low <24, medium 25 to 49, high 50 to 88, very high 89 to 405.	Mortality (30-day mortality)	Mortality rate by volume was, low 7.8%, medium 6.6%, high 6.2% and very high 5.2%. Higher volume predicted lower mortality in the multivariate model (OR 1.52; 95% CI, 1.33 to 1.73). Because high-volume hospitals perform more endovascular repairs, an analysis of volume and mortality adjusting for the type of repair was conducted. After this adjustment, the low-volume hospitals still had a 50% higher mortality rate compared with the highest-volume hospitals (OR 1.52; 95% CI, 1.35-1.72).	Multiple logistic regression analysis adjusting for age, sex, race, admission acuity (elective, urgent, or emergency), median income, and coexisting diseases. Accounted for the non-independence of patients within hospitals by calculating robust variance estimates designed to deal with clustering of this nature. The proportion of the hospital volume effect attributable to endovascular repair was estimated by running a logistic regression model with and without the variable for type of repair.
Dimick 2002a (and 2004)	USA, Maryland	52 hospitals	2987 patients	Abdominal aorta aneurysm (code not reported),	Open (ICD-9 codes 38.44 and 39.25)	Low <20, medium 20 to 36, and high >36.	Mortality (in-hospital mortality)	In the multivariate analysis, the adj odds for mortality was lower for high volume for those over 65 years (OR 0.57, 95% CI	Univariate predictions and multiple-logistic regression for in-hospital death and complications adj for

				ruptured or acute abdominal aorta aneurysm (ICD- 9 code 441.3)				0.37 to 0.86; p<0.008), but not for those under 65 years (OR 1.1; 95% CI 0.4 to 4.3)	age, sex, race, comorbidities, and severity of disease. For length of stay, multiple linear regression of log-transformed length of stay was used for the multivariate analysis.
Pronovost 1999	USA, Maryland	46 hospitals	2606 patients	Abdominal aorta aneurysm (code not reported), ruptured or acute abdominal aorta aneurysm (ICD- 9 code 441.3)	Open (ICD-9 codes 38.44 and 39.25)	<36 low	Mortality (in-hospital mortality)	Low volume hospitals had a higher mean mortality (8% versus 5%; p<0.005). This relationship was confirmed in the multivariate analysis adj. OR 1.7 (95% CI 1.3 to 2.3).	Multivariate analysis, adj for age, sex, race, nature of admission, ruptured or unruptured and comorbidity, and multiple regression analysis.
Glance 2007	USA, California	301 hospitals	8855 patients	Abdominal aortic aneurysm and ruptured (codes not reported)	Open (ICD-9 codes 38.34, 38.44 and 38.64)	High volume >50 procedures. To identify low-volume hospitals, all hospitals were divided into quartiles based on annual volume. Low-volume was defined as those in the lowest quartile.	Mortality (in-hospital mortality)	Numbers not reported, only in figure. The authors conclude that there does not seem to be a precise relationship between volume and mortality.	Logistic regression, adjusting for age, gender, transfer status, admission type and comorbidities.

Table 15. Mortality in all patients undergoing open surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Dimick 2002a (and 2004)	USA, Maryland	52 hospitals	2987 patients	Abdominal aorta aneurysm (code not reported), Ruptured or acute abdominal aorta aneurysm (ICD- 9 code 441.3)	Open (ICD-9 codes 38.44 and 39.25)	Low <20, medium 20 to 36, and high >36.	Complications	Patients at high volume hospitals had decreased relative risk of several complications: pulmonary failure (RR, 0.45; 95% CI, 0.36 to 0.55), reintubation (RR, 0.53; 95% CI, 0.44 to 0.64), pneumonia (RR, 0.74; 95% CI 0.55 to 0.99), cardiac complications (RR 0.63; 95% CI, 0.51 to 0.78), and shock (RR 0.27; 95% CI, 0.10 to 0.78). Furthermore, hospital complications was found to explain much of the effect of volume on mortality.	Univariate predictions and multiple-logistic regression for in-hospital death and complications adj for age, sex, race, comorbidities, and severity of disease. For length of stay, multiple linear regression of log-transformed length of stay was used for the multivariate analysis.

Table 16. Complications in all patients undergoing open surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Pronovost 1999	USA, Maryland	46 hospitals	2606 patients	Abdominal aorta aneurysm (code not reported), Ruptured or acute abdominal aorta aneurysm (ICD- 9 code 441.3)	Open (ICD-9 codes 38.44 and 39.25)	<36 low	Length of stay (days at intensive care unit)	Low volume hospitals were associated with a reduction in days in intensive care in the multivariate analysis adj. with -22 % (95% CI -43 to 0).	Multivariate analysis, adj for age, sex, race, nature of admission, ruptured or unruptured and comorbidity, and multiple regression analysis.
Dimick 2002a (and 2004)	USA, Maryland	52 hospitals	2987 patients	Abdominal aorta aneurysm (code not reported), Ruptured or acute abdominal aorta aneurysm (ICD- 9 code 441.3)	Open (ICD-9 codes 38.44 and 39.25)	Low <20, medium 20 to 36, and high >36.	Length of stay (hospital days)	In the univariate and multivariate analysis, there was no statistically significant relationship between hospital volume and length of stay. Numbers not reported.	Univariate predictions and multiple-logistic regression for in-hospital death and complications adj for age, sex, race, comorbidities, and severity of disease. For length of stay, multiple linear regression of log-transformed length of stay was used for the multivariate analysis.
Pronovost 1999	USA, Maryland	46 hospitals	2606 patients	Abdominal aorta aneurysm (code not reported), Ruptured or acute abdominal aorta aneurysm (ICD- 9 code 441.3)	Open (ICD-9 codes 38.44 and 39.25)	<36 low	Length of stay (hospital days)	There was little or no difference between low and high volume in hospital length of stay, with a 6% higher length of stay in the low volume hospitals in the multivariate analysis (95% CI -3% to 15%).	Multivariate analysis, adj for age, sex, race, nature of admission, ruptured or unruptured and comorbidity, and multiple regression analysis.

Table 17. Length of stay in all patients undergoing open surgery

Study ID	Setting	Unit (surgeon/	Patients (description	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis

		department/ hospital)	and N)						
Gonzalez 2014	USA	Hospitals, number unclear	20690 patients	Abdominal aortic aneurysm and ruptured (codes not reported)	Open and endovascular (procedure codes not reported)	Divided into quintiles, high volume represented the highest quintile, and low the lowest quintile. Not further described.	Mortality (30-day mortality)	Compared with the highest-volume hospitals, the lowest-volume hospitals had increased rates of mortality (OR 1.80; 95% CI, 1.56 to 2.07)	Calculation of risk adjusted mortality rates (by patient age, sex, race, urgency and operation and comorbidities), and logistic regression
Gonzalez 2014	USA	Hospitals, number unclear	20690 patients	Abdominal aortic aneurysm and ruptured (codes not reported)	Open and endovascular (procedure codes not reported)	Divided into quintiles, high volume represented the highest quintile, and low the lowest quintile. Not further described.	Mortality (Failure to rescue)	Compared with the highest-volume hospitals, the lowest-volume hospitals had increased odds of failure to rescue (OR 1.38; 95%CI 1.16 to 1.64)	Calculation of risk adjusted mortality rates (by patient age, sex, race, urgency and operation and comorbidities), and logistic regression
Jibawi 2006	UK, England	223 hospital trusts	31078 patients	Abdominal aorta aneurysm and ruptured abdominal aortic aneurysm (ICD-10 codes I 71.x)	Open and endovascular (OPCS-4 codes L16.x - L.26.x)	Identified as part of the analysis	Mortality (in-hospital mortality)	Based on a bivariate correlation, there was an inverse correlation between volume and hospital mortality (-0.315, $p<0.001$). In the analysis using logarithmic transformation, the association was stronger (-0.447, $p<0.001$). Cut-off where no difference was seen between volume categories was estimated to be 14 procedures per year.	Bivariate correlation (Pearson's), and logarithmic transformation
Hernandez-Boussard 2012	USA	Hospitals, number unclear	182843 patients	Abdominal aortic aneurysm and ruptured	Open and endovascular (ICD-9 codes 38.44 and	Low <28, medium 28-61 and high >61	Mortality (in-hospital mortality)	The adj % mortality was higher in low than for high volume. % mortality by category was: low 2.66,	Rao-Scott chi-squared for categoricalal variables and Kruskal–Wallis Test for

				(codes not reported)	39.71)			medium 0.53 and high 0.23, p<0.0001	continuous variables. The Cochran-Armitage trend test was used to analyse outcomes by hospital volume. Risk adjusted rates adjusted for age, sex, age–sex interactions, DRG, and comorbidities. All models accounted for the clustered nature, admission within year specific hospital cluster, of the study sample.
Anderson 2014	USA	Hospitals, numbers unclear	159333 patients	Abdominal aortic aneurysm and ruptured (codes not reported)	Open and endovascular (procedure codes not reported)	>50 high	Mortality (in-hospital mortality)	Using adjusted logistic regressions, patients had decreased odds ratios of inpatient mortality over time when they received care at a high-volume hospital. Numbers not reported, only in figure for the following time periods 1998-1999, 2000-2001, 2002-2003, 2004-2005, 2006-2007, 2008-2009, 2010. The association was statistical significant for all periods with exception of in 2010.	Logistic regression and adjusting for age, race, sex, comorbidity, and teaching hospital status. Separate analyses were performed for each 2-year interval in the study period to observe changing odds ratios over time.

Table 18. Mortality in all patients undergoing open and endovascular surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Hernandez-Boussard 2012	USA	Hospitals, number unclear	182843 patients	Abdominal aortic aneurysm and ruptured (codes not reported)	Open and endovascular surgery (ICD-9 codes 38.44 and 39.71)	Low <28, medium 28-61 and high >61	Complications	Patients with one or more complications were 8.84% in the low-volume group, 7.78% in the medium-volume group, and 7.23% in the high-volume group. The volume-complications relationship had a p-value of 0.001. The relationship was stronger for blood-stream infections (all numbers are rates per 1000) (low 11.38, medium 9.75 and high 9.63, p<0.0006), post-operative pulmonary embolism and deep vein thrombosis (low 3.5, medium 2.85 and high 1.65, p<0.0001), sepsis (low 14.64, medium 13.62 and high 12.48, p<0.001), wound dehiscence (low 5.09, medium 3.13 and high 3.14, p<0.0001)and accidental punctures or lacerations (low 3.54, medium 3.96 and high 3.66, p=0.0233), and with little or no association for	Rao-Scott chi-squared for categoricalal variables and Kruskal–Wallis Test for continuous variables. The Cochran-Armitage trend test was used to analyse outcomes by hospital volume. Risk adjusted rates adjusted for age, sex, age–sex interactions, DRG, and comorbidities. All models accounted for the clustered nature, admission within year specific hospital cluster, of the study sample.

								pressure ulcers (low 12.18, medium 8.56 and high 12.26, p=0.31), failure to rescue (low 118.46, medium 121.61 and high 120.86, p<0.11) and respiratory failure (low 45.47, medium 22.67 and high 40.06, p=0.06).	
Gonzalez 2014	USA	Hospitals, number unclear	20690 patients	Abdominal aortic aneurysm and ruptured (codes not reported)	Open and endovascular (procedure codes not reported)	Divided into quintiles, high volume represented the highest quintile, and low the lowest quintile. Not further described.	Complications	Compared with the highest-volume hospitals, the lowest-volume hospitals had a small increase in major postoperative complications (OR 1.18; 95% CI 1.09 to 1.27)	Calculation of risk adjusted mortality rates (by patient age, sex, race, urgency and operation and comorbidities), and logistic regression

Table 19. Complications in all patients undergoing open and endovascular surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Illonzo 2014	USA	Hospitals, number of hospitals unclear	195928 patients	Abdominal aorta aneurysm (codes not reported)	Endovascular (codes not reported)	Low <4, medium 5 to 17, high 18 to 177	Mortality (30 day mortality after complications associated with procedure)	High volume hospitals had a higher success rate of rescue compared to low volume hospitals ($p<0.001$). Trend in failure to rescue 0.7% for high volume vs 1.69% for low volume.	Multivariate logistic regression analysis adj for age, gender, race, comorbidities, hospital annual volume, and year of the surgery.
Landon 2010	USA	Hospitals, numbers unlcear	29390 cases	Abdominal aorta aneurysm (ICD-9 code 441.4)	Endovascular (ICD-9 code 39.71)	1: <9, 2: 10 to 17, 3: 18 to 29, 4: 30 to 49, 5: >50.	Mortality (30-day mortality)	Mortality by quintile, after adjustment, showed a substantial decrease by higher volume between the first and second quintile (2.5% versus 1.6%), with continued minor decreases over quintiles 3 to 5.	All models were adjusted for baseline clinical and demographic characteristics. Observed mortality in each quintile was compared with predicted adjusted mortality computed under the counterfactual assumption that all procedures occurred at a hospital in the lowest-volume quintile.
McPhee 2011	USA	Hospitals	8121 procedures	Abdominal aorta aneurysm (ICD-9 code 441.4)	Endovascular (ICD-9 code 39.71)	Low <15, medium 16 to 70, and high >70	Mortality (In-hospital mortality)	The association between hospital volume and mortality for endovascular procedures was uncertain, although low volume hospitals had a higher mortality (OR, 2.3; 95% CI, 0.96-5.3).	Multivariable logistic regression models, adj for patient level factors such as age, gender, comorbidity and hospital level characteristics.
Dua 2014	USA	Hospitals, N unclear	Unclear	Abdominal aorta	Endovascular (ICD-9 code	No-cut off, this is	Mortality (In-hospital	Hospitals with mortality higher than 13%	Statistical analysis was completed

				aneurysm (ICD-9 code 441.4 and 441.9)	39.71)	explored as part of the analysis, threshold set at <8	mortality)	complete fewer than eight procedures. These hospitals also have a mortality of up to 100% (OR 7.7 to 33.2) when compared to the mean 6 two standard deviations of all hospitals; (95% CI 0.21 to 0.93; p < .001).	using analysis of variance for continuous variables (number of cases) and x2 for categorical variables (i.e., hospital covariates, inpatient mortality). The Mann-Whitney U test was used for LOS and median total costs. Mann-Kendall trend analysis was completed to determine if trends outside the 95% CI were statistically significant; s values and P values are reported in conjunction with odds ratios (ORs).
Brooke 2008	USA, California	81 hospitals	3120 cases	Abdominal aorta aneurysm (codes not reported)	Endovascular (ICD-9 code 39.71)	>50 high	Mortality (In-hospital mortality)	The average rates of mortality at time-point 1 (2000-2003): high volume 6 (1.16%)/ low volume 8 (2.02%) Time-point 2 (2003-2005): high volume 8 (0.63%)/ low volume 18 (1.91%). In the adj regression model, the effect of volume on mortality was uncertain. The ratio of rate ratio for both time points was 0.39 (95% Ci 0.07 to 1.80; p= 0.26).	Rate of rate ratio for two periods (relative risk) was calculated. The effect of Leapfrog standards on hospital LOS was analysed using a linear regression model and fit using a random intercept for each hospital and a log-normal distribution. Adj for age, sex, comorbidities, type of admissions
Vogel 2011	USA	Hospitals , range from 1188 to 1291	42155 procedures	Abdominal aorta aneurysm (ICD-9 code 441.4)	Endovascular (ICD-9 code 39.71)	Top ten % volume was categorised as high-volume, all remaining hospitals placed in the low-group	Mortality (In-hospital mortality)	Patients in low-volume hospitals were more likely to die after surgery; OR 1.35, 95% CI 1.08 to 1.68.	Multivariable analysis with forward step-wise regressions, adj for age, sex, race, comorbidities and hospital procedure.

Table 20. Mortality in patients undergoing elective endovascular surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Dua 2014	USA	Hospitals, numbers unclear	Unclear	Ruptured or acute abdominal aorta aneurysm (ICD-9 code 441.3)	Endovascular (ICD-9 codes 39.71)	No-cut off, this is explored as part of the analysis, threshold set at <8	Mortality (in hospital mortality)	Hospitals that complete endovascular surgery for ruptured AAA have a 95% CI of 0% to 100% for mortality, indicative of the high mortality risk associated with rupture. Hospitals that complete more than 8 procedures for ruptured AAA have mortality between 20% and 40%. These trends are not statistically significant (t= -0.02; p=0.05).	Statistical analysis was completed using analysis of variance for continuous variables (number of cases) and x2 for categorical variables (i.e., hospital covariates, inpatient mortality). The Mann-Whitney U test was used for LOS and median total costs. Mann-Kendall trend analysis was completed to determine if trends outside the 95% CI were statistically significant; s values and P values are reported in conjunction with odds ratios (ORs).
McPhee 2009	USA	Hospitals, numbers unclear	Unclear	Ruptured or acute abdominal aorta aneurysm (ICD-9 code 441.3)	Endovascular (ICD-9 codes 39.71)	Low <19, medium 19 to 40, and high >40	Mortality (in hospital mortality)	In the multivariate analysis, the differences in mortality by category was uncertain: low versus high OR 1.06 (95% CI 0.85 to 1.32), and medium versus high OR 1.2 (95% CI 0.96 to 1.49)	Multivariable logistic regression models, controlled for age, sex, comorbidities, insurance type, year of procedure, hospital characteristics

Table 21. Mortality in patients undergoing acute/ ruptured endovascular surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Illonzo 2014	USA	Hospitals, number of hospitals unclear	195928 patients	Abdominal aortic aneurysm (codes not reported)	Endovascular (procedure codes not reported)	Low <4, medium 5 to 17, high 18 to 177	Complications (cardiac arrest, vascular device implant and graft complications, amputation and wound complications)	High volume hospitals had less complications compared to low volume hospitals (11.91% vs 21.32%; P<.001). This included fewer cases of sepsis (0.5% vs 1.22%; p<0.001), prolonged ventilation (0.41% vs 1.26%; p<0.001), and arterial reinterventions (0.73% vs 1.03%; p<0.002).	Multivariate logistic regression analysis adj for age, gender, race, comorbidities, hospital annual volume, and year of the surgery.
Vogel 2011	USA	Hospitals , range from 1188 to 1291	42155 procedures	Abdominal aorta aneurysm (ICD-9 code 441.4)	Endovascular surgery (ICD-9 code 39.71)	Top ten % volume was categorised as high-volume, all remaining hospitals placed in the low-group	Complications (pneumonia, urinary tract infection, sepsis and surgical site infection)	Mean frequency of any complications after endovascular procedures were: high volume had 502 (3.1%) complications and low had 911 (3.51%). For pneumonia, high volume had 153 (0.94%) complications and low had 330 (1.27%). For sepsis, high volume had 50 (0.31%) and low-volume had 116 (0.45%). For UTI high volume had 280 (1.73%) and low-volume had 439 (1.69%). For SSI high volume had 51 (0.31%) and low-volume had 85 (0.33%). In the logistic regression, patients in low volume hospitals were more likely to develop pneumonia (OR 1.34; 95% CI 1.11 to 1.63) and sepsis (OR 1.44; 95% CI 1.03 to 2.01)	Multivariable analysis with forward step-wise regressions, adj for age, sex, race, comorbidities and hospital procedure.

Table 22. Complications in patients undergoing elective endovascular surgery

Study	Setting	Unit	Patients	Condition	Procedure	Volume cut-off	Outcome	Results	Description of analysis

ID		(surgeon/ department/ hospital)	(description and N)	(diagnosis)					
Vogel 2011	USA	Hospitals , range from 1188 to 1291	42155 procedures	Abdominal aorta aneurysm (ICD-9 code 441.4)	Endovascular (ICD-9 code 39.71)	Top ten % volume was categorised as high-volume, all remaining hospitals placed in the low-group	Length of stay (intensive unit days)	Intensive unit days were lower in high-volume hospitals. Mean intensive unit days 0.84 (SD 2.58) and low-volume 1.30 (SD 2.64), p<0.0001	Multivariable analysis with forward step-wise regressions, adj for age, sex, race, comorbidities and hospital procedure.
Brooke 2008	USA	81 hospitals	3120 cases	Abdominal aorta aneurysm (codes not reported)	Endovascular (ICD-9 code 39.71)	>50 high	Length of stay (hospital days)	The average rates of length of stay at time-point 1 (2000-2003): high volume 3.02 days (SD 2.2)/ low volume 4.10 days (SD 2.9) Time-point 2 (2003-2005): high volume 2.30 days (SD 1.4)/ low volume 3.44 days (SD 2.4). In the adj regression model, the effect of volume on length of stay was not statistically significant. Figures not reported.	Rate of rate ratio for two periods (relative risk) was calculated. The effect of Leapfrog standards on hospital LOS was analysed using a linear regression model and fit using a random intercept for each hospital and a log-normal distribution. Adj for age, sex, comorbidities, type of admissions
Vogel 2011	USA	Hospitals , range from 1188 to 1291	42155 procedures	Abdominal aorta aneurysm (ICD-9 code 441.4)	Endovascular (ICD-9 code 39.71)	Top ten % volume was categorised as high-volume, all remaining hospitals placed in the low-group	Length of stay (hospital days)	Hospital days were lower in high-volume hospitals. Mean hospital days in high volume 2.75 (SD4.07) and low-volume 3.02 (SD 3.74), p<0.0001	Multivariable analysis with forward step-wise regressions, adj for age, sex, race, comorbidities and hospital procedure.

Table 23. Length of stay in patients undergoing elective endovascular surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Vogel 2011	USA	Hospitals , range from 1188 to 1291	42155 procedures	Abdominal aorta aneurysm (ICD-9 code 441.4)	Endovascular (ICD-9 code 39.71)	Top ten % volume was categorised as high-volume, all remaining hospitals placed in the low-group	Costs (hospital resource utilisation, charges and supplies)	Costs were lower in high-volume hospitals in hospital charges, but not for supplies. Mean USD hospital charges in high volume 68172 (SD 46168) and low-volume 73014 (SD 47551), p-value <0.0001, and for med/sur supplies 38144 (SD 19317) and low-volume 38042 (SD 21797), p-value =0.6	Multivariable analysis with forward step-wise repressions, adj for age, sex, race, comorbidities and hospital procedure.

Table 24. Costs in patients undergoing elective endovascular surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Dimick 2008	USA	1357 hospitals	26750 patients	Abdominal aortic aneurysm (ICD-9 code 441.4) and ruptured (ICD-9 code 441.3)	Endovascular (ICD-9 code 39.71)	Low <23, medium 24 to 47, high 48 to 94, very high 96 to 430	Mortality (30-day mortality)	Mortality rate by volume was, low 3.5%, medium 2.5%, high 2.3% and very high 2.2%. Higher volume predicted lower mortality in the multivariate model. A strong relationship between volume and mortality (OR 1.68; 95% CI, 1.32-2.22).	Multiple logistic regression analysis adjusting for age, sex, race, admission acuity (elective, urgent, or emergency), median income,and coexisting diseases. Accounted for the non-independence of patients within hospitals by calculating robust variance estimates designed to deal with clustering of this nature. The proportion of the hospital volume effect attributable to endovascular repair was estimated by running a logistic regression model with and without the variable for type of repair.
Holt 2009	UK, England	91 hospitals (trusts)	1645 patients	Abdominal aortic aneurysm and ruptured (ICD-10 codes 71.3 or 71.4)	Endovascular (OPCS codes L28.1 to 9, L26.5, L26.6, L26.7)	Unclear, divided into five quintiles.	Mortality (In-hospital mortality)	In the multivariate analysis, higher volume was associated with a lower rate of mortality OR 0.993; 95% CI 0.987 to 1.000, p=0.0572.	The effect of volume on outcome was evaluated using both crude data and after risk-adjustment. The samples were the same for both crude and adjusted analyses. Multiple logistic regression model, controlled for gender, comorbidities and age.

Table 25. Mortality in all patients undergoing endovascular surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Holt 2009	UK, England	91 Hospitals (trusts)	1645 patients	Abdominal aortic aneurysm and ruptured (ICD-10 codes 71.3 or 71.4)	Endovascular (OPCS codes L28.1 to 9, L26.5, L26.6, L26.7)	Unclear, divided into five quintiles.	Length of stay (hospital days)	The median length of stay was lower at higher volume hospitals for EVR with a median of 7.25 days in the highest volume quintile against 10.2 days in all other quintiles combined.	The effect of volume on outcome was evaluated using both crude data and after risk-adjustment. The samples were the same for both crude and adjusted analyses. Multiple logistic regression model, controlled for gender, comorbidities and age.

Table 26. Length of stay in all patients undergoing endovascular surgery

The association of surgeon volume with outcomes in patients with abdominal aorta aneurysms

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Huber 2001	USA	Surgeons, number unclear	Unclear	Abdominal aorta aneurysm (codes not reported)	Open (Current Procedural Terminology (CPT) codes 35081, repair defect of artery, abdominal aorta, 35091 repair defect of artery, aorta, involving visceral vessels, and 35102 repair defect of artery, aorta, involving iliac vessels for elective AAA repair)	1: <3, 2: 4 to 6, 3: 7 to 10, and 5: >11	Mortality (30-day mortality)	The % mortality rate was lower for high volume compared to low-volume. The mortality rate was 7.5 for low and 4.0 for those with more than 11 AAA repairs, respectively.	Analysis poorly described, results reported as %. Mortality rates were adjusted for race, sex, and age, but not for comorbidities
Kantonen 1997 (and 1999)	Finland	Surgeons, number unclear	929 patients	Abdominal aorta aneurysm (codes not reported)	Open (procedure codes not reported)	Unclear	Mortality (30-day mortality)	There was an association, judged to be strong by the authors, between surgeons' total vascular case load and aneurysm case load on mortality. No numbers reported, only p-values ($p<0.01$).	Correlation between volume and mortality was tested using linear regression analysis.
Dimick 2003	USA	897 surgeons	3912 patients	Abdominal aorta aneurysm	Open (ICD-9 codes 38.44 and 39.25)	>10 high	Mortality (in-hospital mortality)	Surgery by a high volume surgeon was associated with 40% reduction in	Univariate analysis and multiple regression with

				(codes not reported)				mortality (95% CI, 12% to 60%; p<0.01).	hospital clustering, adj for age, race, gender, nature of admission, comorbidity, and hospital specialty.
McPhee 2011	USA	Surgeons, number unclear	Unclear	Abdominal aorta aneurysm (ICD-9 code 441.4)	Open surgery (ICD-9 codes 38.44 and 39.25)	Low <2, medium 3 to 9, and high >9	Mortality (in-hospital mortality)	Overall, low- (7.5%) and medium-volume (4.3%) surgeons had higher mortality rates than higher-volume surgeons (3.0%); p<0.0001. In the multivariate analysis, low surgeon volume compared to high volume was associated with increased mortality (OR 2.0; 95% CI 1.3 to 3.1; p<0.0008). the difference in mortality between medium and high was uncertain OR 1.3, 95% CI 0.84 to 1.9	Multivariable logistic regression models, adj for patient level factors such as age, gender, comorbidity and hospital level characteristics.
Pearce 1999	USA, Florida	Surgeons, range over time 647 to 829	13415 procedures	Abdominal aorta aneurysm (ICD-9 code 441.4)	Open (ICD-9 codes 38.34 and 38.44)	Unclear	Mortality and morbidity (hospital mortality, myocardial infarction or cerebrovascular accident)	A doubling of surgeon volume was associated with 11% reduction in risk (Coefficient Relative risk ratio 0.9, p=0.0002)	Multiple logistic regression, adj for age, sex, emergency admission status, hospital characteristics, year of discharge.
Tu 2001	Canada, Ontario	130 surgeons	5878 patients	Abdominal aorta aneurysm (codes not reported)	A bit unclear but probably R-codes 802, 816, 817)	Low <5, medium 5-13, and >13	Mortality (in-hospital mortality)	There was higher mortality in lower volume, low compared to high: OR 1.83, 95% CI 1.01 to 3.32, p< 0.04), and medium compared to high OR 1.40, 95% CI 0.97 to 2.02, p< 0.07)	Multivariate logistic regression analysis adj patient demographics, transfer status, and comorbidities.

Table 27. Mortality in patients undergoing elective open surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Kantonen 1997 (and 1999)	Finland	Surgeons, number unclear	610 patients	Ruptured or acute abdominal aorta aneurysm (codes not reported)	Open (procedure codes not reported)	Unclear	Mortality (30-day mortality)	There was no association according to the authors. Numbers not reported, only plotted in figure.	Correlation between volume and mortality was tested using linear regression analysis.
Dardik 1998	USA, Maryland	226 surgeons	527 procedures	Ruptured or acute abdominal aorta aneurysm (ICD-9 codes 441.02 and 441.3)	Open (ICD-9 codes 38.34, 38.44, 38.64, 38.84 and 39.54)	Low 1-4, medium 5 to 9, and high >10	Mortality (in hospital mortality)	There was a lower rate of in-hospital mortality associated with high-volume surgeons. Low 50.8% (2.8), medium 47.1% (4.6), high 36.3% (5.1), $p<0.05$. In the multivariate analysis, high volume surgeons had a lower mortality rate compared with low and medium volume: OR 0.54 (95% CI 0.33 to 0.88), $p<0.014$	Categoricalal variables were analysed by Pearson's test or Fisher's Exact Test. Continuous variables were analysed by analysis of variance for parametric variables and the Mann-Whitney U test or Kruskal-Wallis test for nonparametric variables. Multiple logistic regression was used for multivariate analysis and controlled for age, sex, race, hypertension, diabetes, comorbidities, and health behaviours.
Modrall 2011	USA	6857 surgeons	22986 patients	Abdominal aortic aneurysm (ICD-9 code 441.4 and 441.9)	Open (ICD-9 codes 38.34 and 38.44)	Divided into diciles, lowest had <1 procedures, highest had >12.	Mortality (in-hospital mortality)	Increasing volume per surgeon was not a significant predictor of in-hospital mortality in the multivariate analysis (data not shown), whereas increasing composite surgeon volume (all vascular)	Multiple logistic regression, adj for age, gender, race, elective repair, comorbidity, source of payment, and hospital characteristics

								remained a significant predictor of lower in-hospital mortality OR 0.994; 95% CI 0.992 to 0.996; p<0.0001.	
Rutledge 1996	USA, North Carolina	Surgeons, number unclear	1480 patients	Ruptured or acute abdominal aorta aneurysm (ICD-9 codes 441.3)	Open (procedure codes not reported)	Unclear	Mortality (in-hospital survival)	The association between the surgeon volume and patient survival was found to be statistically significant by logistic regression analysis, with a p value of 0.025. Numbers not reported.	Logistic regression was used to assess the association between hospital AAA caseload and patient survival after RAAA.

Table 28. Mortality in patients undergoing acute open surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Dardik 1998	USA, Maryland	226 surgeons	527 procedures	Ruptured or acute abdominal aorta aneurysm (ICD-9 codes 441.02 and 441.3)	Open (ICD-9 codes 38.34, 38.44, 38.64, 38.84 and 39.54)	Low 1-4, medium 5 to 9, and high >10	Length of stay (hospital days)	There was little or no association between volume and hospital length of stay (days). Low 11.7 (0.8), medium 11.6 (1.0), high 12.4 (1.8), p=0.46. The association of volume with length of stay was not evaluated in the multivariate analysis.	Categoricalal variables were analysed by Pearson's test or Fisher's Exact Test. Continuous variables were analysed by analysis of variance for parametric variables and the Mann-Whitney U test or Kruskal-Wallis test for nonparametric variables. Multiple logistic regression was used for multivariate analysis and controlled for age, sex, race, hypertension, diabetes, comorbidities, and health behaviours.

Table 29. Length of stay in patients undergoing acute open surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Dardik 1998	USA, Maryland	226 surgeons	527 procedures	Ruptured or acute abdominal aorta aneurysm (ICD-9 codes 441.02 and 441.3)	Open (ICD-9 codes 38.34, 38.44, 38.64, 38.84 and 39.54	Low 1-4, medium 5-9, and high >10	Costs (total hospital charges)	There was lower hospital charges associated with higher volume surgeons (USA dollars). Low 27362 (1283), medium 28575 (1748), high 23740 (2356), p=0.018. The association of volume with charges was not evaluated in the multivariate analysis.	Categoricalal variables were analysed by Pearson's test or Fisher's Exact Test. Continuous variables were analysed by analysis of variance for parametric variables and the Mann-Whitney U test or Kruskal-Wallis test for nonparametric variables. Multiple logistic regression was used for multivariate analysis and controlled for age, sex, race, hypertension, diabetes, comorbidities, and health behaviours.

Table 30. Costs in patients undergoing acute open surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Birkmeyer 2003	USA	Surgeons 6276	Patients 39794	Abdominal aorta aneurysm (codes not reported)	Open and endovascular (procedure codes not reported)	Low <8, medium 8 to 17.5 and high >17.5	Mortality (30-day mortality)	In the multivariate analysis, higher volume was associated with lower mortality rates. Adj OR 1.55 (95%CI 1.36 to 1.77). Surgeon volume effect present with and without adjustment for hospital volume, in the adjusted analysis, hospital volume accounted for 15% of the effect.	Multiple logistic regression with adjustment for characteristics of the patients (age, gender, comorbidities and race)
Dueck 2004	Canada, Ontario	Surgeons, number unclear	13701 patients	Abdominal aortic aneurysm (fee code R802, R816, and R817)	Open and endovascular (procedure codes not reported)	Continuous variable analysed as annual volume per 10 cases	Mortality (30-day mortality)	The effect of surgeon volume was explored in the univariate and multivariate models. Higher surgeon volume indicated somewhat higher survival. Hazard ratio in the univariate model was 0.99 (95% CI 0.98 to 1.01), and in the multivariate model 0.91 (95% CI 0.88 to 0.94).	Univariate proportional hazards survival analysis was performed for each variable, a multivariate model was constructed. Adj for the following variables in the analysis; age, gender, income, hospital factors, year of operations.

Table 31. Mortality in patients undergoing elective open and endovascular surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Dueck 2004	Canada, Ontario	Surgeons, number unclear	2601 patients	Ruptured or acute abdominal aorta aneurysm (fee code E627)	Open (procedure codes not reported)	Continuous variable analysed as annual volume per 5 cases	Mortality (30-day mortality)	Surgeon volume effect explored in both univariate and multivariate models. An association was found in both models. Hazard ratio in the univariate model was 0.90 (96% CI 0.84 to 0.95), and in the multivariate model 0.87 (95% CI 0.81 to 0.94) p<0.0002	Univariate proportional hazards survival analysis was performed for each variable, a multivariate model was constructed. Adj for the following variables in the analysis; age, gender, income, hospital factors, year of operations.

Table 32. Mortality in patients undergoing acute open and endovascular surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Pronovost 1999	USA, Maryland	Surgeons, number unclear	2606 patients	Abdominal aorta aneurysm (code not reported), ruptured or acute abdominal aorta aneurysm (ICD- 9 code 441.3)	Open (ICD-9 codes 38.44 and 39.25)	<8 low	Mortality (in-hospital mortality)	In the bivariate analysis, low volume surgeons had a higher risk of mortality than high volume surgeons (10% versus 8%; p<0.003). When adjusted in the multivariate analysis, there was little or no relationship between volume and mortality	Multivariate analysis, adj for age, sex, race, nature of admission, ruptured or unruptured and comorbidity, and multiple regression analysis.

Table 33. Mortality in all patients undergoing open surgery

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
McPhee 2011	USA	Surgeons, numbers unclear	Unclear	Abdominal aorta aneurysm (ICD-9 code 441.4)	Endovascular (ICD-9 code 39.71)	Low <4, medium 4 to 24,and high >24	Mortality (In-hospital mortality)	The association between surgeon volume and mortality was uncertain, although low volume surgeons had a higher mortality: OR 1.6 (95% CI, 0.76 to 3.4).	Multivariable logistic regression models, adj for patient level factors such as age, gender, comorbidity and hospital level characteristics.

Table 34. Mortality in patients undergoing elective endovascular surgery