ORIGINAL RESEARCH

Unwarranted Variation in the Quality of Care for Patients With Diseases of the Thoracic Aorta

Alex Bottle, MSc, PhD;* Giovanni Mariscalco, MD, PhD;* Matthew A. Shaw, MA; Umberto Benedetto, MD; Athanasios Saratzis, MD; Silvia Mariani, MD; Mohamad Bashir, MD, MRCS, PhD; Paul Aylin, FFPH; David Jenkins, BSc, MBBS, FRCS, MS; Aung Y. Oo, FRCS; Gavin J. Murphy, MD, FRCS; on behalf of the UK Aortic Forum†

***Background*—**Thoracic aortic disease has a high mortality. We sought to establish the contribution of unwarranted variation in care to regional differences in outcomes observed in patients with thoracic aortic disease in England.

***Methods and Results*—**Data from the Hospital Episode Statistics (HES) and the National Adult Cardiac Surgery Audit (NACSA) were extracted. A parallel systematic review/meta-analysis through December 2015, and structure and process questionnaire of English cardiac surgery units were also accomplished. Treatment and mortality rates were investigated. A total of 24 548 adult patients in the HES study, 8058 in the NACSA study, and 103 543 from a total of 33 studies in the systematic review were obtained. Treatment rates for thoracic aortic disease within 6 months of index admission ranged from 7.6% to 31.5% between English counties. Risk-adjusted 6-month mortality in untreated patients ranged from 19.4% to 36.3%. Regional variation persisted after adjustment for disease or patient factors. Regional cardiac units with higher case volumes treated more-complex patients and had significantly lower risk-adjusted mortality relative to low-volume units. The results of the systematic review indicated that the delivery of care by multidisciplinary teams in high-volume units resulted in better outcomes. The observational analyses and the online survey indicated that this is not how services are configured in most units in England.

***Conclusions*—**Changes in the organization of services that address unwarranted variation in the provision of care for patients with thoracic aortic disease in England may result in more-equitable access to treatment and improved outcomes. **(*J Am Heart Assoc*. 2017;6:e004913. DOI: 10.1161/JAHA.116.004913.)**

Key Words: aortic disease • aortic dissection • cardiac surgery • quality of care

Diseases of the thoracic aorta are increasing in prevalence worldwide.[1,2] In the United Kingdom (UK), between 1999 and 2010, hospital admissions for thoracic aortic dissection increased from 7.2 to 8.8 and for thoracic aortic aneurysm from 4.4 to 9.0 per 100 000 inhabitants.[3] These diseases have a high mortality; in the UK, mortality rates for thoracic aortic dissection and aneurysm are 3.2 and 7.5 per 100 000 inhabitants, respectively.[3] There is evidence of regional variation in clinical outcomes for patients with thoracic aortic disease (TAD)[4–11]; for example, operative mortality rates for acute type A dissection, the most common acute presentation of TAD, range from 2.8% to 47.6% between centers.[4,9–16] This may reflect differences in socioeconomic, ethnic, and other demographic characteristics of local populations, but there is also evidence of variation in the provision of aortic services in the UK and elsewhere.[7,10,16]

From the Dr Foster Unit, Department of Primary Care and Public Health, School of Public Health, Imperial College, London, United Kingdom (A.B., P.A.); Leicester Cardiovascular Biomedical Research Unit & Department of Cardiovascular Sciences, Glenfield Hospital, University of Leicester, United Kingdom (G.M., A.S., S.M., G.J.M.); Information Department (M.A.S.) and Department of Cardiothoracic Surgery (A.Y.O.), Liverpool Heart and Chest Hospital, Liverpool, United Kingdom; School of Clinical Sciences, Bristol Heart Institute, University of Bristol, United Kingdom (U.B.); Department of Health Economics, University of Liverpool, United Kingdom (M.B.); Department of Cardiothoracic Surgery, Papworth Hospital, Cambridge, United Kingdom (D.J.).

Accompanying Data S1, Tables S1 through S15 and Figures S1 through S10 are available at http://jaha.ahajournals.org/content/6/3/e004913/DC1/embed/inline-supplementary-material-1.pdf

*Dr Bottle and Dr Mariscalco contributed equally to this work.

†A complete list of the UK Aortic Forum Collaborators can be found in the Appendix at the end of the article.

Correspondence to: Giovanni Mariscalco, MD, PhD, Leicester Cardiovascular Biomedical Research Unit & Department of Cardiovascular Sciences, Clinical Science Wing, Glenfield Hospital, University of Leicester, Groby Road, Leicester LE39QP, United Kingdom. E-mail: gm247@le.ac.uk

Received November 8, 2016; accepted February 7, 2017.

Targeting unwarranted variation is a key objective for health services as a means of improving the quality and equity of access to care.[17]

The aim of the current study was to evaluate the contribution of unwarranted variations in care to regional differences in outcome observed in TAD patients in England and identify areas of structure and process for quality improvement.

Methods

Study Design

We measured mortality (primary outcome) along with a range of other important measures of quality, such as equity of access, timeliness of surgery, and the effect of treatment on longer-term patient outcomes in national databases used to monitor quality of care by National Health Service (NHS) England; the National Adult Cardiac Surgery Audit (NACSA), used by the National Institute for Comparative Outcomes Research (NICOR) to monitor cardiac surgeon and unit specific hospital mortality, and the administrative NHS database Hospital Episode Statistics (HES), used by Dr Foster to measure hospital performance. We also asked cardiac surgical units in England to complete a questionnaire on the structure and organization of TAD services. Because there is no agreed service specification for TAD services in England and elsewhere,[7,10,16,18,19] and current recommendations for service organization are not evidence based,[20–24] we also conducted a parallel systematic review of existing studies that have considered quality standards for TAD service delivery. Data were extracted from the HES and the NICOR NACSA registry, according to The REporting of studies Conducted using Observational Routinely collected health Data (RECORD) statement (Table S1).[25] The need to obtain informed consent from patients was waived by the University of Leicester Research Governance Office because the identifiable information was either removed or pseudonymized. The study was approved by the NICOR NACSA Research Board (study reference 14-ACS-25). A systematic review and meta-analysis on the standard of care for the management of TAD was also performed and adhered to MOOSE and PRISMA guidelines (Tables S2 and S3).[26,27]

Data Sources and Study Populations

Data, outcomes, and study populations obtained from HES and NICOR NACSA registries are fully reported in Data S1. Briefly, HES is the national hospital administrative database for England and covers all admissions to public (NHS) hospitals in the country.[28] The data contain demographic, administrative, and clinical information, including procedures and operations (Table S4). The NICOR NACSA registry (version 4.1.2) contains prospectively data for all English adult patients undergoing major thoracic aortic surgery and undergoes robust validation and checking procedures to maintain data quality.[16,29–31]

To complement the NACSA study, we also contacted the Society for Cardiothoracic Surgery Unit Representatives for every cardiac surgery unit in England assessing their current service organization for TAD. Surgeons were queried on the presence of a dedicated aortic team, a specific on-call rota for thoracic aortic disease, a hybrid theater, and an aortic multidisciplinary team (MDT) recognized in the consultant job plan.

The study was approved by the NICOR NACSA Research Board (study reference 14-ACS-25). The need to obtain informed consent from patients was waived by the University of Leicester Research Governance Office because the identifiable information was either removed or pseudonymized.

Systematic Review and Meta-Analysis

Electronic search strategy, objectives, criteria for study selection, eligibility, data collection, and assessment of study quality were published online and registered in the PROSPERO International Prospective Register of Systematic Reviews (PROSPERO registry—CRD42015024137).[32]

Briefly, 3 reviewers systematically searched electronic databases (MEDLINE [PubMed and Ovid], Embase, SCOPUS, and Cochrane Library) without date or language restriction from inception to the end of December 2015. Our keywords and MeSH terms pertinent to the exposure of interest were used in relevant combinations and included: “aorta”, “aorta, thoracic”, “aorta, thoracoabdominal”, “aortic aneurysm”, “aortic dissection”, “standard of care”, “health care”, “treatment outcome”, “hospital mortality”, “hospital volume”, “surgeon volume”, “volume outcome relationship”, “teaching hospital”, and “urban hospital”. In addition, the reference lists of all retrieved articles were reviewed for further identification of potentially relevant studies that were not previously identified.

All adult major thoracic aortic procedures were considered. Exposures of interest included hospital volume activity, generally defined as yearly number of major aortic operations performed, subdivided in low- or high-volume, surgeon volume, presence of multidisciplinary thoracic aortic surgery program, and teaching/urban hospital status. The primary outcome of interest was all-cause mortality in hospital or within 30 days from index admission or procedure. Secondary outcomes included postoperative stroke, re-exploration for bleeding/tamponade, postoperative renal failure, and total length of hospital stay. Inclusion and exclusion criteria for qualitative/quantitative analyses were summarized according to PICOS approach (Table S5).

Year of publication, study design, country, sample size, recruitment period, inclusion and exclusion criteria, measured

outcomes, aortic center configuration, and definition of low- and high-volume threshold, baseline patient demographics (age, sex), and outcomes among low- and high-volume groups were extracted. Quality assessment was performed using the Newcastle-Ottawa Scale (NOS).[33]

Statistical Analysis

HES cohort

Outcomes were calculated as crude proportions and adjusted for a number of patient factors as listed in Tables S6 and S7. Comorbidity information was taken from the index admission or any admission for any reason in the previous year. All outcomes were binary, so logistic regression was used. These models were hierarchical with 2 levels, with random effects for each county. Predicted probabilities for each patient were derived from the fixed-effects part of the model.[34] Hierarchical models adjust for the clustering of patients within county and allow the estimation of the proportion of variation in the outcome that is attributable to each level of the model (ie, to patient factors and to county). To obtain adjusted outcome rates by county, observed and predicted probabilities were summed by county, with the former divided by the latter to obtain relative risks. These were then multiplied by the national crude outcome rate to obtain adjusted rates. Rates were put onto funnel plots with 95% and 99.8% control limits, the latter to determine how many counties were statistical outliers. To assess model fit, deviance residuals were plotted and the Hosmer-Lemeshow risk deciles and chi-squared value also inspected. Discrimination was assessed using the area under the receiver-operating characteristic curve (c statistic). This was done for logistic regression without adjustment for clustering, because there is no consensus over how to calculate the equivalent measures for hierarchical models.[35] As well as random effects for each geographical area, random slopes were tried in the model for receiving surgery for several binary patient factors: age over 75 versus younger, 1 or more versus none of 5 major comorbidities, dissection versus none, and aneurysm versus none. This was to see whether any of these factors had different effects on the outcome depending on the area. We did not find such effects and therefore report only results from using fixed slopes. Finally, obtained rates for TAD treatment by county as well as 6-month mortality for treated and untreated patients were mapped using ArcMap version 10.3 (ESRI, Redlands, CA).

NACSA cohort

Categorical and dichotomous variables were summarized as absolute number and percentage. Non-normally distributed continuous data were summarized as medians and interquartile ranges (IQRs). The effects of operational and institutional characteristics on in-hospital mortality were assessed using multiple logistic regression models. Relevant patient-level variables were offered to the models to adjust for any potential confounding factors. Results of the regression analyses were expressed as odds ratios (ORs) and 95% CIs. Box and whisker plots were used to present case mix distributions by center: These plots show the 25th percentile, median and 75th percentile of a given distribution at the bottom, middle and top of the boxes, respectively, then the mean is then plotted as a dot, and the lower and upper whiskers then represent the 5th and 95th percentiles, respectively. Scatter plots were generated to assess the relationship between observed in-hospital mortality and volume, and ordinary least squares (OLS) regression lines were included for visual inspection. Statistical analyses were performed with SAS software (version 9.3; SAS Institute Inc., Cary, NC). In all cases, $P<0.05$ was considered statistically significant.

Systematic review and meta-analysis

Treatment effect on operative outcomes is reported as ORs with a 95% CI. Yates correction was implemented if a cell contained a zero in the 2×2 contingency table.[36] Individual ORs (OR <1: high volume centers better) and variance were computed by using number of events and sample size and pooled by using Mantel–Haenszel method and random-effects model.[37] A fixed-effects model was also computed as sensitivity analysis. A subgroup analysis according to the primary aortic pathology (aneurysm vs aortic dissection) was performed, being a possible significant effect modifier. Finally, to account for inherent patient selection bias related with an observational study design, individual risk-adjusted ORs for the primary endpoint were obtained when reported, and pooled adjusted risk estimates were computed by using log transformation and a generic inverse-variance weighting method. I^2 statistic was used to estimate the percentage of total variation across studies attributed to heterogeneity rather than chance. Suggested thresholds for heterogeneity were used, with I^2 values of 25% to 49%, 50% to 74%, and ≥75%, indicative of low, moderate, and high heterogeneity.[38] Publication bias was evaluated using visual inspection of funnel plot asymmetry and by Egger's test.[39] $P<0.05$ was used as the level of significance and 95% CIs were reported where appropriate. Statistical analysis was conducted using meta package for R (version 4.3-2; R Foundation for Statistical Computing, Vienna, Austria).[40,41]

Results

HES Cohort

Of 26 551 patients with a TAD admission in England between 2004–2005 and 2010–2011, 25 282 had not had such an

admission in the previous 5 years and were defined as index admissions. Seven hundred thirty-four (2.8%) were excluded because of lack of area identifiers, leaving a final population of 24 548 adult patients coded as having a new diagnosis of TAD. Of these, 16 448 (67%) were affected by aneurysms, 6345 (25.9%) by dissections, and 1665 (6.8%) by unspecified TAD. A total of 5445 (22%) underwent treatment (surgical and/or endovascular) within 6 months of diagnosis. The 6-month mortality in treated patients was 17.7% and in untreated patients was 30%. Patient characteristics are summarized in Table 1.

Variation attributable to patient-related factors

Predictive variables for receiving treatment, or an emergent procedure, are reported in Table S6. Briefly, increasing age, pre-existing diabetes mellitus, comorbidities, and a diagnosis of cancer were associated with a conservative approach. The greater the deprivation status, the lower were the odds of being treated. Patients affected by aortic dissection and comorbid conditions, including ischemic heart disease and congenital and other vascular disorders, were more prone to be treated on an emergent basis. Predictors of 6-month mortality in treated and untreated patients are summarized in Table S7. In patients receiving treatment, mortality was associated with increasing age, comorbidity presence, and nonelective admission. Emergent/urgent admission, increasing age, severe comorbidity, and the presence of aortic dissection were associated with mortality in untreated patients.

Table 1. National Crude Outcome Rates Split by Age, Major Comorbidity, and TAD Subtype (HES Cohort)

Patient Factor*	Receiving Operation (%)	Nonemergent Operation (%)	Postoperative Mortality (%)	Mortality in Patients With No Operation (%)
Age <75, y	31.6	54.4	14.0	18.4
Age 75+, y	11.6	52.6	24.3	40.7
TAD: dissection	19.4	10.9	21.5	39.9
TAD: aneurysm	15.8	69.3	12.5	26.4
No major comorbidity	27.6	50.1	12.2	27.6
1+ major comorbidities	18.8	58.2	21.0	31.7
All patients combined	22.2	53.7	16.7	30.5

HES indicates Hospital Episodes Statistics; TAD, thoracic aortic disease.
*Patients with neither dissection nor aneurysm recorded have been omitted from the rows for TAD subtype. Major comorbidities covered ischemic heart disease, cerebrovascular disease, chronic obstructive pulmonary disease, renal disease, and cancer. Mortality is defined as death in or out of hospital within 6 months of diagnosis or operation.

Variation attributable to non-patient-related factors

Significant variance by county of residence was observed in terms of the percentages of patients receiving treatment within 6 months of their index admission, ranging from 7.6% in Leicestershire to 31.5% in the West Midlands (Figure 1). The percentage of subjects treated emergently ranged from 29.6% in Merseyside to 67.9% in Durham (Figure 2). Multilevel modeling confirmed the statistically significant differences in treatment rates by county of residence. A null model containing only random effects for the counties estimated the variance between counties in log odds of treatment as 0.096 (SE, 0.024); adding patient factors to this null model actually increased the estimated between-county variance (to 0.105; SE, 0.026). To adjust for regional differences in detection rates, the TAD admission rates per 100 000 resident populations for each county were entered into the model. This reduced the between-county variance in treatment rates by 40% to 0.060 (SE, 0.016). Despite this, the overall number of counties flagged as high or low outliers on funnel plots using 99.8% control limits were very similar to those observed using crude TAD admission rates.

Regional differences by county were also observed for 6-month mortality (Figure 1 and Figure S1). For treated patients, risk-adjusted mortality rates ranged from 6.5% in Oxfordshire to 23.3% in North Yorkshire. Risk-adjusted mortality rates in untreated patients ranged from 19.4% in Leicestershire to 36.3% in East Sussex. Adding patient factors to the null model reduced the variation in mortality in treated patients attributable to county of origin by 27%, therefore becoming nonsignificant (variance estimate, 0.037; SE, 0.023). A 62% fall in the variation in mortality was observed in untreated patients, although the between-county variance remained statistically significantly greater than zero, but modest in size (0.027; SE, 0.009).

Using Pearson correlation with counties weighted by their total number of index admissions, we compared the sets of county-level adjusted outcome rates. The proportion of patients receiving treatment showed positive, but nonsignificant, correlations with the proportion of treatments done nonemergently (ρ=+0.20; P=0.209) and the postoperative mortality rate (ρ=+0.25; P=0.114). Conversely, the proportion of treated patients demonstrated a positive and statistically significant correlation with the mortality rate in untreated patients (ρ=+0.47; P=0.002). This latter relation was driven by patients without dissection: for these patients alone, the correlation was +0.68 (P<0.001), whereas for those with dissection it was −0.28 (P=0.079). In order to verify whether the positive correlation between treatment rates and 6-month

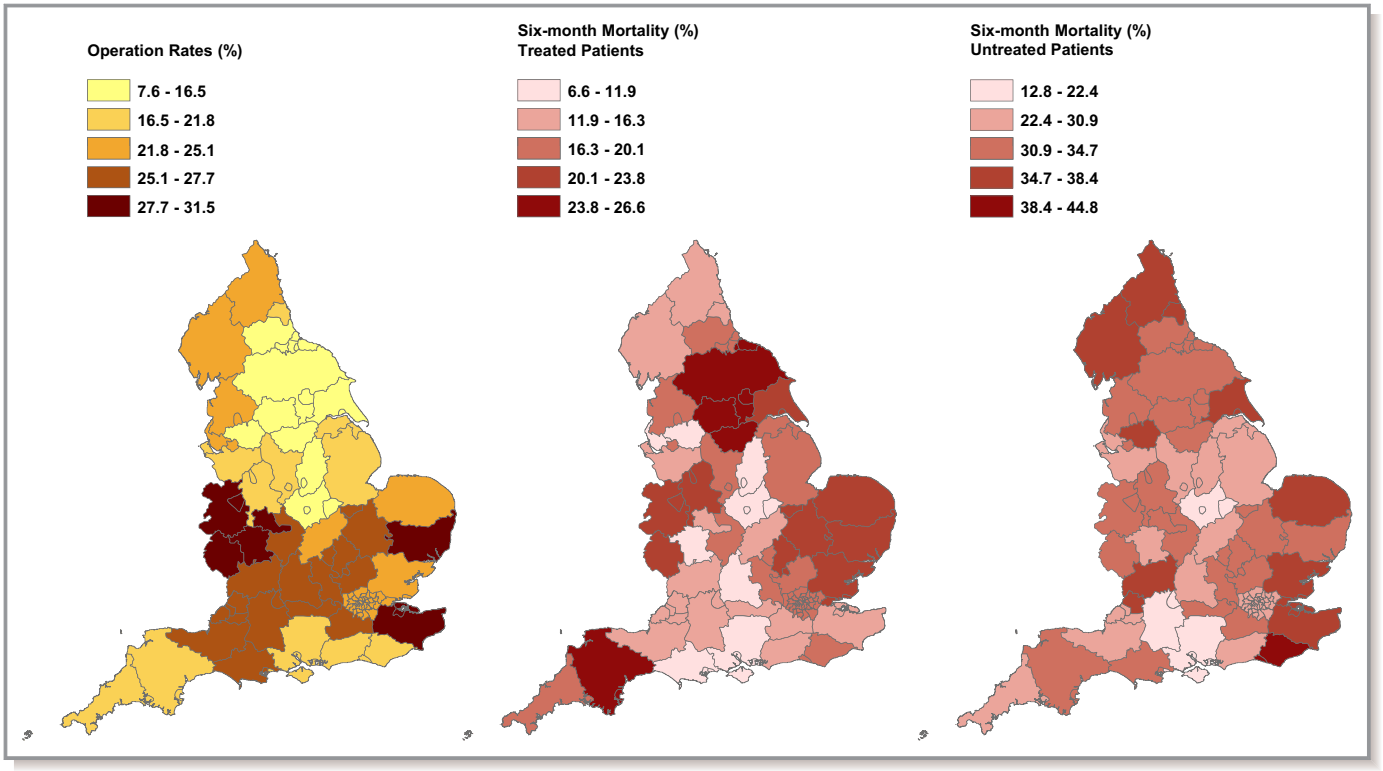


Figure 1. Geographical variation by county across England with reference to treatment rates in patients diagnosed with thoracic aortic disease (left panel), 6-month mortality in treated (mid panel) and untreated (right panel) patients. From HES (Hospital Episodes Statistics) cohort data.

mortality in both treated and untreated patients may reflect an underlying difference in access to care, patients' risk profiles were analyzed. No correlation between the proportion of high-risk patients treated by county, defined as those in the highest tertile for predicted probability, and mortality rate in the untreated was observed (ρ=+0.17; P=0.294).

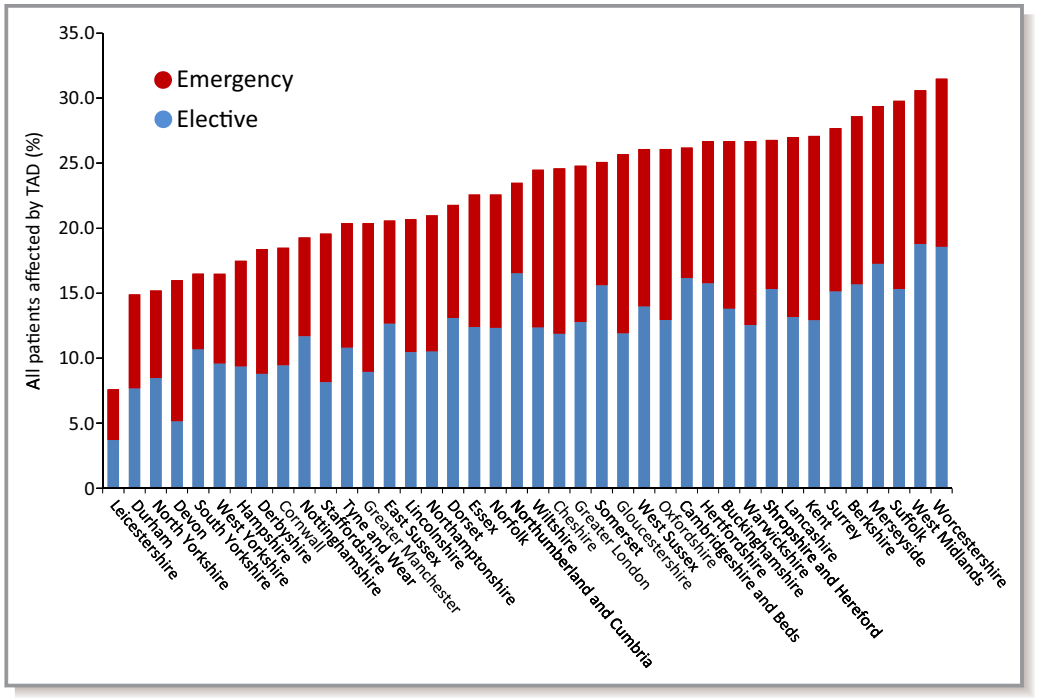


Figure 2. Percentage of patients affected by thoracic aortic disease (TAD) by county and urgency of the operation received (elective vs emergent). From HES (Hospital Episodes Statistics) cohort data.

Table 2. Baseline, Operative, and Mortality Details by Center Volume (Tertiles of Latest 3-Year Activity) (NACSA Cohort)

Patient Factor*	Low-Volume Center (n=1308)	Medium-Volume Center (n=2159)	High-Volume Center (n=4591)
Demographics			
Age at operation, y	64 (52, 72)	64 (52, 73)	64 (51, 73)
BMI, kg/m^2	27.2 (24.4, 30.2)	27.0 (24.1, 30.4)	26.7 (23.9, 29.9)
Female sex	450 (34.4)	715 (33.1)	1526 (33.2)
Comorbidities			
Unstable angina	77 (5.9)	114 (5.3)	181 (3.9)
NYHA ≥III	411 (31.4)	721 (33.4)	1184 (25.8)
MI within 90 days of operation	58 (4.4)	72 (3.3)	138 (3.0)
Previous cardiac surgery	150 (11.5)	307 (14.2)	795 (17.3)
Previous aortic surgery	27 (2.1)	71 (3.3)	237 (5.2)
Diabetes mellitus	102 (7.8)	175 (8.1)	276 (6.0)
Current smoker	166 (12.7)	236 (12.2)	478 (10.4)
Hypertension	838 (64.1)	1419 (65.7)	2779 (60.5)
Creatinine >200 μmol/L	39 (3.0)	62 (2.9)	123 (2.7)
History of renal dysfunction	16 (1.2)	37 (1.7)	81 (1.8)
History of pulmonary disease	153 (11.7)	267 (12.4)	554 (12.1)
History of stroke	119 (9.1)	192 (8.9)	350 (7.6)
Neurological dysfunction	55 (4.2)	91 (4.2)	160 (3.5)
Peripheral vascular disease	213 (16.3)	452 (20.9)	647 (14.1)
Preoperative nonsinus heart rhythm	182 (13.9)	278 (12.9)	478 (10.4)
Triple vessel disease	68 (5.2)	134 (6.2)	169 (3.7)
Left main stem disease	30 (2.3)	45 (2.1)	77 (1.7)
Moderate ejection fraction (30–50%)	308 (23.6)	419 (19.4)	857 (18.7)
Poor ejection fraction (<30%)	57 (4.4)	92 (4.3)	179 (3.9)
PA systolic >60 mm Hg	26 (2.0)	26 (1.2)	42 (0.9)
Preoperative IV nitrates	62 (4.7)	118 (5.5)	231 (5.0)
Preoperative IV inotropes	35 (2.7)	58 (2.7)	133 (2.9)
Preoperative ventilation	22 (1.7)	42 (2.0)	102 (2.2)
Preoperative cardiogenic shock	88 (6.7)	100 (4.6)	154 (3.4)
Nonelective priority	497 (38.0)	801 (37.1)	1643 (35.8)
Urgent priority	202 (15.4)	396 (18.3)	697 (15.2)
Emergency priority	267 (20.4)	355 (16.4)	888 (19.3)
Salvage priority	28 (2.1)	50 (2.3)	58 (1.3)
Dominant pathology			
Aneurysm	697 (53.3)	1248 (57.8)	2477 (54.0)
Dissection	326 (24.9)	481 (22.3)	1012 (22.0)
Trauma	7 (0.5)	7 (0.3)	36 (0.8)
"Other"	166 (12.7)	366 (17.0)	702 (15.3)
Data N/A	112 (8.6)	57 (2.6)	364 (7.9)

Continued

Table 2. Continued

Patient Factor*	Low-Volume Center (n=1308)	Medium-Volume Center (n=2159)	High-Volume Center (n=4591)
Aortic segment			
Root/ascending aorta	1211 (92.6)	1798 (83.3)	3839 (83.6)
Aortic arch	75 (5.7)	275 (12.7)	412 (9.0)
Descending aorta	17 (1.3)	58 (2.7)	245 (5.3)
Thoracoabdominal aorta	5 (0.4)	28 (1.3)	95 (2.1)
Surgical data			
Concomitant valve operation	948 (72.5)	1339 (62.0)	3032 (66.0)
Concomitant CABG operation	237 (18.1)	399 (18.5)	846 (18.4)
Concomitant "other" cardiac operation	510 (39.0)	728 (33.7)	1408 (30.7)
CPB time, min	178 (129, 240)	152 (114, 208)	162 (116, 229)
ACC time, min	114 (82, 154)	104 (74, 136)	105 (75, 143)
Circulatory arrest time, min	26 (18, 37)	25 (17, 34)	27 (18, 39)
Outcome			
In-hospital mortality	138 (10.6)	206 (9.5)	404 (8.8)

ACC indicates aortic cross-clamp; BMI, body mass index; CABG, coronary artery bypass grafting; CPB, cardiopulmonary bypass; IV, intravenous; NACSA, National Adult Cardiac Surgery audit; N/A, not available; NYHA, New York Heart Association; PA, pulmonary artery.
*Numerical data are expressed as median and interquartile range (IQR); categorical data as absolute number (percentage).

NACSA Cohort

We considered that confounders not contained within HES data might also contribute to unwarranted variance. We therefore evaluated regional variance in treatment of TAD using the NACSA registry, which contains validated data on the severity and complexity as well as the treatment of TAD by regional cardiac centers.

Study cohort

Of the 219 741 patients that underwent surgery in cardiac surgery centers in England, complete case data were available on 8058 major aortic surgery cases from 29 hospitals that comprised the analysis data set. Patient characteristics and operative details are summarized in Table 2 and Table S8. All centers provided data on patients operated on root/ascending aorta and aortic arch segments, 28 (96.6%) centers on the descending thoracic aorta, and 17 (58.6%) on the thoracoabdominal aorta (Figure 3).

Variation attributable to patient-related factors

There were differences between centers with respect to predicted operative risk (Figure 3C); the median calculated logistic EuroSCORE of in-hospital mortality ranged from 4.6% to 9.1%. Pathology, emergent treatment, and the most distal aortic surgery segment treated (case complexity) were important determinants of hospital mortality (Table 3).

Variation attributable to non-patient-related factors

There were differences between centers with respect to the complexity and volume of cases performed. The largest volume of cases by a single center was 662 and the smallest 117 (Figure 3A). The percentage of root/ascending aortic operations as a share of total aortic operations ranged from 45.1% to 96.0%, for aortic arch procedures the range was from 1.7% to 32.1%, for descending thoracic aortic procedures from 0.7% to 18.7%, and for thoracoabdominal aortic procedures from 0.2% to 9.9% (Table S9 and Figure S2). More-complex surgery was more common in high-volume centers. The results of the survey of service organization are shown alongside details of case volume, complexity, and outcome by unit in Figure 3D. All the units responded to the questionnaire. This demonstrated regional variation in care delivery in terms of the presence of dedicated aortic teams, multidisciplinary aortic team meetings, specific on-call rotas for aortic emergencies, or use of hybrid operating theaters.

Table 3 and Table S10 show unadjusted and fully risk-adjusted in-hospital mortality effects by operation category, tertile of volume activity, dominant pathology, and priority. Case complexity was a principal determinant of in-hospital mortality. Relative to proximal segments (root/ascending) the adjusted ORs for aortic arch procedures as well as descending thoracic and thoracoabdominal aortic procedures were 1.88 (95% CI, 1.48–2.37), 2.47 (95% CI, 1.77–3.44), and 3.05 (95% CI, 1.82–5.11), respectively. For the increasing volume

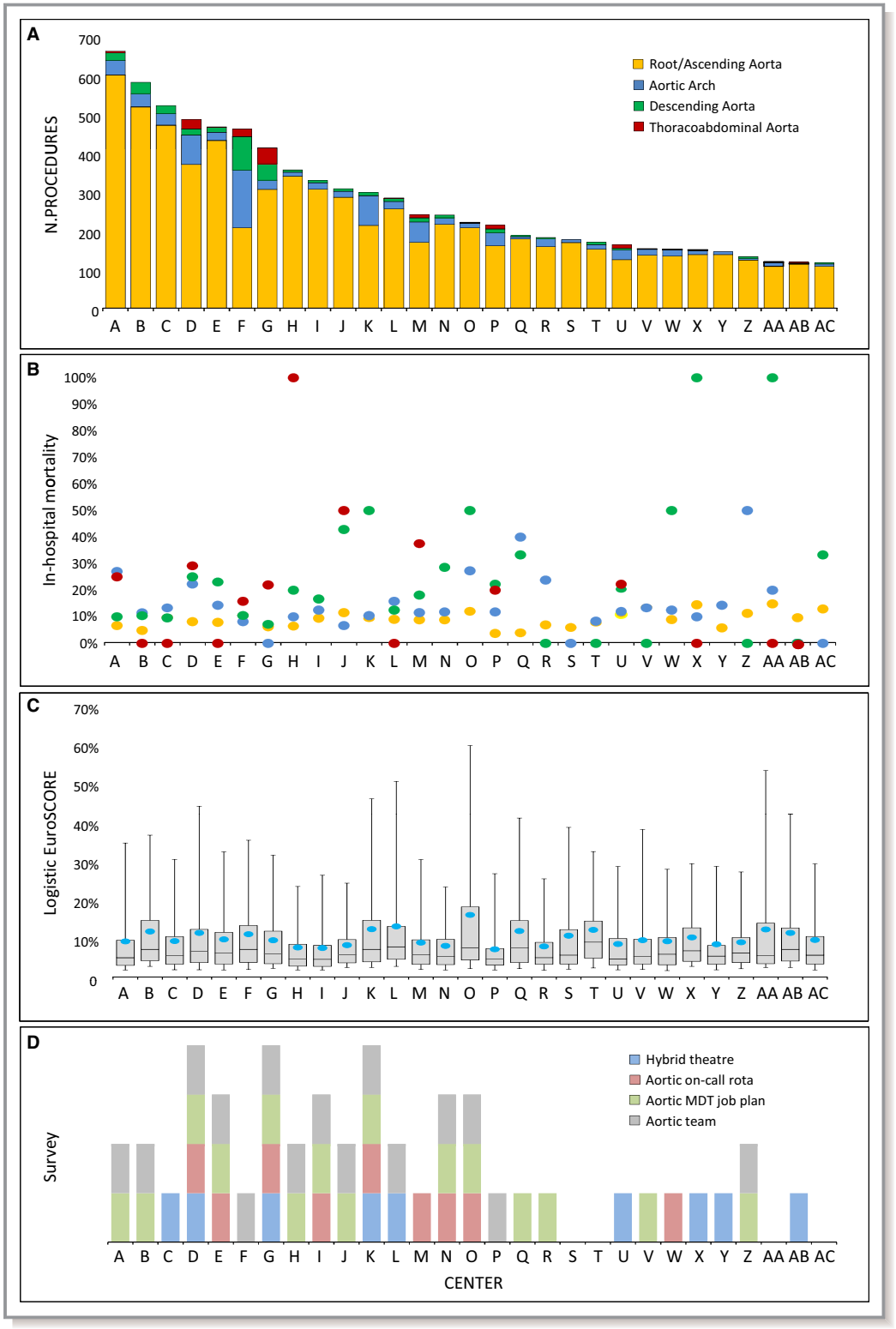


Figure 3. Activity (total number of procedures) (A) and in-hospital mortality rate (B) by center, by most distal aortic segment; patient risk profile by center expressed by EuroSCORE II (C). From NACSA (National Adult Cardiac Surgery Audit) cohort data. Results of the national survey assessing current service organization for thoracic aortic disease in cardiac surgery centers across England; surgeons were queried on the presence of a dedicated aortic team, a specific on-call rota for thoracic aortic disease, a hybrid theater, and an aortic multidisciplinary team (MDT) recognized in the consultant job plan (D): The presence of a vertical bar for a given center means that that center had the particular feature given in the chart key.

Table 3. Unadjusted and Risk-Adjusted In-Hospital Mortality Effects (NACSA Cohort)

	Frequency	Observed Mortality (%)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)
Aortic segment*				
Root/ascending aorta	6848	8.3	Reference	Reference
Aortic arch	762	13.3	1.75 (1.42, 2.16)	1.86 (1.47, 2.35)
Descending aorta	320	15.3	1.86 (1.38, 2.51)	2.30 (1.66, 3.18)
Thoracoabdominal aorta	128	22.7	1.91 (1.18, 3.09)	2.75 (1.67, 4.56)
Activity tertile†				
Low-volume (latest 3 years' activity)	1308	10.6	Reference	Reference
Medium-volume (latest 3 years' activity)	2159	9.5	0.89 (0.71, 1.12)	0.80 (0.62, 1.02)
High-volume (latest 3 years' activity)	4591	8.8	0.82 (0.67, 1.00)	0.76 (0.60, 0.95)
Dominant pathology‡				
Aneurysm	4422	4.9	Reference	Reference
Dissection	1819	17.2	4.07 (3.39, 4.89)	2.27 (1.82, 2.82)
Other	1284	13.2	2.97 (2.40, 3.67)	2.05 (1.61, 2.61)
Data N/A	533	9.6	2.07 (1.50, 2.85)	1.78 (1.26, 2.52)
Priority†				
Elective	5117	4.8	Reference	Reference
Nonelective	2941	17.1	4.08 (3.47, 4.78)	2.54 (2.09, 3.08)

*Adjusted for preoperative comorbidities, operative risk factors, and activity tertile.
†Adjusted for preoperative comorbidities, operative risk factors, and most distal aortic segment.
‡Adjusted for preoperative comorbidities, operative risk factors, most distal aortic segment, and activity tertile.

activity tertiles, the corresponding adjusted risk of in-hospital mortality relative to low-volume centers was 0.84 (95% CI, 0.66–1.07) for medium-volume centers and 0.72 (95% CI, 0.57–0.89) for high-volume centers (Table 4). Similar results were observed when cases where stratified by most distal segment, as well for the OLS regression analyses that demonstrated lower mortality in centers with high-volume activity (Figure S3).

Systematic Review and Meta-Analysis

Of the 12 804 records identified, 33 eligible observational cohort studies were included in the systematic review, comprising a total of 103 543 patients (Figure S4).[6–14,42–67] The identified studies (20 multicenter and 13 single-center) were published between 1994 and 2015. Study characteristics and collected study outcomes are summarized in Tables S11 through S13. Quality assessment indicated that 20 of 33 studies were at significant risk of bias (NOS, <8; Table S14). Twelve observational cohort studies analyzing impact of hospital volume on in-hospital mortality were identified for the primary analysis, including a total of 14 562 and 16 036 patients who underwent surgery in high- and low-volume centers, respectively. Pooled unadjusted ORs showed that high-volume centers were associated with a 50% relative risk reduction in mortality when compared with low-volume centers (Figure 4, upper panel),* with a moderate heterogeneity among studies (I^2=53.4%). No publication bias was found (P=0.19; Figure S5). Overall, 9 studies reported on adjusted effect size of hospital volume on mortality (Table S15). Pooled adjusted estimates of individual log ORs confirmed that high-volume centers were independently associated with a significantly reduced incidence of in-hospital/30-day mortality (adjusted OR, 0.56; 95% CI, 0.45–0.70; I^2=70.2%; Figure 4 lower panel).[7,8,10,13,50,58–60,62] Subgroup analysis showed similar effects for high-volume centers with respect to both aneurysms and aortic dissection (Figure S6). Pooled estimates did not reveal any significant differences between high- and low-volume centers with reference to postoperative stroke (OR, 1.29; 95% CI, 0.85–1.95; I^2=58.8%), re-exploration for bleeding/tamponade (OR, 0.91; 95% CI, 0.72–1.15; I^2=68.5%), and postoperative renal failure (OR, 0.82; 95% CI, 0.65–1.04; I^2=77.6%; Figure S7). Centers that introduced a specific multidisciplinary TAD program also reported a significant reduction in mortality

*References: 7–10, 13, 50, 58–60, 62, 65, 66.

Table 4. Mortality Rates by Volume Center Activity (NACSA Cohort)

	Frequency	Observed Mortality (%)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)
Activity tertile*				
Low-volume (latest 3 years' activity)	1308	10.6	Reference	Reference
Medium-volume (latest 3 years' activity)	2159	9.5	0.89 (0.71, 1.12)	0.80 (0.62, 1.02)
High-volume (latest 3 years' activity)	4591	8.8	0.82 (0.67, 1.00)	0.76 (0.60, 0.95)
Activity tertile*				
Low-volume (6 years' activity)	1424	11.1	Reference	Reference
Medium-volume (6 years' activity)	2353	9.5	0.84 (0.68, 1.05)	0.83 (0.66, 1.05)
High-volume (6 years' activity)	4281	8.6	0.75 (0.62, 0.91)	0.71 (0.57, 0.88)

NACSA indicates National Adult Cardiac Surgery audit; OR, odds ratio.
*Adjusted for preoperative comorbidities, operative risk factors, and most distal aortic segment.

(OR, 0.35; 95% CI, 0.13–0.96) although with significant heterogeneity (I^2=75.7%; Figure S8). Surgeon volume (high- vs low-volume surgeon) and hospital status (teaching vs non-teaching hospitals and urban vs rural hospitals) had no effect on hospital outcomes (Figures S9 and S10).

Discussion

The current study has demonstrated significant regional variation in access to treatment, the organization of clinical services, and mortality for patients with TAD in England. An analysis of HES data demonstrated that the variation in the proportion of TAD patients treated within 6 months of diagnosis ranged from 7.6% to 31.5% among counties and remained statistically significant after adjustment for potential confounders, including comorbidity, deprivation, disease severity, and population density. Regional variation was not associated with differences in mortality rates for patients that received treatment, but was associated with differences in mortality in those that did not receive treatment, implying that inequity in access to care has important effects on outcome. The analysis of NASCA data indicated wide regional variation in the volume and complexity of TAD cases undertaken in English cardiac centers. Centers undertaking higher volumes were more likely to treat more-complex disease and had lower risk-adjusted mortality. A systematic review that attempted to benchmark service specifications for TAD indicated that patients treated by multidisciplinary teams in high-volume centers have better clinical outcomes. A survey of structure and processes indicated that this standard of care is not consistently available to patients in England. In addition, our systematic literature search confirmed a world-wide knowledge gap with respect to the safest, most effective referral model/organization of services for the management of TAD. Neither was identified the minimum service specification for centers that undertake interventions on the thoracic aorta.

To our knowledge, this is the first nation-wide analysis of the quantity and quality of care for patients with TAD. The study used prospectively collected data from 2 large independent national databases used by the NHS to monitor quality. These contain data on every patient presenting to hospital with TAD or undergoing surgery for TAD in English hospitals. The limitations are those of all registry analyses, notably the risks of confounding and other sources of bias, including variable data quality. We attempted to minimize confounding by adjusting for a large number of baseline patient-related factors, including demographics, social deprivation, comorbidity, and presentation. Detection bias was mitigated by using objective measures of outcome and exposures of interest. The NACSA database uses consistent, well-defined definitions of exposures and outcomes and undergoes regular internal and external quality assurance processes. Being an administrative database, HES is more likely to have variations in data quality by hospital; under-recording of comorbidities, for instance, is a well-known limitation. For the TAD diagnosis date, we used the date of first recording of TAD in 1 of the diagnosis fields or the date of the TAD procedure if the patient had no earlier TAD admission, implying some uncertainty in the actual diagnosis date. However, certain fields, such as for the primary diagnosis and procedure, have been shown to be reliable by a recent systematic review.[68] A further limitation is that it was not possible to link the HES and NACSA analyses to further explore potential reasons for variability in care. This is because the geographical regions served by individual cardiac centers often overlap. The 2 cohorts also considered different time periods; this was attributed to the availability of complete, cleaned HES data to March 2011, and the availability of data that used consistent definitions for aortic

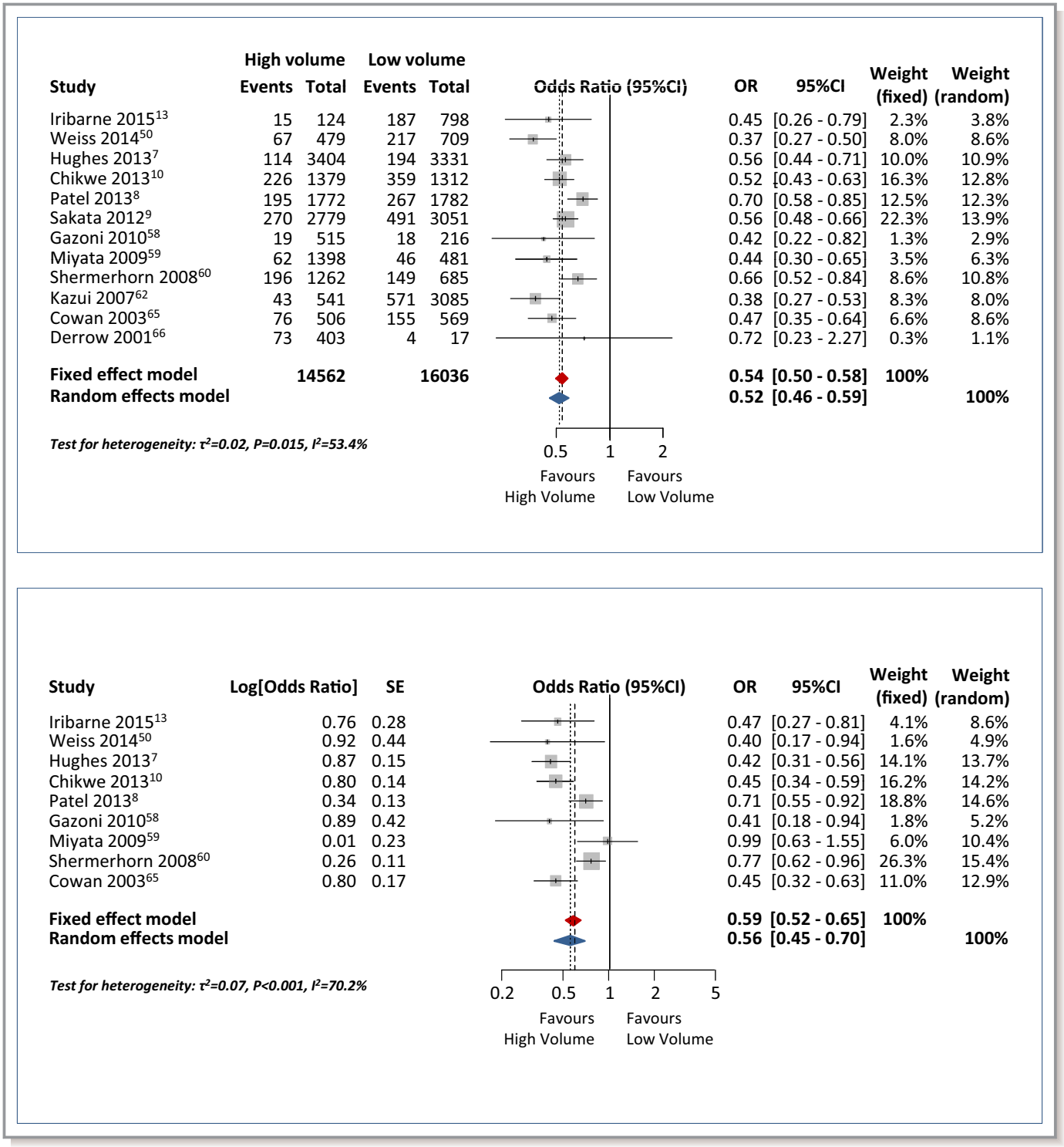


Figure 4. Forest plot with unadjusted (top) and adjusted (bottom) risk estimates for in-hospital/30-day mortality in high- versus low-volume hospitals. OR indicates odds ratio.

disease in the NACSA database between 2007 and 2013. Our analyses did not specifically consider the role of thoracic endovascular aortic repair (TEVAR). It has been suggested that this has important effects on the mortality of aortic disease, and almost all studies have shown excellent operative mortality rates post-TEVAR compared to open repair, with even higher survival rates after emergent aortic procedures.[57,69] The total numbers of TEVARs listed in the HES database to 2011 were small (n=532), however, preventing useful and detailed analysis.

In addition, our analysis did not account for the potential impact of surgical techniques adopted across English units in the outcomes of TAD patients undergoing surgery. Rates and modality of circulatory arrest used during complex TAD operation, arterial cannulation, and cerebral protection strategies per center were not collected in HES and NACSA databases. This precluded further analyses and the possibility to evaluate these surgical strategies as an additional measure of the quality of care in TAD patients, although arterial cannulation strategies and cerebral protection strategies have been proved to influence operative outcomes in aortic surgery.[70,71]

The systematic review was limited in that it relied on the reported information on confounding variables that were controlled for; consistent analyses of all studies can be done only when data on individual patients are combined. Many of the included studies were at risk of bias, and there was substantial heterogeneity in many of the effect estimates. We speculate that this reflected differences in the definitions of exposures of interest, including the definition of a high case volume or what constituted an aortic multidisciplinary team. For example, the definition of high versus low volume was defined, in some studies, as annualized activity versus study period activity, with the numbers of cases expressed varyingly as tertiles or medians.**

These limitations notwithstanding, this study has demonstrated variability in the quality of care for patients with TAD that appears to be unwarranted. This is a common finding in studies of variation in access to care for patients with cardiovascular disease in England and elsewhere.[17,72] Some of the contributory factors to variation identified in this report, such as social deprivation, require complex and difficult solutions; however, variations in structure and processes of care are more readily addressed. For example, service specifications for the provision of vascular surgery in England have led to substantive reorganization of care pathways, the concentration of multidisciplinary expertise in teams, and significant improvements in key markers of quality, such as mortality following elective aneurysm repair.[73,74] In the current study, higher-volume units and those undertaking significant numbers of more-complex procedures were more likely to have structures in place that were identified in the systematic review as being associated with better outcomes, specifically hybrid operating theatres, and adequately resourced MDT aortic teams. On the basis of these results, we suggest that these structures should be included in any future service specification for thoracic aortic disease. The definition of an adequate unit volume is more difficult; the NASCA data identified units in the lowest tertile of total cases (<32 cases per year) as having a higher mortality, often with a denominator that included a less-complex caseload. However, the current study did not specifically address whether this reflects outcomes following the treatment of emergent patients. This is important: Patients with acute type A dissection who do not receive treatment die at a rate of 1% to 2% per hour during the first day and almost half die by 1 week.[75] A reduction in the numbers of units providing emergency services should be balanced by the increase in risk posed by delays in treatment. However, both HES and NACSA databases do not account for information regarding the referral time, interhospital coordination, and transport of patient affected by TAD, especially in the emergent setting, and we were unable to investigate this important aspect of quality of care.[56]

The results of the NASCA analysis also indicated uncertainty as to whether the volume outcome relationship applied to all segments of the aorta, although this may be attributable to a smaller sample size for more-distal segments resulting in less precision in the estimates. The systematic review did not indicate that surgeon volume was associated with outcome. This may also reflect the limits of precision when evaluating small numbers of surgeons, the majority of whom undertake low numbers of cases. Alternatively, as suggested by the systematic review, it may be the structures and process beyond that surgeon that are critical determinants of outcome.

The present analyses also identified potential sources of unwarranted variation that will not be addressed solely by reconfiguration of specialist teams, for example, with respect to differences in treatment rates for aneurysms versus nonaneurysms, or for emergent versus nonemergent surgery. We speculate that additional barriers to treatment exist before hospital treatment. This variation can be addressed by guidelines for screening, for example, in first-degree relatives of patients with acute aortic syndromes or bicuspid aortic valves, the use of appropriate imaging, and referral to the TAD service. However, a barrier to the development of these processes is the absence of evidence from randomized trials as to how TAD should be diagnosed and treated. Recent guidelines were based exclusively on evidence from observational analyses and expert opinion.[20–22]

A final comment is that the variation in TAD services that were observed in this study were not apparent when comparing mortality rates in treated patients by center, the current methods used by Dr Foster (HES), and the National Institute for Comparative Outcomes Research (NASCA) for measuring quality in English cardiac uits.[28–30] It is also noteworthy that there was no evidence from the HES analysis that cardiac surgery units preferentially select patients that will have an acceptable outcome following surgery; treatment rates were not determined by patient mortality risk. This

**References: 6–10,13,34–36,50–55,58–63,65.

refutes a common criticism that the publication of mortality rates in treated patients, as has occurred in England since 2004, contributes to unwarranted variation.[76]

In conclusion, evidence of unwarranted variation in the quality of care supports a reorganization of TAD services in England, with greater emphasis on care delivered by multidisciplinary teams in specialist centers. Similar service specifications and recommendations for standards of care and service delivery for TAD patients have also been commonly observed in other countries, mainly in North America and Europe. However, the safest, most effective referral model/organization of services for the management of TAD has not been identified. Further research must focus on the identification of barriers to early diagnosis and referral for treatment, and comparative trials of treatment options for patients with TAD.

Appendix

Collaborators

UK Aortic Forum (Chairman: Mr Geoff Tsang): Mr Alan J. Bryan, Bristol Heart Institute, University Hospital Bristol NHS Trust; Mr Graham Cooper, Sheffield Teaching Hospitals; Mr Andrew Duncan, Biomedical Research Unit, The Royal Brompton Hospital; Miss Deborah Harrington and Mr Manoj Kuduvalli, Liverpool Heart and Chest Hospital; Mr Jorge Mascaro, Queen Elizabeth Hospital, University Hospitals Birmingham; Mr Ulrich Rosendahl, Aortic Centre, Royal Brompton and Harefield NHS Trust; Mr Geoff Tsang, University Hospital Southampton NHS Foundation Trust; Mr Jonathan Unsworth-White, Southwest Cardiothoracic Centre, Derriford Hospital, Plymouth.

Author Contributions

Bottle, Mariscalco, Murphy, and Shaw had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Bashir, Benedetto, Bottle, Mariscalco, Murphy, and Oo. Acquisition of data: Aylin, Bottle, Mariani, Mariscalco, Saratzis, and Shaw. Analysis and interpretation of data: Benedetto, Bottle, Mariscalco, Murphy, and Oo. Drafting of the manuscript: Bottle, Mariscalco and Murphy. Critical revision of the manuscript for important intellectual content: Aylin, Bashir, Bottle, Jenkins, Mariani, Mariscalco, Murphy, and Oo. Paper supervision: Aylin, Mariscalco, Murphy, and Oo. Statistical analysis: Benedetto, Bottle, and Shaw.

Sources of Funding

This study was supported by Leicester NIHR Cardiovascular Biomedical Research Units and British Heart Foundation. The Dr Foster Unit at Imperial College London (Bottle and Aylin) is partially funded by a grant from Dr Foster, a private health care information company. The Unit is also partly funded by research grants from the National Institute for Health Research (NIHR) Health Services Research and is affiliated with the NIHR Imperial Patient Safety Translational Research Centre. The NIHR Imperial Patient Safety Translational Centre is a partnership between the Imperial College Healthcare NHS Trust and Imperial College London. The Unit is grateful for support from the NIHR Biomedical Research Centre funding scheme.

Disclosures

Mariscalco, Oo and Murphy declare that they have received support from Vascutek, an aortic prosthesis manufacturer, to attend scientific meetings. Oo has received fees for acting as a proctor for Vascutek. Benedetto has received support to attend scientific meetings from Maquet, who also manufacture aortic prostheses. These authors declare that they have no other conflicts of interest. Members of the UK Aortic forum have also declared competing interests: Debora Harrington, Manoj Kuduvalli, Jorge Mascaro, Geoff Tsang, Graham Cooper, and Jonathan Unsworth-White declare that they have received support from Vascutek for attending scientific meetings. These members of the UK Aortic Forum declare that they have no other conflicts of interest. The remaining authors and members of the UK Aortic Forum declare that they have no financial relationships with any organizations that might have an interest in the submitted work in the previous 3 years, no other relationships or activities that could appear to have influenced the submitted work, and no other relevant relationships with industry or other disclosures.

References

1. Sampson UK, Norman PE, Fowkes FG, Aboyans V, Yanna Song, Harrell FE Jr, Forouzanfar MH, Naghavi M, Denenberg JO, McDermott MM, Criqui MH, Mensah GA, Ezzati M, Murray C. Global and regional burden of aortic dissection and aneurysms: mortality trends in 21 world regions, 1990 to 2010. *Glob Heart*. 2014;9:171–180.
2. Olsson C, Thelin S, Ståhle E, Ekbom A, Granath F. Thoracic aortic aneurysm and dissection: increasing prevalence and improved outcomes reported in a nationwide population-based study of more than 14,000 cases from 1987 to 2002. *Circulation*. 2006;114:2611–2618.
3. von Allmen RS, Anjum A, Powell JT. Incidence of descending aortic pathology and evaluation of the impact of thoracic endovascular aortic repair: a population-based study in England and Wales from 1999 to 2010. *Eur J Vasc Endovasc Surg*. 2013;45:154–159.
4. Raghupathy A, Nienaber CA, Harris KM, Myrmel T, Fattori R, Sechtem U, Oh J, Trimarchi S, Cooper JV, Booher A, Eagle K, Isselbacher E, Bossone E; International Registry of Acute Aortic Dissection (IRAD) Investigators. Geographic differences in clinical presentation, treatment, and outcomes in type A acute aortic dissection (from the International Registry of Acute Aortic Dissection). *Am J Cardiol*. 2008;102:1562–1566.
5. Liao JM, Bakaeen FG, Cornwell LD, Simpson K, Lemaire SA, Coselli JS, Chu D. Nationwide trends and regional/hospital variations in open versus endovascular repair of thoracoabdominal aortic aneurysms. *J Thorac Cardiovasc Surg*. 2012;144:612–616.
6. Goodney PP, Brooke BS, Wallaert J, Travis L, Lucas FL, Goodman DC, Cronenwett JL, Stone DH. Thoracic endovascular aneurysm repair, race, and volume in thoracic aneurysm repair. *J Vasc Surg*. 2013;57:56–63.

7. Hughes GC, Zhao Y, Rankin JS, Scarborough JE, O'Brien S, Bavaria JE, Wolfe WG, Gaca JG, Gammie JS, Shahian DM, Smith PK. Effects of institutional volumes on operative outcomes for aortic root replacement in North America. *J Thorac Cardiovasc Surg*. 2013;145:166–170.
8. Patel VI, Mukhopadhyay S, Ergul E, Aranson N, Conrad MF, Lamuraglia GM, Kwolek CJ, Cambria RP. Impact of hospital volume and type on outcomes of open and endovascular repair of descending thoracic aneurysms in the United States Medicare population. *J Vasc Surg*. 2013;58:346–354.
9. Sakata R, Kuwano H, Yokomise H. Hospital volume and outcomes of cardiothoracic surgery in Japan: 2005–2009 national survey. *Gen Thorac Cardiovasc Surg*. 2012;60:625–638.
10. Chikwe J, Cavallaro P, Itagaki S, Seigerman M, Diluozzo G, Adams DH. National outcomes in acute aortic dissection: influence of surgeon and institutional volume on operative mortality. *Ann Thorac Surg*. 2013;95:1563–1569.
11. Wang W, Duan W, Xue Y, Wang L, Liu J, Yu S, Yi D; Registry of Aortic Dissection in China Sino-RAD Investigators. Clinical features of acute aortic dissection from the Registry of Aortic Dissection in China. *J Thorac Cardiovasc Surg*. 2014;148:2995–3000.
12. Russo CF, Mariscalco G, Colli A, Santè P, Nicolini F, Miceli A, De Chiara B, Beghi C, Gerosa G, Glauber M, Gherli T, Nappi G, Murzi M, Molardi A, Merlanti B, Vizzardi E, Bonadei I, Coletti G, Carrozzini M, Gelsomino S, Caiazzo A, Lorusso R. Italian multicentre study on type A acute aortic dissection: a 33-year follow-up. *Eur J Cardiothorac Surg*. 2016;49:125–131.
13. Iribarne A, Milner R, Merlo AE, Singh A, Saunders CR, Russo MJ. Outcomes following emergent open repair for thoracic aortic dissection are improved at higher volume centers. *J Card Surg*. 2015;30:74–79.
14. Andersen ND, Ganapathi AM, Hanna JM, Williams JB, Gaca JG, Hughes GC. Outcomes of acute type a dissection repair before and after implementation of a multidisciplinary thoracic aortic surgery program. *J Am Coll Cardiol*. 2014;63:1796–1803.
15. Pompilio G, Spirito R, Alamanni F, Agrifoglio M, Polvani G, Porqueddu M, Reali M, Biglioli P. Determinants of early and late outcome after surgery for type A aortic dissection. *World J Surg*. 2001;25:1500–1506.
16. Bridgewater B, Keogh B, Kinsman R, Walton P. *The Society for Cardiothoracic Surgery in Great Britain & Ireland: The Sixth National Adult Cardiac Surgical Database Report*. Henley-on-Thames, UK: Dendrite Clinical Systems Ltd; 2009. Available at: http://www.scts.org/_userfiles/resources/SixthNACSDreport2008withcovers.pdf. Accessed June 30, 2015.
17. https://www.england.nhs.uk/rightcare/intel/cfv/atlas/. Accessed May 31, 2016.
18. http://www.england.nhs.uk/commissioning/wp-content/uploads/sites/12/2015/01/a10-spec-adlt-cardiac-surgry.pdf. Accessed June 30, 2016.
19. http://www.vascularsociety.org.uk/wp-content/uploads/2013/06/Service-Specification.pdf. Accessed June 30, 2016.
20. Hiratzka LF, Bakris GL, Beckman JA, Bersin RM, Carr VF, Casey DE Jr, Eagle KA, Hermann LK, Isselbacher EM, Kazerooni EA, Kouchoukos NT, Lytle BW, Milewicz DM, Reich DL, Sen S, Shinn JA, Svensson LG, Williams DM; American College of Cardiology Foundation; American Heart Association Task Force on Practice Guidelines; American Association for Thoracic Surgery; American College of Radiology; American Stroke Association; Society of Cardiovascular Anesthesiologists; Society for Cardiovascular Angiography and Interventions; Society of Interventional Radiology; Society of Thoracic Surgeons; Society for Vascular Medicine. 2010 ACCF/AHA/AATS/ACR/ASA/SCA/SCAI/SIR/STS/SVM Guidelines for the diagnosis and management of patients with thoracic aortic disease. A report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines, American Association for Thoracic Surgery, American College of Radiology, American Stroke Association, Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, Society of Interventional Radiology, Society of Thoracic Surgeons, and Society for Vascular Medicine. *J Am Coll Cardiol*. 2010;55:e27–e129.
21. Erbel R, Aboyans V, Boileau C, Bossone E, Bartolomeo RD, Eggebrecht H, Evangelista A, Falk V, Frank H, Gaemperli O, Grabenwöger M, Haverich A, Iung B, Manolis AJ, Meijboom F, Nienaber CA, Roffi M, Rousseau H, Sechtem U, Sirnes PA, Allmen RS, Vrints CJ; ESC Committee for Practice Guidelines. 2014 ESC guidelines on the diagnosis and treatment of aortic diseases: document covering acute and chronic aortic diseases of the thoracic and abdominal aorta of the adult. The Task Force for the Diagnosis and Treatment of Aortic Diseases of the European Society of Cardiology (ESC). *Eur Heart J*. 2014;35:2873–2926.
22. Svensson LG, Adams DH, Bonow RO, Kouchoukos NT, Miller DC, O'Gara PT, Shahian DM, Schaff HV, Akins CW, Bavaria JE, Blackstone EH, David TE, Desai ND, Dewey TM, D'Agostino RS, Gleason TG, Harrington KB, Kodali S, Kapadia S, Leon MB, Lima B, Lytle BW, Mack MJ, Reardon M, Reece TB, Reiss GR, Roselli EE, Smith CR, Thourani VH, Tuzcu EM, Webb J, Williams MR. Aortic valve and ascending aorta guidelines for management and quality measures: executive summary. *Ann Thorac Surg*. 2013;95:1491–1505.
23. Yan TD, Tian DH, LeMaire SA, Hughes GC, Chen EP, Misfeld M, Griepp RB, Kazui T, Bannon PG, Coselli JS, Elefteriades JA, Kouchoukos NT, Underwood MJ, Mathew JP, Mohr FW, Oo A, Sundt TM, Bavaria JE, Di Bartolomeo R, Di Eusanio M, Trimarchi S; International Aortic Arch Surgery Study Group. Standardizing clinical end points in aortic arch surgery: a consensus statement from the International Aortic Arch Surgery Study Group. *Circulation*. 2014;129:1610–1616.
24. Boodhwani M, Andelfinger G, Leipsic J, Lindsay T, McMurtry MS, Therrien J, Siu SC; Canadian Cardiovascular Society. Canadian Cardiovascular Society position statement on the management of thoracic aortic disease. *Can J Cardiol*. 2014;30:577–589.
25. Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM; RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) statement. *PLoS Med*. 2015;12:e1001885.
26. Stroup DF, Berlin JA, Morton SC, Olkin I, Williamson GD, Rennie D, Moher D, Becker BJ, Sipe TA, Thacker SB. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis Of Observational Studies in Epidemiology (MOOSE) group. *JAMA*. 2000;283:2008–2012.
27. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ*. 2009;339:b2535.
28. http://www.hscic.gov.uk/hes. Accessed June 30, 2015.
29. http://www.ucl.ac.uk/nicor/audits/adultcardiac/documents/datasets/NACSAdatasetV4.1.2. Accessed April 30, 2015.
30. http://www.ucl.ac.uk/nicor/audits/adultcardiac/documents/datasets/nacsacleaning10.3. Accessed April 30, 2015.
31. Hickey GL, Grant SW, Cosgriff R, Dimarakis I, Pagano D, Kappetein AP, Bridgewater B. Clinical registries: governance, management, analysis and applications. *Eur J Cardiothorac Surg*. 2013;44:605–614.
32. Mariscalco G, Murphy GJ, Mariani S, Saratzis A. Standard of care for the management of thoracic aortic disease: a systematic review and meta-analysis. PROSPERO 2015:CRD42015024137.
33. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Available at: http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp. Accessed June 30, 2016.
34. Cohen ME, Dimick JB, Bilimoria KY, Ko CY, Richards K, Hall BL. Risk adjustment in the American College of Surgeons National Surgical Quality Improvement Program: a comparison of logistic versus hierarchical modeling. *J Am Coll Surg*. 2009;209:687–693.
35. van Klaveren D, Steyerberg EW, Perel P, Vergouwe Y. Assessing discriminative ability of risk models in clustered data. *BMC Med Res Methodol*. 2014;14:5.
36. Yates F. Contingency tables involving small numbers and the χ^2 test. *J R Stat Soc*. 1934;suppl 1:217–235.
37. Borenstein M, Hedges LV, Higgins JPT, Rothstein HR. A basic introduction to fixed-effect and random-effects models for meta-analysis. *Res Synth Methods*. 2010;1:97–111. DOI: 10.1002/jrsm.12.
38. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med*. 2002;21:1539–1558.
39. Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *BMJ*. 1997;315:629–634.
40. R Core Team. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing; 2013. Available at: http://www.R-project.org/. Accessed March 1, 2016.
41. https://cran.r-project.org/web/packages/meta/meta.pdf. Accessed March 1, 2016.
42. Schaffer JM, Lingala B, Fischbein MP, Dake MD, Woo YJ, Mitchell RS, Miller DC. Midterm outcomes of open descending thoracic aortic repair in more than 5,000 Medicare patients. *Ann Thorac Surg*. 2015;100:2087–2094.
43. Schaffer JM, Lingala B, Miller DC, Woo YJ, Mitchell RS, Dake MD. Midterm survival after thoracic endovascular aortic repair in more than 10,000 Medicare patients. *J Thorac Cardiovasc Surg*. 2015;149:808–820.
44. Bhatt P, Patel NJ, Patel A, Sonani R, Patel A, Panaich SS, Thakkar B, Savani C, Jhamnani S, Patel N, Patel N, Pant S, Patel S, Arora S, Dave A, Singh V, Chothani A, Patel J, Ansari M, Deshmukh A, Bhimani R, Grines C, Cleman M, Mangi A, Forrest JK, Badheka AO. Impact of hospital volume on outcomes of endovascular stenting for adult aortic coarctation. *Am J Cardiol*. 2015;116:1418–1424.
45. Brat R, Gaj J, Barta J. Early and mid-term outcomes of the aortic arch surgery: experience from the low-volume centre. *J Cardiothorac Surg*. 2015;10:31.
46. Grau JB, Kuschner CE, Ferrari G, Wilson SR, Brizzio ME, Zapolanski A, Yallowitz J, Shaw RE. Effects of a protocol-based management of type A aortic dissections. *J Surg Res*. 2015;197:265–269.

47. Lenos A, Bougioukakis P, Irimie V, Zacher M, Diegeler A, Urbanski PP. Impact of surgical experience on outcome in surgery of acute type A aortic dissection. *Eur J Cardiothorac Surg*. 2015;48:491–496.
48. Murzi M, Miceli A, Di Stefano G, Cerillo AG, Kallushi E, Farneti P, Solinas M, Glauber M. Enhancing quality control and performance monitoring in thoracic aortic surgery: a 10-year single institutional experience. *Eur J Cardiothorac Surg*. 2015;47:608–615.
49. Sales Mda C, Frota Filho JD, Aguzzoli C, Souza LD, Rösler AM, Lucio EA, Leães PE, Pontes MR, Lucchese FA. Aortic Center: specialized care improves outcomes and decreases mortality. *Rev Bras Cir Cardiovasc*. 2014;29:494–504.
50. Weiss A, Anderson JA, Green A, Chang DC, Kansal N. Hospital volume of thoracoabdominal aneurysm repair does not affect mortality in California. *Vasc Endovascular Surg*. 2014;48:378–382.
51. Arnaoutakis DJ, Propper BW, Black JH III, Schneider EB, Lum YW, Freischlag JA, Perler BA, Abularrage CJ. Racial and ethnic disparities in the treatment of unruptured thoracoabdominal aortic aneurysms in the United States. *J Surg Res*. 2013;184:651–657.
52. Soppa G, Abdulkareem N, Smelt J, Van Besouw JP, Jahangiri M. High-volume practice by a single specialized team reduces mortality and morbidity of elective and urgent aortic root replacement. *Aorta (Stamford)*. 2013;1:40–44.
53. Tsagakis K, Konorza T, Dohle DS, Kottenberg E, Buck T, Thielmann M, Erbel R, Jakob H. Hybrid operating room concept for combined diagnostics, intervention and surgery in acute type A dissection. *Eur J Cardiothorac Surg*. 2013;43:397–404.
54. Chavanon O, Baguet JP, Albaladéjo P, Blin D, Vanzetto G. Direct admission to the operating room: an efficient strategy for patients with diagnosed or highly suspected acute type A aortic dissection. *Can J Cardiol*. 2011;27:685–691.
55. Gopaldas RR, Dao TK, LeMaire SA, Huh J, Coselli JS. Endovascular versus open repair of ruptured descending thoracic aortic aneurysms: a nationwide risk-adjusted study of 923 patients. *J Thorac Cardiovasc Surg*. 2011;142:1010–1018.
56. Harris KM, Strauss CE, Duval S, Unger BT, Kroshus TJ, Inampudi S, Cohen JD, Kapsner C, Boland LL, Eales F, Rohman E, Orlandi QG, Flavin TF, Kshettry VR, Graham KJ, Hirsch AT, Henry TD. Multidisciplinary standardized care for acute aortic dissection: design and initial outcomes of a regional care model. *Circ Cardiovasc Qual Outcomes*. 2010;3:424–430.
57. Davies MG, Younes HK, Harris PW, Masud F, Croft BA, Reardon MJ, Lumsden AB. Outcomes before and after initiation of an acute aortic treatment center. *J Vasc Surg*. 2010;52:1478–1485.
58. Gazoni LM, Speir AM, Kron IL, Fonner E, Crosby IK. Elective thoracic aortic aneurysm surgery: better outcomes from high-volume centers. *J Am Coll Surg*. 2010;210:855–859.
59. Miyata H, Motomura N, Ueda Y, Tsukihara H, Tabayashi K, Takamoto S. Toward quality improvement of thoracic aortic surgery: estimating volume-outcome effect from nationwide survey. *Eur J Cardiothorac Surg*. 2009;36:517–521.
60. Schermerhorn ML, Giles KA, Hamdan AD, Dalhberg SE, Hagberg R, Pomposelli F. Population-based outcomes of open descending thoracic aortic aneurysm repair. *J Vasc Surg*. 2008;48:821–827.
61. Knipp BS, Deeb GM, Prager RL, Williams CY, Upchurch GR Jr, Patel HJ. A contemporary analysis of outcomes for operative repair of type A aortic dissection in the United States. *Surgery*. 2007;142:524–528.
62. Committee for Scientific Affairs, Kazui T, Osada H, Fujita H. An attempt to analyze the relation between hospital surgical volume and clinical outcome. *Gen Thorac Cardiovasc Surg*. 2007;55:483–492.
63. Rigberg DA, McGory ML, Zingmond DS, Maggard MA, Agustin M, Lawrence PF, Ko CY. Thirty-day mortality statistics underestimate the risk of repair of thoracoabdominal aortic aneurysms: a statewide experience. *J Vasc Surg*. 2006;43:217–222.
64. Narayan P, Caputo M, Rogers CA, Alwair H, Mahesh B, Angelini GD, Bryan AJ. Early and mid-term outcomes of surgery of the ascending aorta/arch: is there a relationship with caseload? *Eur J Cardiothorac Surg*. 2004;25:676–682.
65. Cowan JA Jr, Dimick JB, Henke PK, Huber TS, Stanley JC, Upchurch GR Jr. Surgical treatment of intact thoracoabdominal aortic aneurysms in the United States: hospital and surgeon volume-related outcomes. *J Vasc Surg*. 2003;37:1169–1174.
66. Derrow AE, Seeger JM, Dame DA, Carter RL, Ozaki CK, Flynn TC, Huber TS. The outcome in the United States after thoracoabdominal aortic aneurysm repair, renal artery bypass, and mesenteric revascularization. *J Vasc Surg*. 2001;34:54–61.
67. Albrink MH, Rodriguez E, England GJ, McKeown PP, Hurst JM, Rosemurgy AS II. Importance of designated thoracic trauma surgeons in the management of traumatic aortic transection. *South Med J*. 1994;87:497–501.
68. Burns EM, Rigby E, Mamidanna R, Bottle A, Aylin P, Ziprin P, Faiz OD. Systematic review of discharge coding accuracy. *J Public Health (Oxf)*. 2012;34:138–148.
69. von Allmen RS, Anjum A, Powell JT. Outcomes after endovascular or open repair for degenerative descending thoracic aortic aneurysm using linked hospital data. *Br J Surg*. 2014;101:1244–1251.
70. Benedetto U, Mohamed H, Vitulli P, Petrou M. Axillary versus femoral arterial cannulation in type A acute aortic dissection: evidence from a meta-analysis of comparative studies and adjusted risk estimates. *Eur J Cardiothorac Surg*. 2015;48:953–959.
71. Angeloni E, Melina G, Refice SK, Roscitano A, Capuano F, Comito C, Sinatra R. Unilateral versus bilateral antegrade cerebral protection during aortic surgery: an updated meta-analysis. *Ann Thorac Surg*. 2015;99:2024–2031.
72. https://www.bhf.org.uk/publications/statistics/cvd-stats-2015. Accessed May 31, 2016.
73. Karthikesalingam A, Hinchliffe RJ, Loftus IM, Thompson MM, Holt PJ. Volume-outcome relationships in vascular surgery: the current status. *J Endovasc Ther*. 2010;17:356–365.
74. Holt PJ, Poloniecki JD, Khalid U, Hinchliffe RJ, Loftus IM, Thompson MM. Effect of endovascular aneurysm repair on the volume-outcome relationship in aneurysm repair. *Circ Cardiovasc Qual Outcomes*. 2009;2:624–632.
75. Booher AM, Isselbacher EM, Nienaber CA, Trimarchi S, Evangelista A, Montgomery DG, Froehlich JB, Ehrlich MP, Oh JK, Januzzi JL, O'Gara P, Sundt TM, Harris KM, Bossone E, Pyeritz RE, Eagle KA; IRAD Investigators. The IRAD classification system for characterizing survival after aortic dissection. *Am J Med*. 2013;126:730.e19-24.
76. Moffatt-Bruce SD, Nguyen MC, Fann JI, Westaby S. Our new reality of public reporting: shame rather than blame? *Ann Thorac Surg*. 2016;101:1255–1261.

ONLINE-ONLY SUPPLEMENTARY MATERIAL

Bottle A, Mariscalco G, Shaw MA, Benedetto U, Saratzis A, Mariani S, Bashir M, Aylin P, Jenkins D, Oo AY, Murphy GJ; on behalf of the UK Aortic Forum. Unwarranted variation in the quality of care for patients with diseases of the thoracic aorta.

This supplementary material has been provided by the authors to give readers additional information about their work.

Supplemental Methods

Data sources and study populations

Data were extracted from the HES and the NICOR NACSA registry, according to The REporting of studies Conducted using Observational Routinely collected health Data (RECORD) statement.[1] The need to obtain informed consent from patients was waived by the University of Leicester Research Governance Office since the identifiable information was either removed or pseudonymized. The study was approved by the NICOR NACSA Research Board (study reference 14-ACS-25).

HES cohort

Hospital Episodes Statistics is the national hospital administrative database for England and covers all admissions to public (NHS) hospitals in the country.[2] The data contain demographic, administrative and clinical information including procedures and operations. The database includes 20 diagnostic fields coded using ICD-10 and 24 procedure fields coded using the UK's own OPCS-4 system (Office of Population, Censuses and Surveys: Classification of interventions and procedures, 4th Revision). Admissions with a primary or secondary diagnosis code of TAD (ICD10 I710, I711, I712, I715, I716) or with a procedure for TAD repair (OPCS codes L181, L182, L191, L192, L201, L202, L208, L209, L211, L212, L273, L283, L221) were extracted for the financial years 2005/6 to 2010/11 inclusive (the most recent for which we had out-of-hospital deaths from the Office for National Statistics [ONS] files linked to HES) (Table S1 in the online-only Data Supplement). Using HES's anonymised patient identifier and admission dates, admissions were ordered chronologically by patient, with their first one between 2005/6 and 2010/11 flagged. After tracking back five years from this first TAD admission (back to 2000/1), patients were excluded if they had had a TAD admission or procedure during these five years. The remainder were considered index TAD admissions. We then tracked forward in time from these index admissions to capture any TAD procedures (surgery or endovascular procedures) within six months.

Outcomes of interest were: having an operation (surgical and/or endovascular) either during the index or within six months of it; having an elective rather than an emergency operation; post-operative mortality within six months; and mortality within six months in patients not having an operation. Death was defined as that in or out of hospital within six months of the index admission date.

For each patient, the postcode sector was mapped to a county via online look-ups between postcode sector and local authority and then local authority and county. "County" is actually unitary authority, but many retain their county names and we therefore refer to "county" throughout. Some had to be combined due to small numbers, finally leaving 40 counties (e.g., the Isle of Wight was merged with Hampshire).

NACSA cohort

Prospectively collected data for all adult patients undergoing major aortic surgery were extracted from the NICOR NACSA registry (version 4.1.2) on 20th November 2014. All surgical procedures included in the study were performed in England between the 1st of April 2007 and the 31st of March 2013 and constituted the "complete-case" dataset. NICOR manage the audit and receive clinical direction and strategy from the Society for Cardiothoracic Surgery in Great Britain and Ireland (SCTS).16 Reproducible cleaning algorithms were applied to the database.29,30 Briefly, duplicate records and non-adult cardiac surgery entries were removed, transcriptional discrepancies harmonised and clinical and temporal conflicts and extreme values corrected or removed. The output from the pre-processing is regularly checked by reporting data summaries back to individual units for local validation and inspection as part of the NACSA in the UK.[3-7]

For each operation, records on patient characteristics and demographics, comorbidities, intraoperative factors, and postoperative outcomes were collected. Administrative data were also extracted including: patient admission, procedure and discharge dates and responsible consultant surgeon. For each record, calibrated logistic EuroSCORE was calculated.[8] Missing data were assumed to be absent for categorical variables or replaced with the mean value for continuous variables. Ejection fraction was the categorical variable with the highest incidence of missing data (3.5%). The proportions of missing data for continuous variables were: age, 0%; BMI, 3.6%; cardiopulmonary bypass time, 2.3%; and aortic cross clamp time, 2.9%. The primary outcome measure was in-hospital mortality, defined as death in hospital following the index surgical procedure and prior

to transfer from the cardiac surgery unit as per the definition used in the national audit. Therefore, records were excluded from the analysis if in-hospital mortality status was missing (n=32, 0.4%).

Operations were divided into four separate categories based on the operated segment most distal to the aortic valve included in the procedure, including the aortic root or ascending aorta, aortic arch, descending aorta, and the thoracoabdominal aorta. Elective, urgent or emergency procedures were all included. Where operational pathology was available, it was divided into three categories: aneurysm, dissection and "other", the latest containing the categories "trauma" and "other".

To complement the NACSA study we contacted the Society for Cardiothoracic Surgery Unit Representative for every cardiac surgery unit in England and asked 4 questions with respect to the current configuration of TAD services in their unit. The questions were: 1. Is there a dedicated Aortic Team? 2. Is there a specific on call rota for aortic emergencies? 3. Is there a hybrid operating theatre? 4. Is there a specific aortic multidisciplinary team (MDT) meeting recognized in the consultant job plans? Obtained data were cross-referenced with the NACSA data on aortic case-volume, complexity and outcomes. Statistical analysis

Supplemental Tables

Table S1. The RECORD statement – checklist of items, extended from the STROBE statement

	Item No.	STROBE items and Recommendation[9]	Location in manuscript where items are reported (pag.n.)	RECORD items and Recommendation[1]	Location in manuscript where items are reported (pag.n.)
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	1,2 2	RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	1,2 1,2 1,2
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported	3		3
Objectives	3	State specific objectives, including any prespecified hypotheses	3		3
Methods					
Study Design	4	Present key elements of study design early in the paper	3,4 Supplemental Material		
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4,5 Supplemental Material		
Participants	6	*(a) Cohort study* - Give the eligibility criteria, and the sources and methods		RECORD 6.1: The methods of study population selection (such as codes or	3,4 Supplemental Material

		of selection of participants. Describe methods of follow-up *Case-control study* - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study* - Give the eligibility criteria, and the sources and methods of selection of participants *(b) Cohort study* - For matched studies, give matching criteria and number of exposed and unexposed *Case-control study* - For matched studies, give matching criteria and the number of controls per case		algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.	3,4 Supplemental Material	RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	3,4 Supplemental Material
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	3,4, Supplemental Material		
Bias	9	Describe any efforts to address potential sources of bias	Supplemental Material		
Study size	10	Explain how the study size was arrived at	3,4		

Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	3,4 Supplemental Material		
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) *Cohort study* - If applicable, explain how loss to follow-up was addressed *Case-control study* - If applicable, explain how matching of cases and controls was addressed *Cross-sectional study* - If applicable, describe analytical methods taking account of sampling strategy (e) Describe any sensitivity analyses	5,6 Supplemental Material		
Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population. RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	3-6 Supplemental Material
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	3,4 Supplemental Material
Results					
Participants	13	(a) Report the numbers of individuals	8-11	RECORD 13.1: Describe in detail the	8-11

		at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram		selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) *Cohort study* - summarise follow-up time (*e.g.*, average and total amount)	8-11		
Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time *Case-control study* - Report numbers in each exposure category, or summary measures of exposure *Cross-sectional study* - Report numbers of outcome events or summary measures	8-11		
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	8-11		
Other analyses	17	Report other analyses done—e.g.,	8-11		

		analyses of subgroups and interactions, and sensitivity analyses	Supplemental Material		
Discussion					
Key results	18	Summarise key results with reference to study objectives	12,13		
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	13-15	RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported.	13-15
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	12,16		
Generalisability	21	Discuss the generalisability (external validity) of the study results	16		
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	17		
Accessibility of protocol, raw data, and programming code				RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	Supplemental Material

Table S2. MOOSE Checklist for Meta-analyses of Observational Studies[10]

Item N.	Recommendation	Reported on Page N.
Reporting of background should include		
1	Problem definition	3
2	Hypothesis statement	3
3	Description of study outcome(s)	4,5, tab S5
4	Type of exposure or intervention used	5, tab S5
5	Type of study designs used	4,5
6	Study population	5
Reporting of search strategy should include		
7	Qualifications of searchers (eg, librarians and investigators)	4,5
8	Search strategy, including time period included in the synthesis and key words	4,5
9	Effort to include all available studies, including contact with authors	Ref.#32
10	Databases and registries searched	5 Ref.#32
11	Search software used, name and version, including special features used (eg, explosion)	Ref.#32
12	Use of hand searching (eg, reference lists of obtained articles)	Ref.#32
13	List of citations located and those excluded, including justification	fig S4 Ref.#32
14	Method of addressing articles published in languages other than English	Ref.#32
15	Method of handling abstracts and unpublished studies	Ref.#32
16	Description of any contact with authors	Ref.#32
Reporting of methods should include		
17	Description of relevance or appropriateness of studies assembled for assessing the hypothesis to be tested	Ref.#32
18	Rationale for the selection and coding of data (eg, sound clinical principles or convenience)	Ref.#32
19	Documentation of how data were classified and coded (eg, multiple raters, blinding and interrater reliability)	Ref.#32
20	Assessment of confounding (eg, comparability of cases and controls in studies where appropriate)	Ref.#32
21	Assessment of study quality, including blinding of quality assessors, stratification or regression on possible predictors of study results	5 Ref.#32
22	Assessment of heterogeneity	Supplement
23	Description of statistical methods (eg, complete description of fixed or random effects models, justification of whether the chosen models account for predictors of study results, dose-response models, or cumulative meta-analysis) in sufficient detail to be replicated	Supplement
24	Provision of appropriate tables and graphics	Supplement
Reporting of results should include		
25	Graphic summarizing individual study estimates and overall estimate	fig 4

		fig S9-13
26	Table giving descriptive information for each study included	tab S11-13
27	Results of sensitivity testing (eg, subgroup analysis)	11,12
28	Indication of statistical uncertainty of findings	11,12
Reporting of discussion should include		
29	Quantitative assessment of bias (eg, publication bias)	Supplement
30	Justification for exclusion (eg, exclusion of non-English language citations)	Ref.#32
31	Assessment of quality of included studies	tab S14
Reporting of conclusions should include		
32	Consideration of alternative explanations for observed results	13,14
33	Generalization of the conclusions (ie, appropriate for the data presented and within the domain of the literature review)	16
34	Guidelines for future research	16
35	Disclosure of funding source	17,18

Table S3. PRISMA checklist of Items to Include when Reporting a Systematic Review or Meta-analysis[11]

Section/topic	#	Checklist Item	Reported on Page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	3
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	tab V
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	4,5 Ref.#32
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	4,5 tab S5
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	4,5 Ref.#32
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	5 Ref.#32
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	2 Ref.#32
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	5 Ref.#32
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	Ref.#32
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	Ref.#32

Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	Supplement
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	Supplement
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	Supplement
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	Supplement
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	11,12
Study characteristics	18	For each study, present characteristics for which data were extracted and provide the citations.	tab S11-13
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	tab S14
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	fig 4 tab S12-13
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	fig 4 fig S9-13
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	tab S14-15
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	Supplement
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	13
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	14-16
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	16
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	17,18

Table S4. List of ICD-10 codes for the comorbidities used in the HES analysis

Code	Description
I10-I15 Hypertensive diseases	I10 Essential (primary) hypertension I11 Hypertensive heart disease I12 Hypertensive renal disease I13 Hypertensive heart and renal disease I15 Secondary hypertension
I20-I25 Ischaemic heart diseases	I20 Angina pectoris I21 Acute myocardial infarction I22 Subsequent myocardial infarction I23 Certain current complications following acute myocardial infarction I24 Other acute ischaemic heart diseases I25 Chronic ischaemic heart disease
I30-I52 Other forms of heart disease	I34 Nonrheumatic mitral valve disorders I35 Nonrheumatic aortic valve disorders I36 Nonrheumatic tricuspid valve disorders I37 Pulmonary valve disorders
I60-I69 Cerebrovascular diseases	I60 Subarachnoid haemorrhage I61 Intracerebral haemorrhage I62 Other nontraumatic intracranial haemorrhage I63 Cerebral infarction I63.0 Cerebral infarction due to thrombosis of precerebral arteries I63.1 Cerebral infarction due to embolism of precerebral arteries I63.2 Cerebral infarction due to unspecified occlusion or stenosis of precerebral arteries I63.3 Cerebral infarction due to thrombosis of cerebral arteries I63.4 Cerebral infarction due to embolism of cerebral arteries I63.5 Cerebral infarction due to unspecified occlusion or stenosis of cerebral arteries I63.6 Cerebral infarction due to cerebral venous thrombosis, nonpyogenic I63.8 Other cerebral infarction I63.9 Cerebral infarction, unspecified I64 Stroke, not specified as haemorrhage or infarction I65 Occlusion and stenosis of precerebral arteries, not resulting in cerebral infarction I66 Occlusion and stenosis of cerebral arteries, not resulting in cerebral infarction I67 Other cerebrovascular diseases I68 Cerebrovascular disorders in diseases classified elsewhere I69 Sequelae of cerebrovascular disease
I70 Atherosclerosis	I70.0 Atherosclerosis of aorta I70.1 Atherosclerosis of renal artery I70.2 Atherosclerosis of arteries of extremities I70.8 Atherosclerosis of other arteries I70.9 Generalized and unspecified atherosclerosis
I71 Aortic Aneurysms not affecting the thoracic aorta	I71.3 Abdominal aortic aneurysm, ruptured I71.4 Abdominal aortic aneurysm, without mention of rupture I71.8 Aortic aneurysm of unspecified site, ruptured I71.9 Aortic aneurysm of unspecified site, without mention of rupture
I72 Other aneurysm and dissection (not affecting the thoracic aorta)	I72.0 Aneurysm and dissection of carotid artery I72.1 Aneurysm and dissection of artery of upper extremity I72.2 Aneurysm and dissection of renal artery I72.3 Aneurysm and dissection of iliac artery I72.4 Aneurysm and dissection of artery of lower extremity I72.5 Aneurysm and dissection of other precerebral arteries I72.8 Aneurysm and dissection of other specified arteries I72.9 Aneurysm and dissection of unspecified site
I73 Other peripheral vascular diseases	I73.0 Raynaud syndrome I73.1 Thromboangiitis obliterans [Buerger] I73.8 Other specified peripheral vascular diseases

	I73.9 Peripheral vascular disease, unspecified
I77 Other disorders of arteries and arterioles	I77.6 Arteritis, unspecified I77.8 Other specified disorders of arteries and arterioles I77.2 Rupture of artery
I79 Disorders of arteries, arterioles and capillaries in diseases classified elsewhere	I79.0 Aneurysm of aorta in diseases classified elsewhere I79.1 Aortitis in diseases classified elsewhere I79.2 Peripheral angiopathy in diseases classified elsewhere I79.8 Other disorders of arteries, arterioles and capillaries in diseases classified elsewhere
Q20-Q28 Congenital malformations of the circulatory system	Q20 Congenital malformations of cardiac chambers and connections Q21 Congenital malformations of cardiac septa Q22 Congenital malformations of pulmonary and tricuspid valves Q23 Congenital malformations of aortic and mitral valves Q24 Other congenital malformations of heart Q25 Congenital malformations of great arteries Q26 Congenital malformations of great veins Q27 Other congenital malformations of peripheral vascular system Q28 Other congenital malformations of circulatory system
Q79.6 Ehlers-Danlos syndrome	
Q87 Other specified congenital malformation syndromes affecting multiple systems	Q87.4 Marfan syndrome Q87.5 Other congenital malformation syndromes with other skeletal changes Q87.8 Other specified congenital malformation syndromes, not elsewhere classified
J40-J44 Chronic obstructive pulmonary disease	J40 Bronchitis, not specified as acute or chronic J41 Simple and mucopurulent chronic bronchitis J42 Unspecified chronic bronchitis J43 Emphysema J44 Other chronic obstructive pulmonary disease
E10-E14 Diabetes mellitus	E10 Insulin-dependent diabetes mellitus E11 Non-insulin-dependent diabetes mellitus E12 Malnutrition-related diabetes mellitus E13 Other specified diabetes mellitus E14 Unspecified diabetes mellitus
E66 Obesity	
E78 Disorders of lipoprotein metabolism and other lipidaemias	

Table S5. PICOS criteria for inclusion and exclusion of studies into meta-analysis

Parameter	Inclusion criteria	Exclusion criteria
Patients	Adult patients affected by TAD	Patients affected by other cardiac diseases other than TAD
Intervention*	Open surgery or endovascular repair of TAD	Study without definition of volume activity
Comparator	Hospital volume activity	-
Outcomes	Primary: in-hospital/30-day mortality (all cause) Secondary: postoperative stroke; re-exploration for bleeding/tamponade; postoperative renal failure; length of hospitalization	Late mortality
Study design	Clinical randomised trials Controlled before-and-after studies Prospective and retrospective cohort studies Cross-sectional studies Case-control studies	Repeat publications of the same analysis or dataset Conference abstracts Editorials & opinion pieces Books or grey literature

Abbreviations: TAD, thoracic aortic disease.

* Main intervention/comparator; other intervention/comparator: surgeon volume (high- *vs.* low-volume); teaching hospital status (teaching *vs.* non-teaching); urban hospital status (urban *vs.* rural); aortic dedicated team presence (aortic team *vs.* no-aortic team); dedicated thoracic aortic surgery program (program *vs.* no program; presence of cardiothoracic unit along with hybrid room.

Table S6. Risk factors for patients affected by thoracic aortic disease who received treatment and for patients who received non-emergent rather than emergent treatment (HES cohort)

Factor		Receiving treatment		Receiving non-emergent rather than emergency treatment	
	Value	OR (95% CI)	P-value	OR (95% CI)	P-value
Age	0-39	2.15 (1.82 to 2.53)	<.0001	0.68 (0.50 to 0.91)	0.01
	40-44	1.55 (1.27 to 1.90)	<.0001	1.12 (0.77 to 1.64)	0.5504
	45-49	1.36 (1.13 to 1.64)	0.0012	0.98 (0.68 to 1.40)	0.9022
	50-54	1.32 (1.12 to 1.56)	0.0011	0.98 (0.71 to 1.34)	0.8743
	55-59	1.35 (1.17 to 1.56)	<.0001	0.88 (0.67 to 1.16)	0.3626
	60-64	1.16 (1.01 to 1.32)	0.0315	0.87 (0.67 to 1.12)	0.2699
	65-69	1		1	
	70-74	0.84 (0.75 to 0.95)	0.0041	0.88 (0.70 to 1.10)	0.2626
	75-79	0.61 (0.54 to 0.69)	<.0001	0.85 (0.67 to 1.07)	0.1621
	80-84	0.29 (0.25 to 0.33)	<.0001	0.52 (0.39 to 0.68)	<.0001
	85-89	0.11 (0.09 to 0.14)	<.0001	0.29 (0.18 to 0.46)	<.0001
	90+	0.02 (0.01 to 0.04)	<.0001	0.37 (0.09 to 1.45)	0.1516
Sex	Female	1.04 (0.97 to 1.12)	0.2385	1.00 (0.87 to 1.15)	0.9975
	Male	1		1	
Year	2004	1.24 (1.09 to 1.40)	0.0009	0.88 (0.69 to 1.13)	0.3185
Year	2005	1.30 (1.15 to 1.47)	<.0001	0.84 (0.66 to 1.06)	0.1313
Year	2006	1.36 (1.20 to 1.53)	<.0001	0.75 (0.60 to 0.94)	0.0131
Year	2007	1.21 (1.07 to 1.35)	0.0014	0.83 (0.66 to 1.04)	0.1012
Year	2008	1.01 (0.90 to 1.13)	0.8694	0.97 (0.77 to 1.21)	0.7698
Year	2009	0.98 (0.87 to 1.09)	0.6823	0.93 (0.74 to 1.16)	0.5082
Year	2010	1		1	
Deprivation	1 (least deprived)	1		1	
Deprivation	2	0.95 (0.86 to 1.04)	0.2541	1.05 (0.87 to 1.26)	0.6245
Deprivation	3	0.88 (0.79 to 0.97)	0.0093	0.74 (0.61 to 0.90)	0.0021
Deprivation	4	0.82 (0.73 to 0.91)	0.0001	0.83 (0.68 to 1.01)	0.0605
Deprivation	5 (most deprived)	0.69 (0.62 to 0.78)	<.0001	0.61 (0.49 to 0.76)	<.0001
Atherosclerosis		1.45 (1.24 to 1.68)	<.0001	0.98 (0.74 to 1.29)	0.8616
Cancer		0.70 (0.62 to 0.80)	<.0001	1.25 (0.97 to 1.60)	0.0847
Congenital malformation circulatory disorders		1.17 (1.03 to 1.34)	0.0182	1.82 (1.43 to 2.31)	<.0001
COPD		0.64 (0.57 to 0.71)	<.0001	0.79 (0.63 to 0.98)	0.0332
Cerebrovascular disease		0.83 (0.73 to 0.94)	0.0025	0.86 (0.67 to 1.11)	0.2421
Diabetes		0.82 (0.73 to 0.93)	0.0019	1.02 (0.80 to 1.30)	0.8775
Hypertension		1.04 (0.97 to 1.12)	0.3026	1.15 (1.00 to 1.33)	0.0444
Ischaemic heart disease		0.84 (0.78 to 0.91)	<.0001	1.38 (1.20 to 1.60)	<.0001
Lipid disorders		1.06 (0.97 to 1.15)	0.1928	1.57 (1.33 to 1.84)	<.0001
Other aneurysm		1.07 (0.86 to 1.34)	0.5549	0.86 (0.58 to 1.28)	0.4506
Other aortic disease		2.42 (2.24 to 2.63)	<.0001	1.32 (1.15 to 1.53)	0.0001
Disorders of other arteries		2.04 (1.05 to 2.77)	<.0001	0.30 (0.18 to 0.49)	<.0001
Other congenital malformation		0.90 (0.72 to 1.12)	0.3464	3.17 (2.04 to 4.91)	<.0001
Other IHD		1.41 (1.31 to 1.51)	<.0001	1.52 (1.33 to 1.74)	<.0001

Other PVD		0.90 (0.78 to 1.05)	0.1857	0.85 (0.64 to 1.14)	0.2802
Renal disease		0.58 (0.50 to 0.68)	<.0001	0.74 (0.55 to 1.00)	0.0466
Dissection		0.71 (0.66 to 0.77)	<.0001	0.06 (0.05 to 0.08)	<.0001

Abbreviations: CI, confidence interval; COPD, chronic pulmonary disease; HES, hospital episodes statistics; IHD, ischemic heart disease; OR, odds ratio; PVD, peripheral vascular disease.

Table S7. Risk factors for 6-month mortality in patients receiving treatment for thoracic aortic disease and in those not receiving any thoracic aortic treatment (HES cohort)

Factor		Mortality in those receiving treatment		Mortality in those not receiving treatment	
	Value	OR (95% CI)	p value	OR (95% CI)	p value
Age	0-39	0.75 (0.51 to 1.10)	0.1407	0.45 (0.33 to 0.61)	<.0001
Age	40-44	0.37 (0.20 to 0.67)	0.0011	0.70 (0.50 to 0.98)	0.0351
Age	45-49	0.41 (0.24 to 0.71)	0.0014	0.49 (0.35 to 0.67)	<.0001
Age	50-54	0.60 (0.39 to 0.93)	0.0211	0.57 (0.43 to 0.75)	<.0001
Age	55-59	0.77 (0.55 to 1.08)	0.1307	0.72 (0.58 to 0.90)	0.0039
Age	60-64	0.93 (0.69 to 1.26)	0.6272	0.89 (0.74 to 1.08)	0.2349
Age	65-69	1		1	
Age	70-74	1.12 (0.85 to 1.46)	0.4236	1.32 (1.14 to 1.54)	0.0003
Age	75-79	1.35 (1.03 to 1.77)	0.0272	1.66 (1.44 to 1.92)	<.0001
Age	80-84	1.57 (1.14 to 2.16)	0.0057	2.03 (1.77 to 2.34)	<.0001
Age	85+	2.72 (1.71 to 4.32)	<.0001	2.85 (2.47 to 3.28)	<.0001
sex	Female	0.96 (0.81 to 1.13)	0.6129	0.79 (0.74 to 0.85)	<.0001
sex	Male	1		1	
Year	2004	1.38 (1.02 to 1.85)	0.0343	1.70 (1.50 to 1.94)	<.0001
Year	2005	1.84 (1.39 to 2.44)	<.0001	1.65 (1.46 to 1.88)	<.0001
Year	2006	1.20 (0.90 to 1.59)	0.2115	1.40 (1.23 to 1.58)	<.0001
Year	2007	1.20 (0.91 to 1.58)	0.2048	1.21 (1.07 to 1.37)	0.0021
Year	2008	1.16 (0.87 to 1.53)	0.3118	1.13 (1.00 to 1.27)	0.0445
Year	2009	0.97 (0.73 to 1.29)	0.8283	1.03 (0.92 to 1.16)	0.5994
Year	2010	1		1	
Elective adm	No	0.29 (0.24 to 0.34)	<.0001	0.26 (0.23 to 0.28)	<.0001
Elective adm	Yes	1		1	
Deprivation	1 (least deprived)	1		1	
Deprivation	2	1.11 (0.88 to 1.40)	0.3893	1.02 (0.91 to 1.14)	0.7717
Deprivation	3	1.18 (0.94 to 1.50)	0.1581	1.12 (1.00 to 1.25)	0.0413
Deprivation	4	1.20 (0.94 to 1.53)	0.1517	1.18 (1.05 to 1.32)	0.0047
Deprivation	5 (most deprived)	1.13 (0.86 to 1.49)	0.3757	1.11 (0.98 to 1.25)	0.0877
Atherosclerosis		1.73 (1.27 to 2.35)	0.0005	1.17 (0.99 to 1.38)	0.0658
Cancer		1.72 (1.31 to 2.27)	0.0001	1.65 (1.49 to 1.83)	<.0001
Congenital malformation circulatory disorders		0.88 (0.62 to 1.24)	0.4621	0.70 (0.51 to 0.94)	0.0188
COPD		1.37 (1.07 to 1.74)	0.0126	1.28 (1.17 to 1.40)	<.0001
Cerebrovascular disease		1.92 (1.50 to 2.46)	<.0001	1.25 (1.13 to 1.39)	<.0001
Diabetes		1.25 (0.95 to 1.65)	0.1103	1.06 (0.94 to 1.18)	0.3545
Hypertension		0.85 (0.71 to 1.00)	0.0508	0.93 (0.86 to 1.00)	0.0557
Ischaemic heart disease		1.45 (1.22 to 1.72)	<.0001	0.81 (0.75 to 0.87)	<.0001
Lipid disorders		0.77 (0.63 to 0.94)	0.0092	0.73 (0.66 to 0.80)	<.0001
Other aneurysm		1.05 (0.65 to 1.70)	0.8285	1.09 (0.85 to 1.39)	0.5058
Other aortic disease		1.17 (0.97 to 1.40)	0.0969	1.18 (1.07 to 1.29)	0.0008
Disorders of other arteries		0.92 (0.52 to 1.64)	0.7854	1.02 (0.68 to 1.53)	0.9235
Other congenital malformation		0.71 (0.38 to 1.34)	0.2933	0.68 (0.43 to 1.07)	0.096

Other IHD		1.00 (0.85 to 1.18)	0.9932	1.15 (1.07 to 1.23)	0.0002
Other PVD		1.28 (0.93 to 1.78)	0.1332	1.44 (1.25 to 1.66)	<.0001
Renal disease		2.11 (1.56 to 2.85)	<.0001	1.55 (1.38 to 1.73)	<.0001
Dissection		1.07 (0.88 to 1.30)	0.509	1.83 (1.69 to 1.98)	<.0001

Abbreviations: Adm, admission; CI, confidence interval; COPD, chronic pulmonary disease; HES, hospital episodes statistics; IHD, ischemic heart disease; OR, odds ratio; PVD, peripheral vascular disease.

Table S8. Baseline, operative and mortality details by most distal aortic segment (NACSA cohort)

Variables*	Root/Ascending Aorta (n = 6848)	Aortic Arch (n = 762)	Descending Aorta (n = 320)	Thoracoabdominal (n = 128)
Demographics				
Age at operation (years)	64 (51, 73)	68 (57, 74)	62 (45, 71)	63 (48, 70)
BMI (kg/m2)	26.9 (24.1, 30.1)	26.5 (23.8, 29.8)	26.1 (23.4, 29.3)	25.0 (21.8, 28.3)
Female gender	2216 (32.4)	308 (40.4)	117 (36.6)	50 (39.1)
Co-morbidities				
Unstable angina	332 (4.9)	29 (3.8)	7 (2.2)	4 (3.1)
NYHA ≥ III class	2075 (30.3)	165 (21.7)	58 (18.1)	18 (14.1)
MI within 90 days of operation	246 (3.6)	15 (2.0)	0 (0)	7 (5.5)
Previous cardiac surgery	984 (14.4)	121 (15.9)	113 (35.3)	34 (26.6)
Previous aortic surgery	199 (2.9)	59 (7.7)	60 (18.8)	17 (13.3)
Diabetes	487 (7.1)	44 (5.8)	14 (4.4)	8 (6.3)
Current smoker	749 (10.9)	90 (11.8)	46 (14.4)	22 (17.2)
Hypertension	4148 (60.6)	569 (74.7)	231 (72.2)	88 (68.8)
Creatinine > 200 (µmol/l)	190 (2.8)	22 (2.9)	7 (2.2)	5 (3.9)
History of renal dysfunction	106 (1.6)	19 (2.5)	6 (1.9)	3 (2.3)
History of pulmonary disease	783 (11.4)	111 (14.6)	47 (14.7)	33 (25.8)
History of stroke	558 (8.2)	80 (10.5)	19 (5.9)	4 (3.1)
Neurological dysfunction	252 (3.7)	38 (5.0)	14 (4.4)	2 (1.6)
Peripheral vascular disease	909 (13.3)	242 (31.8)	104 (32.5)	57 (44.5)
Non sinus cardiac rhythm	828 (12.1)	85 (11.2)	19 (5.9)	6 (4.7)
Triple vessel disease	318 (4.6)	35 (4.6)	6 (1.9)	12 (9.4)
Left main stem disease	138 (2.0)	8 (1.1)	2 (0.6)	4 (3.1)
Moderate LVEF (30-50%)	1418 (20.7	125 (16.4)	29 (9.1)	12 (9.4)
Poor LVEF (<30%)	308 (4.5)	17 (2.2)	3 (0.9)	0 (0)
PA systolic > 60mmHg	90 (1.3)	4 (0.5)	0 (0)	0 (0)
Pre-operative IV nitrates	324 (4.7)	60 (7.9)	19 (5.9)	8 (6.3)

Pre-operative IV inotropes	187 (2.7)	15 (2.0)	18 (5.6)	6 (4.7)
Pre-operative ventilation	138 (2.0)	15 (2.0)	13 (4.1)	0 (0)
Pre-operative cardiogenic shock	306 (4.5)	24 (3.2)	10 (3.1)	2 (1.6)
Operative details				
Non-elective priority	2438 (35.6)	317 (41.6)	141 (44.1)	45 (35.2)
Urgent priority	1076 (15.7)	127 (16.7)	64 (20.0)	28 (21.9)
Emergency priority	1249 (18.2)	177 (23.2)	68 (21.3)	16 (12.5)
Salvage priority	113 (1.7)	13 (1.7)	9 (2.8)	1 (0.8)
Concomitant CABG operation	1334 (19.5)	122 (16.0)	12 (3.8)	14 (10.9)
Concomitant valve operation	4963 (72.5)	326 (42.8)	24 (7.5)	6 (4.7)
Concomitant 'other' operation	2320 (33.9)	188 (24.7)	99 (30.9)	39 (30.5)
Dominant pathology				
Aneurysm	3800 (55.5)	410 (53.8)	138 (43.1)	74 (57.8)
Dissection	1410 (20.6)	269 (35.3)	93 (29.1)	47 (36.7)
Trauma	27 (0.4)	4 (0.5)	19 (5.9)	0 (0)
'Other'	1113 (16.3)	58 (7.6)	58 (18.1)	5 (3.9)
Data N/A	498 (7.3)	21 (2.8)	12 (3.8)	2 (1.6)
CPB time (minutes)	157 (116, 216)	205 (152, 266)	184 (78, 260)	164 (110, 227)
ACC time (minutes)	107 (79, 142)	112 (70, 156)	42 (0, 100)	27 (0, 117)
Circulatory arrest time (minutes)	25 (18, 33)	28 (18, 46)	36 (28, 57)	27 (15, 42)
Outcome				
In-hospital mortality	569 (8.3)	101 (13.3)	49 (15.3)	29 (22.7)

Abbreviations: ACC, aortic cross clamp time; CABG, coronary artery bypass grafting; CPB, cardiopulmonary bypass; LVEF, left ventricle ejection fraction; N/A, not available; NACSA, National Adult Cardiac Surgery Audit; NYHA, New York Heart Association; PA, pulmonary artery.

*Numerical data are expressed as median and interquartile range (IQR); categorical data as absolute number (percentage).

Table S9. Hospital volume tertiles by most distal aortic segment (calculated by mean 3 year annual activity) (NACSA cohort)

Tertiles of activity*	**Low volume**	**Medium volume**	**High volume**
	(n = 1308)	**(n = 2159)**	**(n = 4591)**
Category range for all aortic surgery	**0 to 31 operations**	**32 to 52 operations**	**53 or more operations**
Root / Ascending Aorta	1211 (92.6)	1798 (83.3)	3839 (83.6)
Aortic Arch	75 (5.7)	275 (12.7)	412 (9.0)
Descending Aorta	17 (1.3)	58 (2.7)	245 (5.3)
Thorocoabdominal Aorta	5 (0.4)	28 (1.3)	95 (2.1)

Half (median) of activity	**Lower half activity**	**Upper half activity**
	(n = 2254)	**(n = 5804)**
Category range for all aortic surgery	**0 to 38 operations**	**39 or more operations**
Root / Ascending aorta	1964 (87.1)	4884 (84.2)
Aortic Arch	214 (9.5)	548 (9.4)
Descending Thoracic Aorta	44 (2.0)	276 (4.8)
Thorocoabdominal Aorta	32 (1.4)	96 (1.7)

Abbreviations: NACSA, National Adult Cardiac Surgery Audit.

*Data are expressed in absolute numbers (percentage).

Tables S10. Unadjusted and adjusted in-hospital mortality rates by aortic procedure and hospital volume (NACSA cohort)*

	Low volume	Medium volume	High volume
Root / Ascending Aorta			
Observed mortality rate (%)	10.7	8.3	7.4
Unadjusted odds ratio (95% CI)	Reference	0.76 (0.60, 0.96)	0.67 (0.54, 0.83)
Adjusted odds ratio (95% CI)	Reference	0.75 (0.57, 0.98)	0.65 (0.51, 0.83)
Aortic Arch			
Observed mortality rate (%)	13.1	13.2	13.4
Unadjusted odds ratio (95% CI)	Reference	1.01 (0.52, 1.97)	1.02 (0.54, 1.93)
Adjusted odds ratio (95% CI)	Reference	1.28 (0.61, 2.65)	1.27 (0.63, 2.55)
Descending Aorta			
Observed mortality rate(%)	20.0	28.1	11.8
Unadjusted odds ratio (95% CI)	Reference	1.56 (0.50, 4.87)	0.53 (0.19, 1.53)
Adjusted odds ratio (95% CI)	Reference	2.36 (0.64, 8.76)	0.75 (0.23, 2.48)
Thorocoabdominal Aorta			
Observed mortality rate (%)	14.3	28.6	22.6
Unadjusted odds ratio (95% CI)	Reference	2.40 (0.41, 14.11)	1.75 (0.36, 8.44)
Adjusted odds ratio (95% CI)	Reference	2.28 (0.35, 14.65)	2.19 (0.42, 11.50)

Abbreviations: CI, confidence interval; NACSA, National Adult Cardiac Surgery Audit.

*Hospital volume was calculated by mean of the last 3 year annual activity and subdivided for tertiles of activity.

Table S11. Characteristics of the studies included in the systematic review

Study (Author, Year)	Design	Country (Source)*	Sample size	Study period	Inclusion criteria	Exclusion criteria	Outcomes	Aortic centre configuration	Hospital Volume Threshold (cases/yr)
Shaffer et al,[12] 2015	Retrospective cohort study, Multicenter	USA (MEDPAR)	5578	1999-2010	Open descending thoracic aorta and thoracoabdominal repair		Postoperative survival	No	LV:<50† MV: 50-200 HV:>200
Shaffer et al,[13] 2015	Retrospective cohort study, Multicenter	USA (MEDPAR)	11996	2005-2010	TEVAR		Postoperative survival	No	LV:<20† MV: 20-99 HV:≥100
Bhatt et al,[14] 2015	Retrospective cohort study, Multicenter	USA (NIS)	105	2000-2011	TEVAR in adult aortic coarctation		Vascular complications (vascular injury, hemorrhage requiring transfusion, aortic dissection, arteriovenous fistula, accidental puncture, other vascular complications), any cardiac complications, open vascular/cardiac surgery, stroke/TIA, any respiratory complications, PE/DVT, anaesthetic complications, infection	NO	LV:<3 HV:≥3
Brat et al,[15] 2015	Retrospective cohort study, Monocenter	Czech Republic (Inst.Dat.)	30	1999-2013	Elective aortic arch aneurysm	Acute operation and aortic dissection	30-day/in-hospital mortality, postop complications (permanent/transient neurological deficit,	No	NA

							haemodialysis, reoperation for bleeding, postoperative blood loss, intubation), LOS		
Grau et al,[16] 2015	Retrospective case controlled, Monocenter	USA (Inst.Dat.)	54	2002-2013	Acute type A aortic dissection		In-hospital mortality, postop complications (cardiac arrest, stroke, ARF, reoperation for bleeding, AF, prolonged intubation), LOS,	Yes	NA
Lenos et al,[17] 2015	Retrospective cohort study, Monocenter	Germany (Inst.Dat.)	162	2002-2013	Acute type A aortic dissection		30-day/in-hospital mortality, 90-day mortality, new permanent neurological deficit, adverse outcome	No	NA
Iribarne et al,[18] 2015	Retrospective cohort study, Multicenter	USA (NIS)	1230	2005-2008	Acute aortic dissection	Non-emergent pts, pts<18 yr, TEVAR	In-hospital mortality, postop complications (AMI, stroke, ARF, pneumonia, septicaemia), LOS, discharge disposition, hospitalization costs	No	LV: ≤ 5 MV: 6-10 HV: >10
Murzi et al,[19] 2015	Retrospective cohort study, Monocenter	Italy (Inst.Dat.)	867	2003-2013	Aortic root, ascending and aortic arch surgery	Descending and thoraco-abdominal aortic surgery	In-hospital mortality, postop complications (AMI, stroke, ARF, reoperation for bleeding, pneumonia, pulmonary complications, delirium, postop aortic dissection, postop AF, renal dysfunction, infective, AV block,	No	NA

							septicaemia, myocardial infarction)		
Andersen et al,[20] 2014	Retrospective case controlled, Monocenter	USA (Inst.Dat.)	128	1999-2011	Acute type A aortic dissection	Iatrogenic dissection	30-day/in-hospital mortality, 30 day/in-hospital postop complications (AMI, stroke, ARF, reoperation for bleeding, prolonged ventilation, delayed sternum closure, DSWI, new-onset dialysis, tracheostomy), surgeon-specific mortality rates, LOS, postoperative survival	Yes	NA
Sales et al,[21] 2014	Retrospective case controlled, Monocenter	Brazil (Inst.Dat.)	332	2003-2010	Thoracic aortic surgery, TAAA surgery		In-hospital mortality, postop complications (AMI, stroke, ARF, reopening for bleeding, pneumonia, mediastinitis, AV block, arrhythmia, sepsis, myocardial ischemia, pleural effusion, low cardiac output), LOS	Yes	NA
Weiss et al,[22] 2014	Retrospective cohort study, Multicenter	USA (OSHPD)	1188	1995-2010	TAAA	TAA, AAA, pts < 18 yr	In-hospital mortality, postop complications (AMI, stroke, ARF, prolonged intubation, ARDS, infection, sepsis, paraplegia)	No	LV: <9 HV: ≥9
Patel et al,[23] 2013	Retrospective cohort study,	USA (MEDPAR)	7071	2004-2007	TAA-descending (intact)	TAA ruptured, TAAA, aortic	30-day mortality, postop complication	No	*Open surgery:*

	Multicenter					dissection, ascending aortic aneurysm, concomitant cardiac procedures, use of cardioplegia, use of HCA	(ARF, reopening for bleeding, cardiac, infectious, pulmonary, graft), 1-/3-/5-year postoperative survival		LV: ≤8 HV:>8 *TEVAR:* LV: ≤8 HV:>8
Arnaoutakis et al,[24] 2013	Retrospective cohort study, Multicenter	USA (NIS)	1865	2005-2009	TAAA (intact)	Ruptured-traumatic-mycotic-syphilitic aneurysms, patients <18 yr or pts > 99 yr	In-hospital mortality, postop complications (cardiac, AMI, nervous, ARF, bleeding, paralysis, respiratory, digestive, visceral vascular, bowel resection, renal, seroma, wound, infectious), hospital charges	No	LV: 1 MV: 1-5 HV: 5-33
Chikwe et al,[25] 2013	Retrospective cohort study, Multicenter	USA (NIS)	5184	2003-2008	Acute aortic dissection	Lack of surgeon identification	In-hospital mortality‡	No	Lowest:<3 Low:>3-8 High:>8-13 Highest:>13
Goodney et al,[26] 2013	Retrospective cohort study, Multicenter	USA (MP/Sf & MDf)	15305	1998-2007	TAA-Descending	Aortic dissection, TAA ascending, TAAA, use of CPB with HCA, debranching procedures, procedures to extend endovascular landing zone	30-day mortality, 1-year mortality and 5-year mortality	No	*Open surgery:* Lowest: 1-4 LV: 5-8 MV: 9-15 HV: 16-46 Highest:>46 *TEVAR:* Lowest: 0-1 LV: 2-3 MV: 4-8 HV: 9-17 Highest:>18

Soppa et al,[27] 2013	Retrospective cohort study, Monocenter	UK (Inst.Dat.)	163	2005-2011	Aortic root dilatation	Marfan	In-hospital mortality, postop complications (stroke, temporary hemofiltration, reopening for bleeding), LOS, follow-up (late dilatation, late reoperations, late death)	Yes	NA
Tsagakis et al,[28] 2013	Retrospective cohort study, Monocenter	Germany (Inst.Dat.)	124	2004-2011	Acute type A aortic dissection	Pts died preoperatively	30-day mortality, postop complications (stroke, temporary hemofiltration, reopening for bleeding, malperfusion, laparotomy, peripheral surgery)	Yes	NA
Hughes et al,[29] 2013	Retrospective cohort study, Multicenter	USA (STS)	13358	2004-2007	TAA-ascending/ Aortic root	Aortic dissection, non-elective cases	30-day/in-hospital mortality, postop complications (stroke, ARF, reopening for bleeding, prolonged ventilation)	No	Lowest:<6 Low: 6-13 MV:13-30 HV: 30-100
Sakata et al,[30] 2012	Retrospective cohort study, Multicenter	Japan (JATS)	14095	2005-2009	Acute type A aortic dissection		30-day mortality	No	Lowest:1-4 Low: 5-9 MV: 10-14 High: 15-19 Highest: ≥20
Chavanon et al,[31] 2011	Retrospective cohort study, Monocenter	France (Inst.Dat.)	380	1990-2009	Acute type A aortic dissection	Iatrogenic dissection, chronic dissection, recurrent dissection	In-hospital mortality	Yes	NA

Gopaldas et al,[32] 2010	Retrospective cohort study, Multicenter	USA (NIS)	923	2006-2008	TAA-descending (ruptured)	Vasculitis, connective tissue disorders, aortic dissection, concomitant aneurysm, patients treated with both open surgery and TEVAR	In-hospital mortality, postop complications (hemopericardium, open cardiac massage, procedure-related complications, deep venous thrombosis, infections, mediastinitis, neurologic complications, pneumothorax, respiratory complications, renal complications, disposition), LOS	No	LV§ HV
Harris et al,[33] 2010	Retrospective case controlled, Monocenter	USA (Inst.Dat.)	101	2003-2009	Acute aortic dissection	Iatrogenic dissection	In-hospital mortality, time from presentation or diagnosis to OR	Yes	NA
Davies et al,[34] 2010	Retrospective case controlled, Monocenter	USA (Inst.Dat.)	621	2007-2008	Acute aortic dissection, symptomatic TAA and TAAA, AAA	IMH, aortic ulcers, chronic aneurysms and dissections	In-hospital mortality, postop complications (AMI, ARF, respiratory failure, pulmonary embolisms, pneumonia, cardiovascular accident, spinal cord ischemia, arrhythmia, bowel ischemia, blood transfusion units [n], coagulopathy), LOS, time to therapy	Yes	NA
Gazoni et al,[35] 2010	Retrospective cohort study,	USA (NIS)	731	2004-2007	Elective TAA+TAAA		30-day/in-hospital mortality, postop	No	LV: ≤39 HV: ≥83

	Multicenter						complications (stroke, ARF, reopening for bleeding, prolonged ventilation, pneumonia), LOS, hospital discharge		
Miyata et al,[36] 2009	Retrospective cohort study, Multicenter	Japan (JACVSD)	2875	2003-2005	Thoracic aortic surgery including combined CABG, valve surgery or other surgical operations	Hospitals <5 procedures/yr, center with incomplete submission data	30-day/in-hospital mortality	No	LV: 5-20¶ MV: 20-40 HV: >40
Schermerhorn et al,[37] 2008	Retrospective cohort study, Multicenter	USA (NIS)	2549	1988-2003	TAA-descending	TAAA, AA, use of cardioplegia, hypothermia, cardiac surgery debranching of epiaortic vessels, intrathoracic bypass, pts<18yr	In-hospital mortality, postop complications (cardiac, stroke, ARF, respiratory, neuro non-stroke), LOS	No	LV: 1 [1,1]** MV: 2 [2,3] HV: 4 [3,25]
Knipp et al,[38] 2007	Retrospective cohort study, Multicenter	USA (NIS)	3013	1995-2003	Acute type A aortic dissection		In-hospital mortality	No	LV: <1 MV: 1-2.5 HV: >2.5
Kazui et al,[39] 2007	Retrospective cohort study, Multicenter	Japan (JATS)	10097	2000-2004	Acute type A aortic dissection		30-day mortality	No	Lowest:1-4 Low: 5-9 MV: 10-14 High: 15-19 Highest: ≥20
Rigberg et al,[40] 2006	Retrospective cohort study, Multicenter	USA (OSHPD)	1010	1991-2002	TAAA	Aortic dissections	30-day mortality, 31-365 days mortality, 1-year mortality	No	LV: 1 MV: 2-7 MV: 7-14

Narayan et al,[41] 2004	Retrospective cohort study, Monocenter	UK (Inst.Dat.)	296	1992-2003	Ascending and aortic arch (+ concomitant cardiac surgeries)		30-day/in-hospital mortality, postop complications (IABP, reopening for bleeding, rewiring, neurological complication [transient, permanent], renal complication), LOS, 1-/3-year postoperative survival	No	NA
Cowan et al,[42] 2003	Retrospective cohort study, Multicenter	USA (NIS)	1542	1988-1998	TAAA (intact)	TAAA ruptured, aortic dissections	In-hospital mortality, postop complications (cardiac, ARF, pulmonary, urinary tract, hemorrhage), LOS	No	LV: 1 [1,3]** MV: 4 [2,9] HV: 12 [5,31]
Derrow et al,[43] 2001	Retrospective cohort study, Multicenter	USA (NIS)	2934 (TAAA, n=540)	1993-1997	TAAA (intact), renal artery bypass, chronic mesenteric ischemia	TAAA ruptured	In-hospital mortality, postop complications, LOS, discharge disposition, hospital charges	No	LV§ HV
Albrink et al,[44] 1994	Retrospective case controlled, Monocenter	USA (Inst.Dat.)	30	1986-1990	Blunt thoracic aortic transection		In-hospital mortality, postop complications (ARF, paraplegia, pneumonia/sepsis, paraparesia, recurrent laryngeal nerve injury, arrhythmia, chylothorax)	Yes	NA

Abbreviations: AAA, abdominal aortic aneurysm; AF, atrial fibrillation; AMI, acute myocardial infarction; ARDS, acute respiratory distress syndrome; ARF, acute renal failure; AV, atrio-ventricular; CPB, cardiopulmonary bypass; DSWI, deep sternal wound infection; DVT, deep venous thrombosis; HCA, hypothermic circulatory arrest; HV, high volume hospital; IABP, intra-aortic balloon pump; IMH, intramural hematoma; Inst.Dat., Institutional Database; LOS, length of stay; LV, low volume hospital; MV, medium volume hospital; NA, not available; OR, operating room; PE, pulmonary embolism; TAA, thoracic aorta aneurysm; TAAA, thoracoabdominal aneurysm; TEVAR, thoracic endovascular aortic repair.

*Data source: JATS=Japanese Association for Thoracic Surgery. JACVSD=Japan Adult Cardiovascular Surgery Database. MEDPAR=Medicare Provider Analysis and Review. MP/Sf & MDf=Medicare Physician/Supplier file and Medicare Denominator file. NIS=Nationwide Inpatient Sample. OSHPD=California Office of Statewide Health Planning and Development. STS-ACSD=Society of Thoracic Surgeons Adult Cardiac Surgery Database. VCSQI=Virginia Cardiac Quality Initiative.

†Volume activity defined over the entire study period.

‡Major postoperative complications listed, but no comparison was made with reference to the hospital or surgeon volume or hospital location or teaching status.

§Not specified the threshold (cases/year); general definition of LV (vs MV) vs HV hospital only.

¶Low volume thoracic aortic center performing <5 case/yr excluded (n=2 hospitals).

**Defined as median [range] of cases.

Table S12. Study outcomes stratified by hospital and surgeon volume

Study (Author, Year)	High-Volume (HV)			Low-Volume (LV)			Mortality (%)		Re-exploration bleeding/ tamponade (%)		Stroke (%)		Acute renal failure (%)		Perioperative MI (%)		LOS (days)	
	Age (yr)	Female (%)	Pts	Age (yr)	Female (%)	Pts	HV	LV	HV	LV	HV	LV	HV	LV	HV	LV	HV	LV
Hospital volume																		
Iribarne et al,[18] 2015	58.7 (16.2)	33.1	124	59.5 (14.6)	32.6	798	12.1	23.4*			9.7	9.5	20.2	30.3*	0.8	5.5*	13.9 (11.7)	14.9 (15.4)
Weiss et al,[22] 2014		49.2	479		42.6	709	20.4	25.2			7.9	2.6*	28.4	22.4*	12.5	13.0*		
Patel et al,[23] 2013 (open repair)	72 (8.1)	49.0	1772	72 (8.1)	51.0	1782	11.0	15*	17.0	16.0			20.0	17.0				
Patel et al,[23] 2013 (TEVAR)	75 (7.9)	42.0	1758	75 (7.7)	43.0	1759	5.5	3.9	13.0	11.0			6.9	5.3				
Chikwe et al,[25] 2013			1379			1312	16.4	27.4*										
Hughes et al,[29] 2013	59.9	29.2	3404	60.9	30.9	3331	3.4	5.8*			1.9	2.3	4.6	5.7				
Sakata et al,[30] 2012			2779			3051	9,7	16.1*										
Gazoni et al,[35] 2010	62.5		515	61.0		216	3.7	8.3*	5.4	7.9	4.8	1.4*	4.5	8.3			8.5 (10.1)	11.6 (17.0)*
Miyata et al,[36] 2009	69 (58-75)	30.9	1398	69 (61-75)	36.4	481	4.4	9.6*										
Schermerhorn et al,[37] 2008	68 (18-92)	42.2	1262	68 (21-89)	43.1	685	15.5	21.7*			3.2	2.3	9.8	10.8			19 (1-330)	15 (15-176)*
Kazui et al,[39] 2007			541			3085	7.9	18.5*										

Cowan et al,[42] 2003	68.3 (9.2)	42.0	506	68.5 (9.9)	40.0	569	15.0	27.3*	10.3	14.8			13.0	12.3*				
Derrow et al,[43] 2001	69.5 (8.8)		403	69.2 (5.9)		17	18.2	25.0									19.3 (18.9)	21.9 (20.1)
Surgeon Volume																		
Lenos et al,[17] 2015	62 (15)	34.7	75	63 (14)	32.2	87	4.0	21.8*			2.7	11.5*						
Murzi et al,[19] 2014		27.6	460		31.7	407	3.7	2.2	9.6	11.3	2.6	2.5	8.7	10.1	2.2	1.5		
Andersen et al,[20] 2014	54 (14)	28.0	72	58 (15)	30.0	56	2.8	33.9*	4.2	33.9*	5.6	12.5	16.7	26.8	1.4	1.8	12 (12)	10 (12)
Chikwe et al,[25] 2013			938			1130	17.0	27.5*										
Narayan et al,[41] 2004	64 (52-72)	29.2	130	60 (47-68)	29.5	166	10.8	13.9	7.7	7.8	3.8	4.8						
Albrink at al,[44] 1994	36.1	13.0	15	35.9	17.0	12	7.0	50*					6.7	41.7*				

Abbreviations: LV, low volume; LOS, length of hospital stay; HV, high volume; SD, standard deviation; TEVAR, thoracic endovascular aortic repair.

Values are expressed as mean (±SD) or median (with interquartile range or normal range) for numerical variables, and percentage for categorical variables

*P-value <0.05 for comparison between LV *versus* HV hospital/surgeon.

Table S13. Study outcomes for study with defined a specific thoracic aortic program

Study (Author, Year)	Post-Thoracic Program			Pre-Thoracic Program			Mortality (%)		Re-exploration bleeding/ tamponade (%)		Stroke (%)		Acute renal failure (%)		Myocardial infarction (%)		LOS (days)	
	Age	Female %	Pts	Age	Female %	Pts	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre
Grau et al,[16] 2015	62 (12)	22.7	38	63 (12)	50*	16	7.9	12.5	21.2	6.3	2.6	6.3	7.9	6.3			8.2 (6)	13.5 (11)*
Andersen et al,[20] 2014	54 (14)	28.0	72	58 (15)	30.0	56	2.8	33.9*	4.2	19.6*	5.6	12.5	16.7	26.8	1.4	1.8	12 (12)	10 (12)
Sales et al,[21] 2014	60 (15)	49.0	175	56 (13)*	51.0	157	9.7	23*	14.3	20.4	4.6	10.9*	2.3	1.9	1.7	1.9	14.8 (14.2)	14.4 (12.8)
Davies et al,[34] 2010	69 (12)	28.0	173	70 (13)	23.0	133	6.0	4.0			9	7	21	14	2	2	10 (6)	11 (8)
Harris et al,[33] 2010	64 (17)	48.0	71	64 (18)	27.0	30	26.8	33.3										
Albrink et al,[44] 1994	36.1	13.0	15	35.9	17.0	12	7.0	50*					6.7	41.7*				

Abbreviations: LOS, length of hospital stay; SD, standard deviation.

Values are expressed as mean (±SD) for the numerical variables, and percentage for the categorical variables.

*P-value <0.05 for comparison between pre-thoracic and post-thoracic program introduction.

Table S14. Quality assessment of observational studies according to the Newcastle-Ottawa Scale

Study* (Author, Year)	Selection	Comparability	Outcome	Exposure	*Total*
Cohort Studies					
Schaffer et al,[12] 2015	4	2	3	-	*9*
Schaffer et al,[13] 2015	4	2	3	-	*9*
Bhatt et al,[14] 2015	4	2	3	-	*9*
Brat et al,[15] 2015	2	1	1	-	*4*
Lenos et al,[17] 2015	3	2	2	-	*7*
Iribarne et al,[18] 2015	4	2	2	-	*8*
Murzi et al,[19] 2014	4	0	1	-	*5*
Weiss et al,[22] 2014	4	0	2	-	*6*
Patel et al,[23] 2013	4	2	2	-	*8*
Arnaoutakis et al,[24] 2013	4	1	2	-	*7*
Chikwe et al,[25] 2013	4	1	2	-	*7*
Goodney et al,[26] 2013	4	2	2	-	*8*
Soppa et al,[27] 2013	4	2	3	-	*9*
Tsagakis et al,[28] 2013	3	0	1	-	*4*
Hughes et al,[29] 2013	4	2	2	-	*8*
Sakata et al,[30] 2012	4	1	2	-	*7*
Chavanon et al,[31] 2011	3	0	2	-	*6*
Gopaldas et al,[32] 2010	4	2	2	-	*8*
Gazoni et al,[35] 2010	4	2	2	-	*8*
Miyata et al,[36] 2009	4	1	2	-	*7*
Schermerhorn et al,[37] 2008	4	2	2	-	*8*
Knipp et al,[38] 2007	4	1	2	-	*7*
Kazui et al,[39] 2007	4	1	2	-	*7*
Rigberg et al,[40] 2006	4	2	3	-	*9*
Narayan et al,[41] 2004	3	2	2	-	*7*
Cowan et al,[42] 2003	4	2	3	-	*9*
Derrow et al,[43] 2001	4	0	2	-	*6*
Mean score	*3.8*	*1.4*	*2.1*	-	*7.3*
Case Controlled Studies					
Grau et al,[16] 2015	2	2	-	3	*7*
Andersen et al,[20] 2014	2	2	-	3	*7*
Sales et al,[21] 2014	2	0	-	2	*4*
Harris et al,[33] 2010	2	2	-	3	*7*
Davies et al,[34] 2010	2	2	-	3	*7*
Albrink et al,[44] 1994	1	1	-	1	*3*
Mean score	*1.8*	*1.5*	-	*2.5*	*5.8*

*A study can be awarded a maximum of 4 points for the Selection category, 2 points for the comparability category and 3 points for the Outcome/Exposure categories. Therefore the maximum points a study can obtain is 9 which indicates a high quality study.

Table S15. List of variables included in the final multivariable model

Study* (Author, Year)	Adjustement perorfemed	Variables included in the final model	Reference	Adjusted OR (95% CI)
Iribarne et al,[18] 2015	Binary logistic regression	Charlson comorbidity score*	LV	0.47 (0.27 to 0.82)
Weiss et al,[22] 2014	Binary logistic regression	Age, sex, race, admission year, Charlson comorbidity index*, aneurysm rupture, elective repair, HV centers with ≥ 9 cases per year	LV	0.40 (0.17 to 0.96)
Hughes et al,[29] 2013	Binary logistic regression	Age, LVEF, BSA, serum creatinine, time trend, active endocarditis, need for dialysis, atrial fibrillation, female gender, hypertension, immunosuppressive treatment, presence of an IABP, inotrope use, peripheral vascular disease, unstable angina (no myocardial infarction<7 days), left main disease, aortic stenosis, aortic insufficiency, mitral stenosis, mitral insufficiency, tricuspid insufficiency, chronic lung disease, cerebrovascular disease or cerebrovascular accident, diabetes, number of diseased coronary vessels, MI, race, admission status, congestive heart failure, NYHA class, reoperation, and concomitant CABG	LV	0.42 (0.31 to 0.58)
Chikwe et al,[25] 2013	Binary logistic regression (4 distinct model including: i) annual thoracic aortic dissection surgeon volume; ii) annual thoracic aortic dissection institution volume; iii) annual total cardiac surgeon volume; iv) annual total cardiac institution volume)	Age, sex, race, payer status, anemia, coagulopathy, congestive heart failure, chronic pulmonary disease, obesity, renal failure, cerebrovascular disease, hypertension, peripheral vascular disease, valve disorders, diabetes, ischemic heart disease, previous cardiac surgery, concomitant CABG, smoking history, hospital location, hospital bed size, and teaching status, annual thoracic annual thoracic aortic dissection surgeon volume, the second model included annual thoracic aortic dissection institution volume, the third model included annual total cardiac surgeon volume, and the fourth model included annual total cardiac institution volume	HV	2.21 (1.72 to 2.86)
Patel et al,[23] 2013	Binary logistic regression	n/a	HV (open repair)	1.4 (1.1 to 1.8)
Gazoni et al,[35] 2010	Binary logistic regression	n/a	LV	0.41 (0.18 to 0.92)

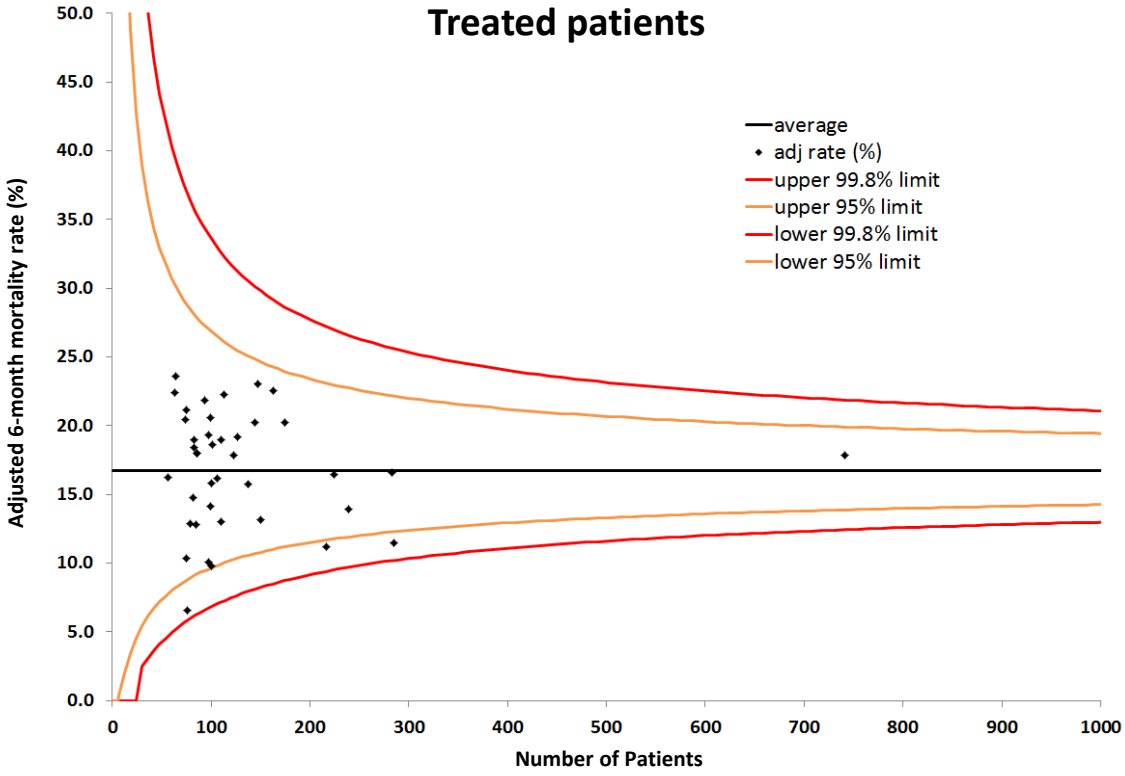
Miyata et al,[36] 2009	Hierarchical mixed-effects logistic regression model	clinical risk factors, procedure year, clinical events (beta-blocker usage), range of replacement (root, ascending, arch, distal aorta, descending, thoracoabdominal, abdominal) hospital procedural volume, and surgeon volume were set as fixed effects, and sites were used as random intercepts	LV	0.989
Shermerhorn et al,[37] 2008	Binary logistic regression with and without comorbidities	Comorbidities	HV	1.3 (1.1 to 1.6)
Cowan et al,[42] 2003	Binary logistic regression	n/a	HV	2.2 (1.6 to 3.1)

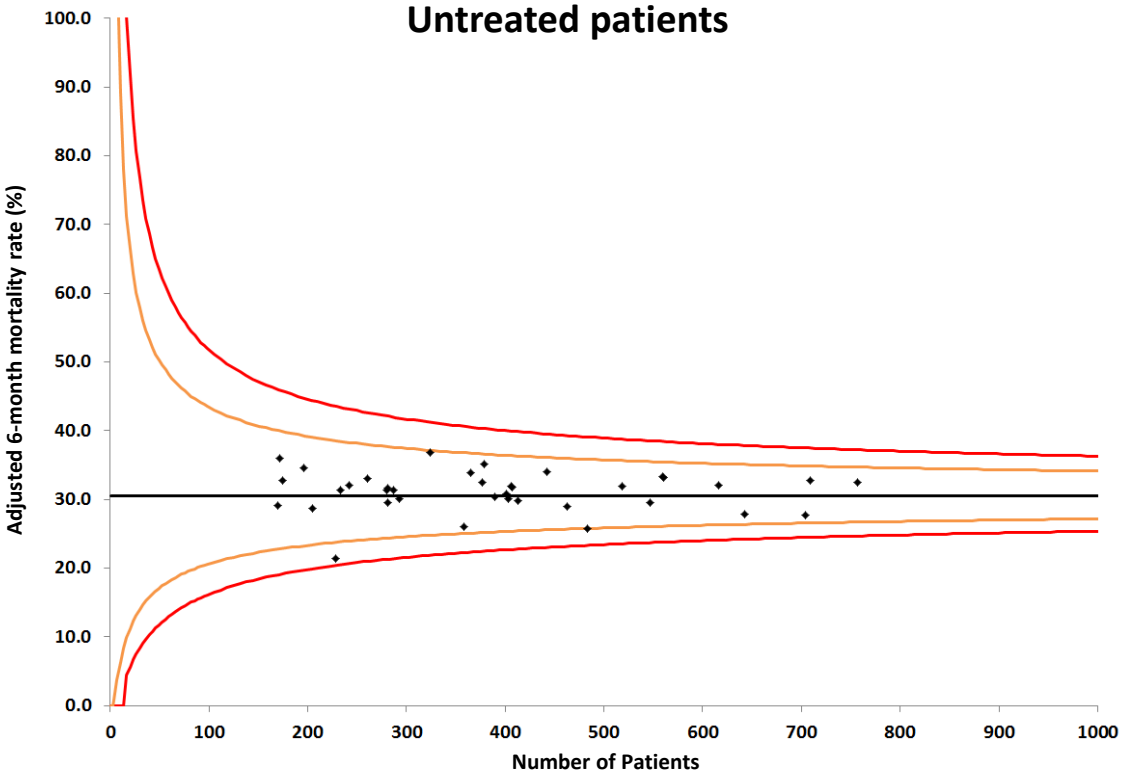
Abbreviations: BSA, body surface area; CABG, coronary artery bypass grafting; CI, confidence interval; HV, high volume; IABP, intra-aortic balloon pump; LV, low volume; n/a, not available; NYHA, New York Heart Association; OR, Odds ratio.

*List of variables defined in Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chron Dis 1987;40:373-83.

Supplemental Figures

Figure S1. Adjusted six-month mortality in patients affected by TAD receiving an operation (treated) and in those who did not (untreated) by county (HES cohort)





Abbreviations: adj, adjusted; TAD, thoracic aortic disease.

Figure S2. Centre activity by the most distal aortic segment (NACSA dataset)

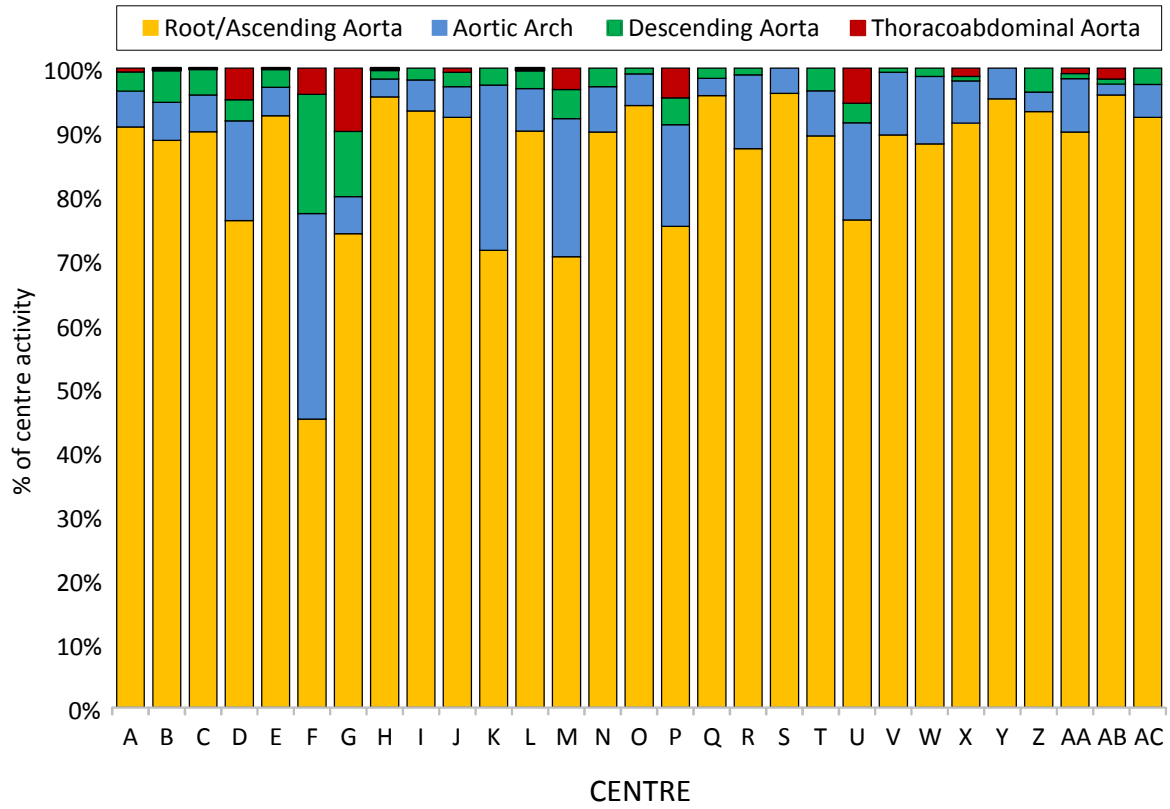
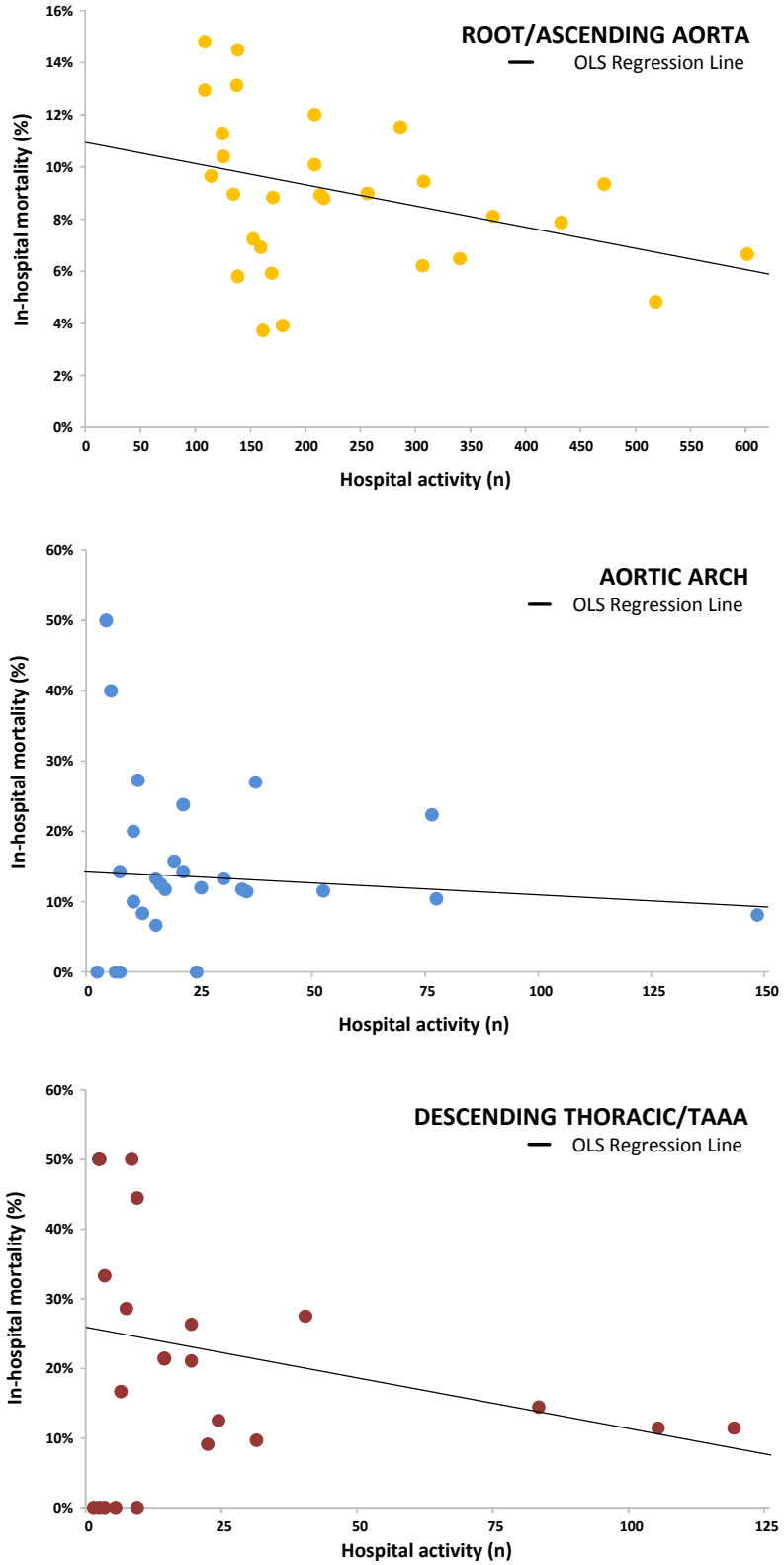


Figure S3. Correlation between the hospital activity (number of cases) and in-hospital mortality (NACSA dataset)



For the regression line in the root and ascending category, r^2=0.13, in the aortic arch category r^2=0.01. Because of the small number in each sub-groups, and for the purposes of the present analysis descending thoracic and thoracoabdominal procedures were grouped together, leaving a r^2 value of 0.07. In all of the categories, the OLS regression lines indicate that a trend towards decreasing mortality was observed in centres with HV activity. Abbreviations: HV, high volume (centre); OLS=ordinary least squares.

Figure S4. PRISMA flow chart of search strategy[11]

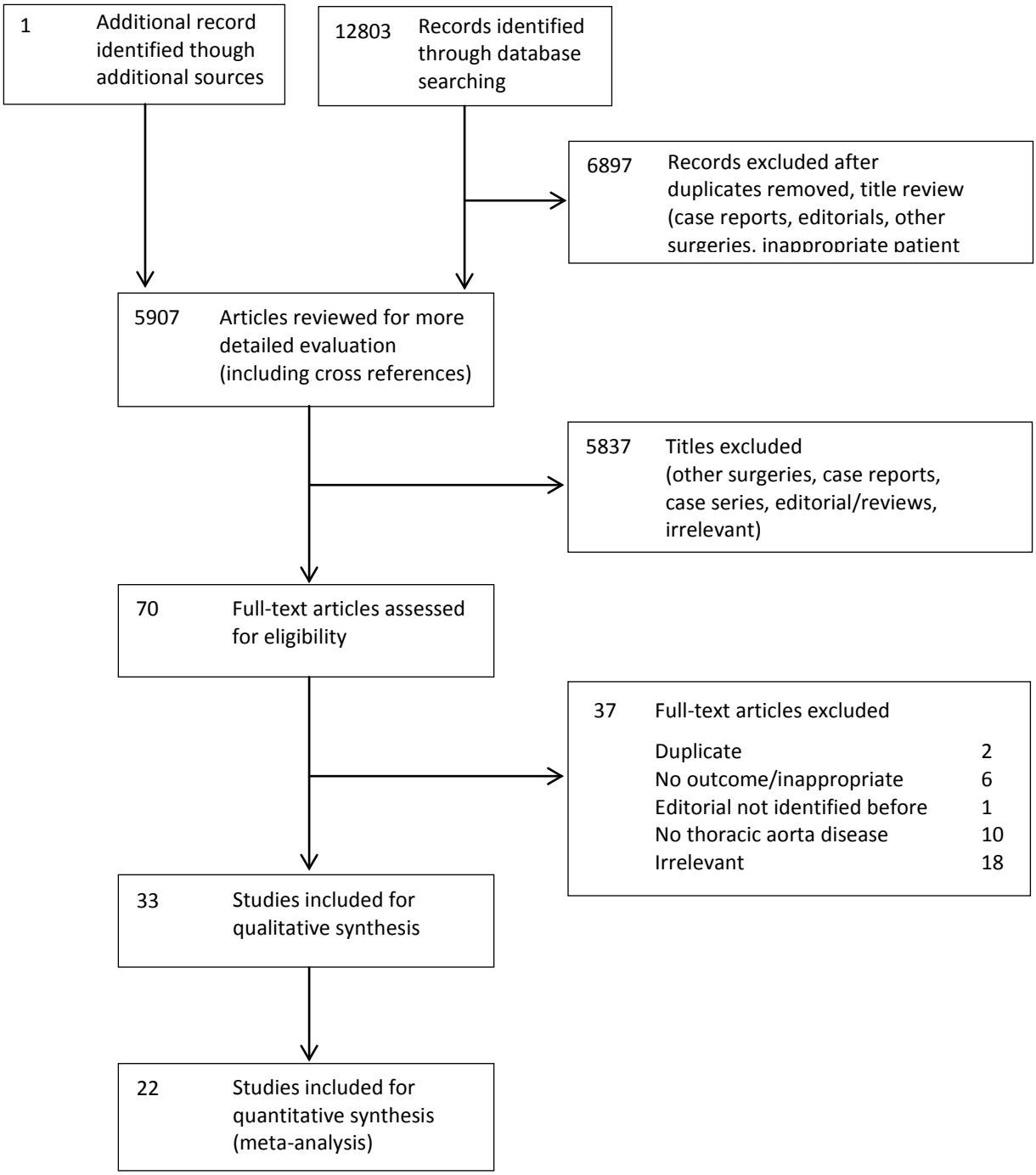


Figure S5. Funnel plots showing the absence of publication bias

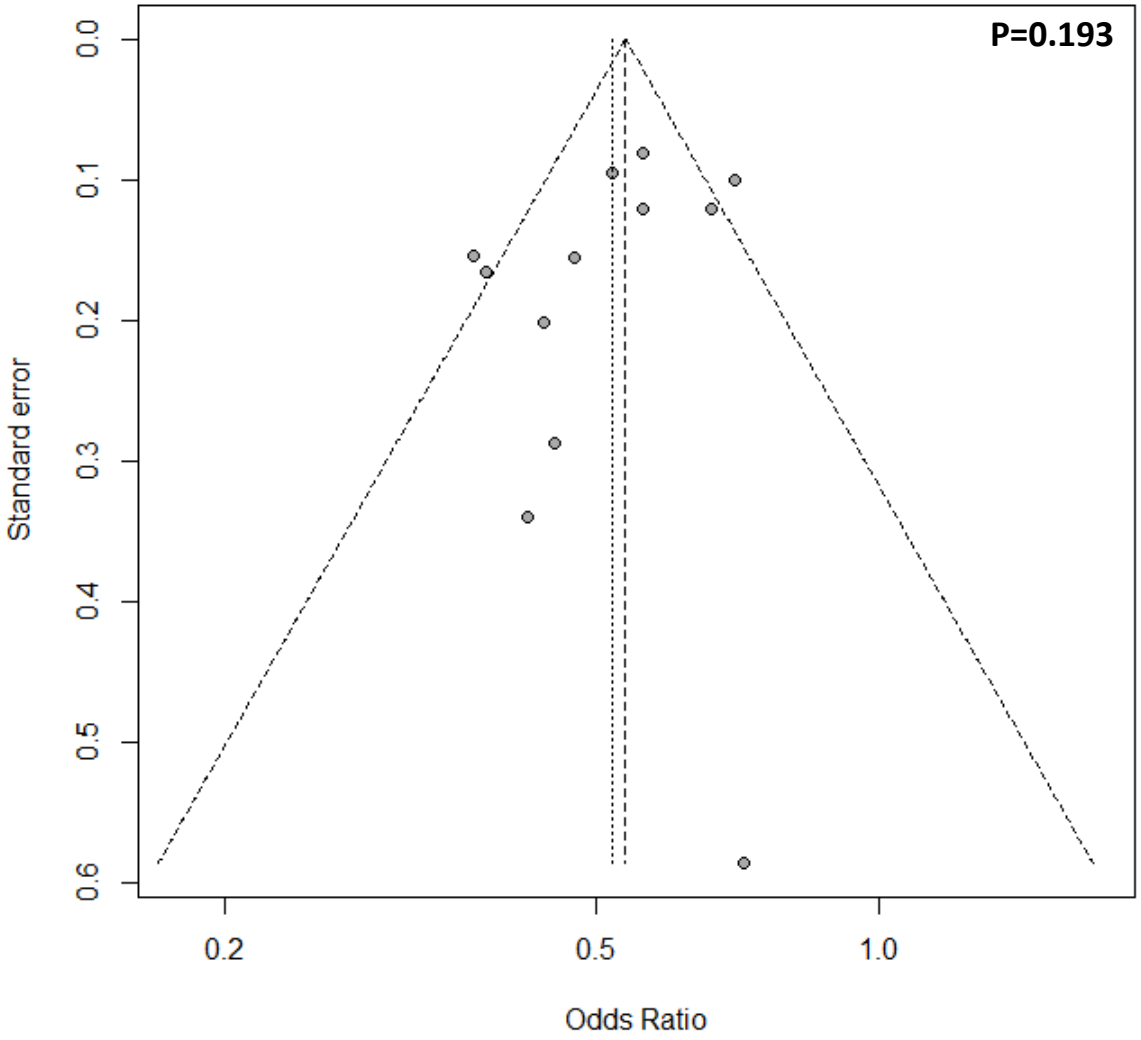
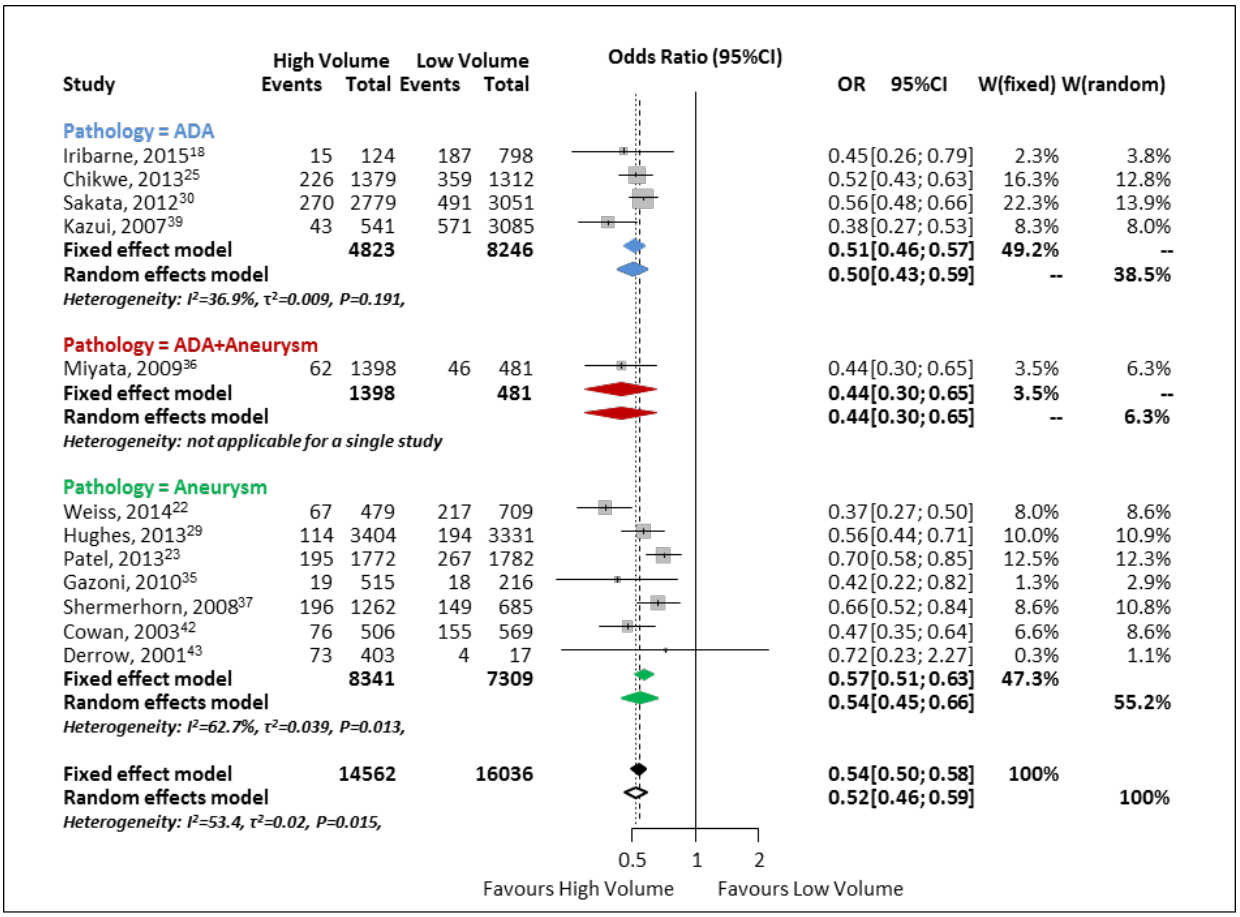
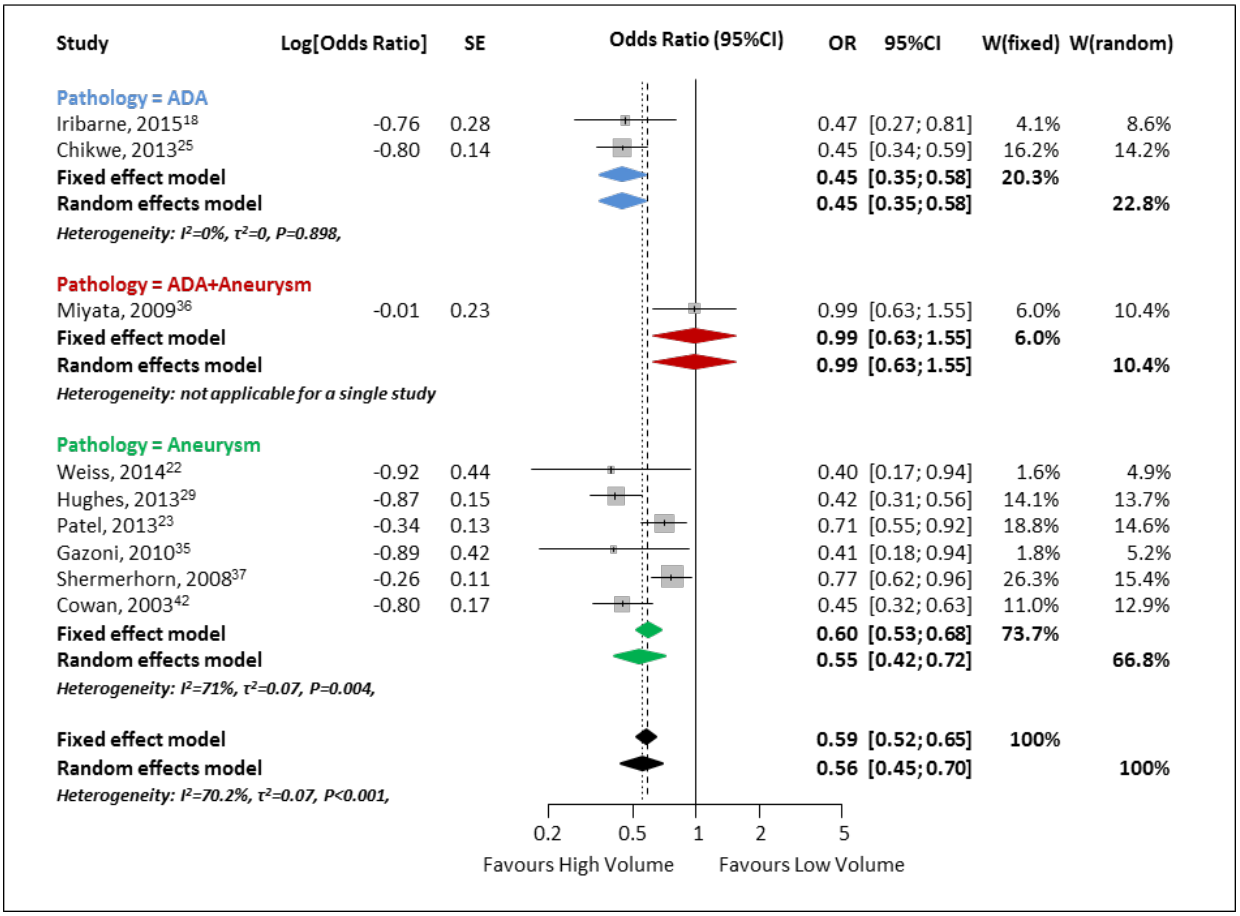


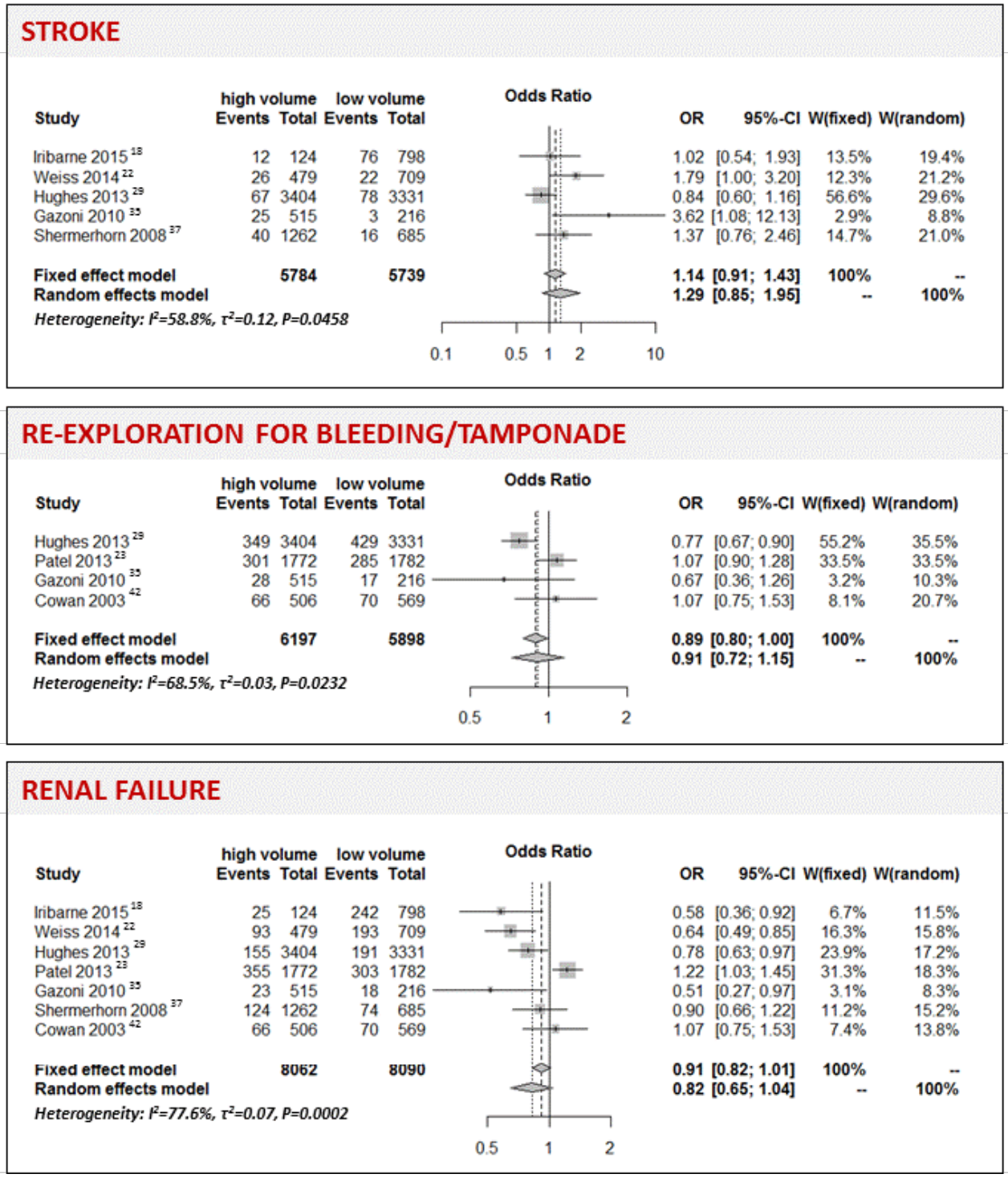
Figure S6. Forest plot for high-volume *versus* low-volume hospitals on operative mortality according to the primary aortic pathology (upper panel), and forest plot reporting risk adjusted estimates for high- *versus* low-volume hospitals on operative mortality according to the primary aortic pathology (lower panel)





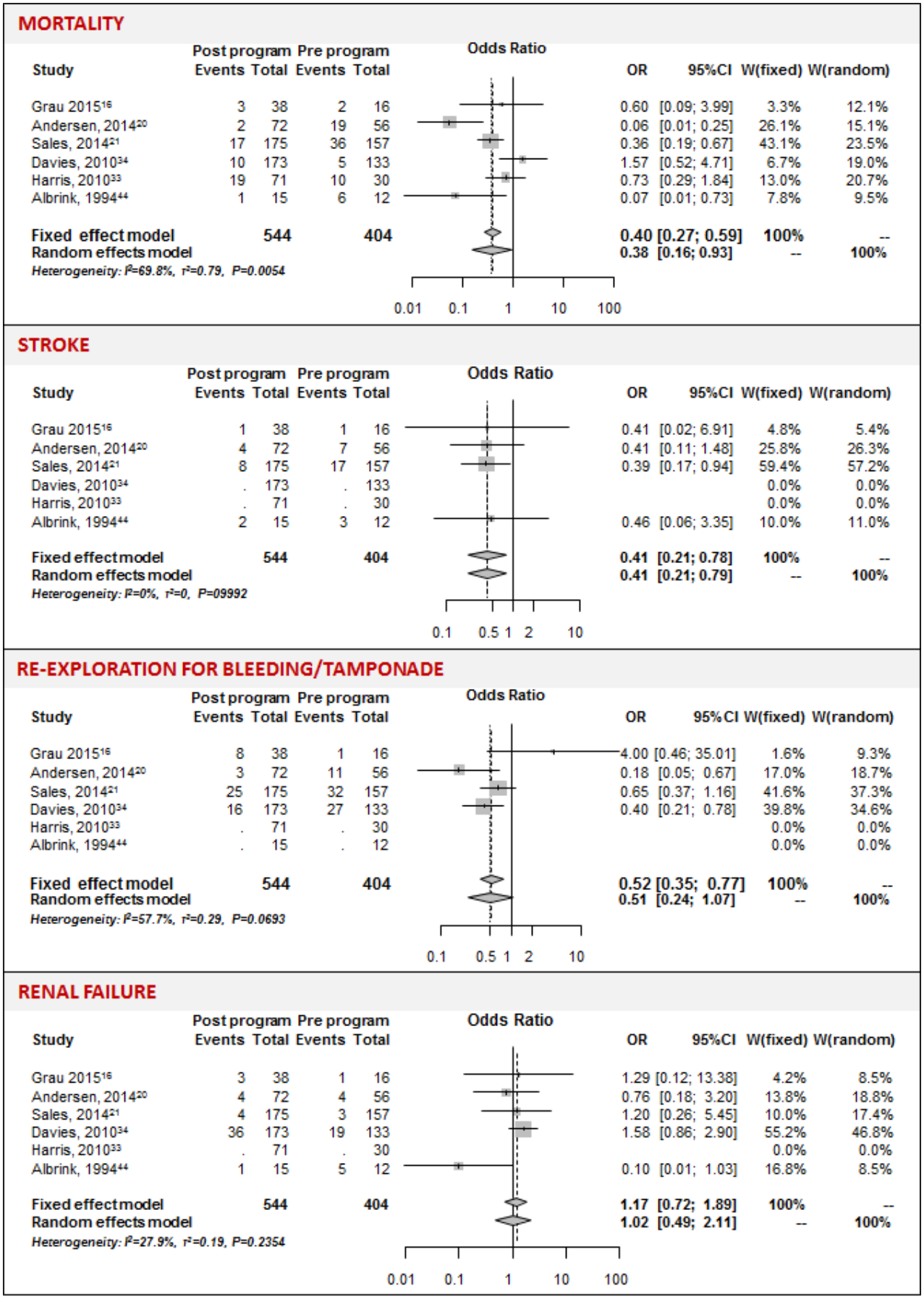
Abbreviations: ADA, acute aortic dissection; CI, confidence interval; OR, odds ratio.

Figure S7. Forest plots comparing the effect of hospital volume for secondary outcomes



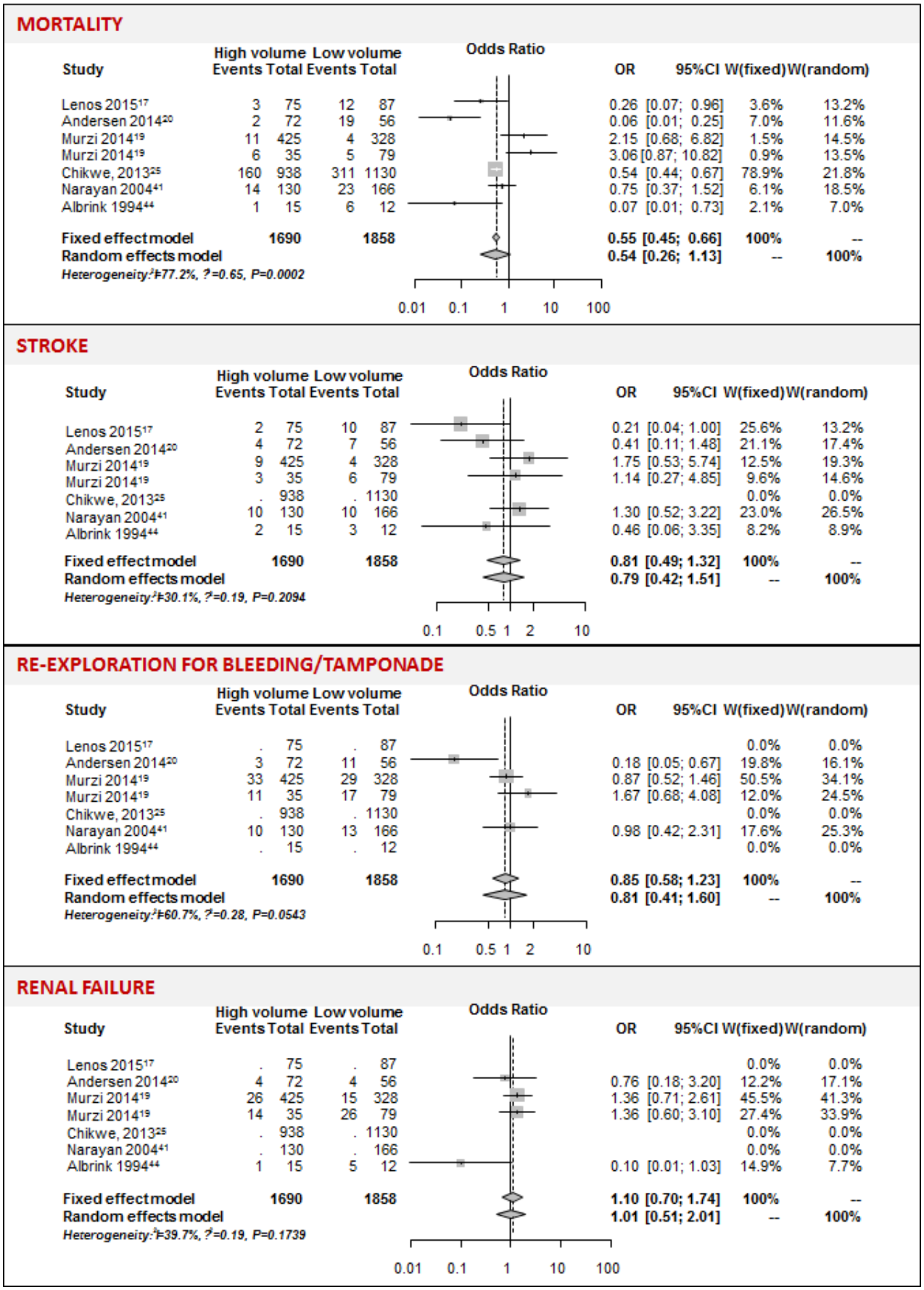
Abbreviations: CI, confidence interval; OR, odds ratio.

Figure S8. Forest plots comparing the effect of a multidisciplinary TAD program presence on outcomes



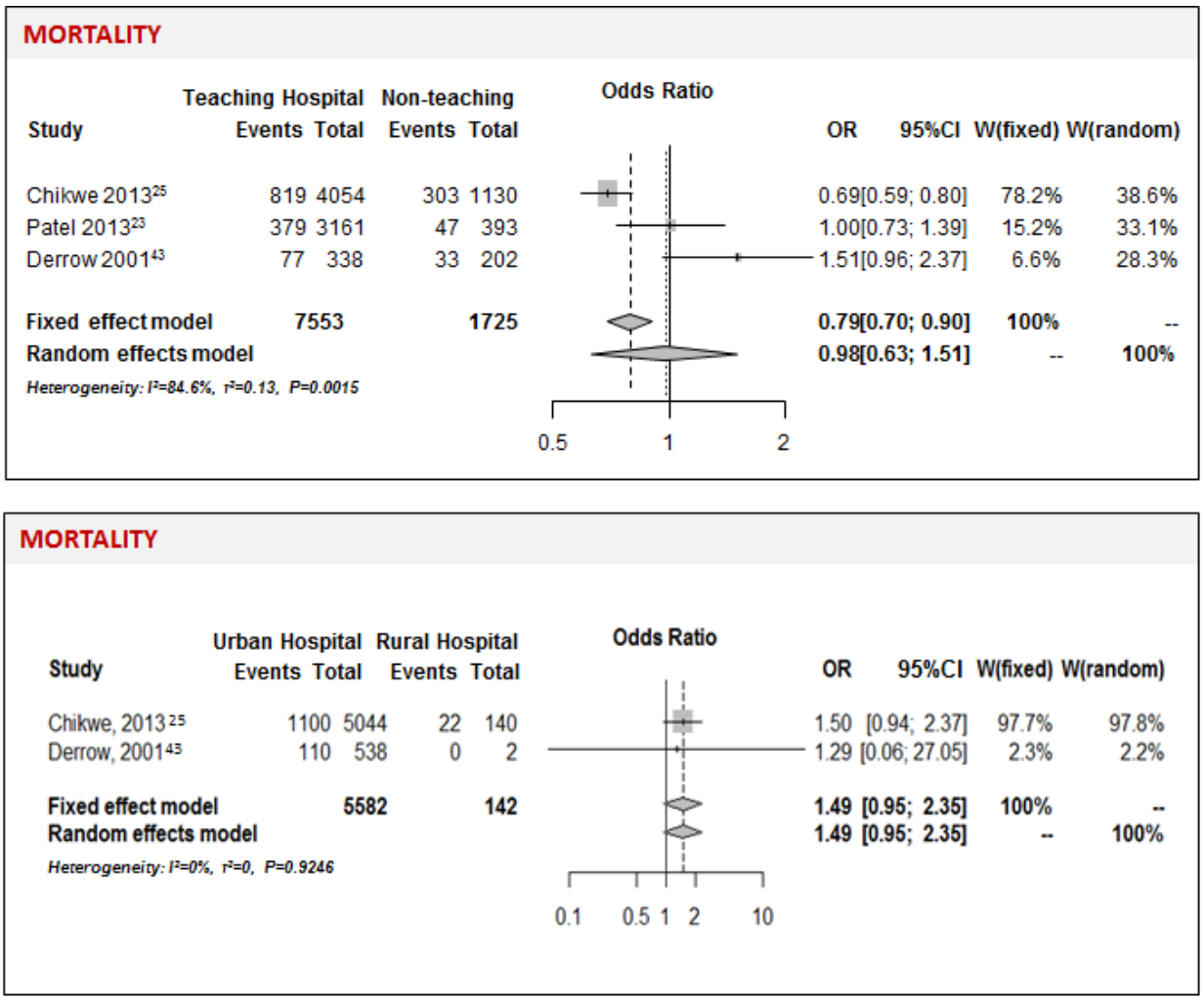
Abbreviations: CI, confidence interval; OR, odds ratio.

Figure S9. Forest plots comparing the effect of surgeon volume for hospital mortality and secondary outcomes



Abbreviations: CI, confidence interval; OR, odds ratio.

Figure S10. Forest plots comparing the effect of hospital status on hospital mortality



Abbreviations: CI, confidence interval; OR, odds ratio.

Supplemental References

1. Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM; RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) statement. *PLoS Med.* 2015;12:e1001885. doi:10.1371/journal.pmed.1001885.
2. http://www.hscic.gov.uk/hes. Accessed June 30, 2015.
3. Bridgewater B, Keogh B, Kinsman R, Walton P. The Society for Cardiothoracic Surgery in Great Britain & Ireland: the Sixth National Adult Cardiac Surgical Database Report. Henley-on-Thames, UK: Dendrite Clinical Systems Ltd, 2009. Available at: http://www.scts.org/_userfiles/resources/SixthNACSDreport2008withcovers.pdf. Accessed June 30, 2015.
4. http//www.ucl.ac.uk/nicor/audits/adultcardiac/documents/datasets/NACSAdatasetV4.1.2.
5. Accessed April 30, 2015.
6. http//www.ucl.ac.uk/nicor/audits/adultcardiac/documents/datasets/nacsacleaning10.3. Accessed April 30, 2015.
7. Hickey GL, Grant SW, Cosgriff R, Dimarakis I, Pagano D, Kappetein AP, Bridgewater B. Clinical registries: governance, management, analysis and applications. *Eur J Cardiothorac Surg.* 2013;44:605-14. doi:10.1093/ejcts/ezt018.
8. Roques F, Michel P, Goldstone AR, Nashef SA. The logistic EuroSCORE. *Eur Heart J.* 2003;24:881-2. doi:10.1016/S0195-668X(02)00799-6.
9. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP; STROBE Initiative. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *BMJ.* 2007;335:806-8. doi:10.1136/bmj.39335.541782.AD.
10. Stroup DF, Berlin JA, Morton SC, Olkin I, Williamson GD, Rennie D, Moher D, Becker BJ, Sipe TA, Thacker SB. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis Of Observational Studies in Epidemiology (MOOSE) group. *JAMA.* 2000;283:2008-12. doi:10.1001/jama.283.15.2008.
11. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ.* 2009;339:b2535. doi:10.1136/bmj.b2535.
12. Schaffer JM, Lingala B, Fischbein MP, Dake MD, Woo YJ, Mitchell RS, Miller DC. Midterm outcomes of open descending thoracic aortic repair in more than 5,000 Medicare patients. *Ann Thorac Surg.* 2015;100:2087-94. doi: 10.1016/j.athoracsur.2015.06.068.
13. Schaffer JM, Lingala B, Miller DC, Woo YJ, Mitchell RS, Dake MD. Midterm survival after thoracic endovascular aortic repair in more than 10,000 Medicare patients. *J Thorac Cardiovasc Surg.* 2015;149:808-20. doi: 10.1016/j.jtcvs.2014.10.036.
14. Bhatt P, Patel NJ, Patel A, Sonani R, Patel A, Panaich SS, Thakkar B, Savani C, Jhamnani S, Patel N, Patel N, Pant S, Patel S, Arora S, Dave A, Singh V, Chothani A, Patel J, Ansari M, Deshmukh A, Bhimani R, Grines C, Cleman M, Mangi A, Forrest JK, Badheka AO. Impact of hospital volume on outcomes of endovascular stenting for adult aortic coarctation. *Am J Cardiol.* 2015;116:1418-24. doi: 10.1016/j.amjcard.2015.07.066.
15. Brat R, Gaj J, Barta J. Early and mid-term outcomes of the aortic arch surgery: experience from the low-volume centre. *J Cardiothorac Surg.* 2015;10:31. doi: 10.1186/s13019-015-0229-6.
16. Grau JB, Kuschner CE, Ferrari G, Wilson SR, Brizzio ME, Zapolanski A, Yallowitz J, Shaw RE. Effects of a protocol-based management of type A aortic dissections. *J Surg Res.* 2015;197:265-9. doi: 10.1016/j.jss.2015.04.018.
17. Lenos A, Bougioukakis P, Irimie V, Zacher M, Diegeler A, Urbanski PP. Impact of surgical experience on outcome in surgery of acute type A aortic dissection. *Eur J Cardiothorac Surg.* 2015;48:491-6. doi: 10.1093/ejcts/ezu454.
18. Iribarne A, Milner R, Merlo AE, Singh A, Saunders CR, Russo MJ. Outcomes following emergent open repair for thoracic aortic dissection are improved at higher volume centers. *J Card Surg.* 2015;30:74-9. doi:10.1111/jocs.12470.
19. Murzi M, Miceli A, Di Stefano G, Cerillo AG, Kallushi E, Farneti P, Solinas M, Glauber M. Enhancing quality control and performance monitoring in thoracic aortic surgery: a 10-year single institutional experience. *Eur J Cardiothorac Surg.* 2015;47:608-15. doi:10.1093/ejcts/ezu249.

20. Andersen ND, Ganapathi AM, Hanna JM, Williams JB, Gaca JG, Hughes GC. Outcomes of acute type a dissection repair before and after implementation of a multidisciplinary thoracic aortic surgery program. *J Am Coll Cardiol.* 2014;63:1796-803. . doi:10.1016/j.jacc.2013.10.085.
21. Sales Mda C, Frota Filho JD, Aguzzoli C, Souza LD, Rösler AM, Lucio EA, Leães PE, Pontes MR, Lucchese FA. Aortic Center: specialized care improves outcomes and decreases mortality. *Rev Bras Cir Cardiovasc.* 2014;29:494-504. doi: 10.5935/1678-9741.20140122.
22. Weiss A, Anderson JA, Green A, Chang DC, Kansal N. Hospital volume of thoracoabdominal aneurysm repair does not affect mortality in California. *Vasc Endovascular Surg.* 2014;48:378-82. doi:10.1177/1538574414540344.
23. Patel VI, Mukhopadhyay S, Ergul E, Aranson N, Conrad MF, Lamuraglia GM, Kwolek CJ, Cambria RP. Impact of hospital volume and type on outcomes of open and endovascular repair of descending thoracic aneurysms in the United States Medicare population. *J Vasc Surg.* 2013;58:346-54. doi:10.1016/j.jvs.2013.01.035.
24. Arnaoutakis DJ, Propper BW, Black JH 3rd, Schneider EB, Lum YW, Freischlag JA, Perler BA, Abularrage CJ. Racial and ethnic disparities in the treatment of unruptured thoracoabdominal aortic aneurysms in the United States. *J Surg Res.* 2013;184:651-7. . doi:10.1016/j.jss.2013.03.018.
25. Chikwe J, Cavallaro P, Itagaki S, Seigerman M, Diluozzo G, Adams DH. National outcomes in acute aortic dissection: influence of surgeon and institutional volume on operative mortality. *Ann Thorac Surg.* 2013;95:1563-9. doi:10.1016/j.athoracsur.2013.02.039.
26. Goodney PP, Brooke BS, Wallaert J, Travis L, Lucas FL, Goodman DC, Cronenwett JL, Stone DH. Thoracic endovascular aneurysm repair, race, and volume in thoracic aneurysm repair. *J Vasc Surg.* 2013;57:56-63. doi:10.1016/j.jvs.2012.07.036.
27. Soppa G, Abdulkareem N, Smelt J, Van Besouw JP, Jahangiri M. High-volume practice by a single specialized team reduces mortality and morbidity of elective and urgent aortic root replacement. *Aorta (Stamford).* 2013;1:40-4. doi: 10.12945/j.aorta.2013.13.001.
28. Tsagakis K, Konorza T, Dohle DS, Kottenberg E, Buck T, Thielmann M, Erbel R, Jakob H. Hybrid operating room concept for combined diagnostics, intervention and surgery in acute type A dissection. *Eur J Cardiothorac Surg.* 2013;43:397-404. doi:10.12945/j.aorta.2013.13.001.
29. Hughes GC, Zhao Y, Rankin JS, Scarborough JE, O'Brien S, Bavaria JE, Wolfe WG, Gaca JG, Gammie JS, Shahian DM, Smith PK. Effects of institutional volumes on operative outcomes for aortic root replacement in NorthAmerica. *J Thorac Cardiovasc Surg.* 2013;145:166-70. doi:10.1016/j.jtcvs.2011.10.094.
30. Sakata R, Kuwano H, Yokomise H. Hospital volume and outcomes of cardiothoracic surgery in Japan: 2005-2009 national survey. *Gen Thorac Cardiovasc Surg.* 2012;60:625-38. doi:10.1007/s11748-012-0128-x.
31. Chavanon O, Baguet JP, Albaladéjo P, Blin D, Vanzetto G. Direct admission to the operating room: an efficient strategy for patients with diagnosed or highly suspected acute type A aortic dissection. *Can J Cardiol.* 2011;27:685-91. doi:10.1016/j.cjca.2011.01.014.
32. Gopaldas RR, Dao TK, LeMaire SA, Huh J, Coselli JS. Endovascular versus open repair of ruptured descending thoracic aortic aneurysms: a nationwide risk-adjusted study of 923 patients. *J Thorac Cardiovasc Surg.* 2011; 142:1010-8. doi:10.1016/j.jtcvs.2011.08.014.
33. Harris KM, Strauss CE, Duval S, Unger BT, Kroshus TJ, Inampudi S, Cohen JD, Kapsner C, Boland LL, Eales F, Rohman E, Orlandi QG, Flavin TF, Kshettry VR, Graham KJ, Hirsch AT, Henry TD. Multidisciplinary standardized care for acute aortic dissection: design and initial outcomes of a regional care model. *Circ Cardiovasc Qual Outcomes.* 2010;3:424-30. doi:10.1161/CIRCOUTCOMES.109.920140.
34. Davies MG, Younes HK, Harris PW, Masud F, Croft BA, Reardon MJ, Lumsden AB. Outcomes before and after initiation of an acute aortic treatment center. *J Vasc Surg.* 2010;52:1478-85. doi:10.1161/CIRCOUTCOMES.109.920140.
35. Gazoni LM, Speir AM, Kron IL, Fonner E, Crosby IK. Elective thoracic aortic aneurysm surgery: better outcomes from high-volume centers. *J Am Coll Surg.* 2010;210:855-9. doi:10.1016/j.jamcollsurg.2010.01.013.
36. Miyata H, Motomura N, Ueda Y, Tsukihara H, Tabayashi K, Takamoto S. Toward quality improvement of thoracic aortic surgery: estimating volume-outcome effect from nationwide survey. *Eur J Cardiothorac Surg.* 2009;36:517-21. doi:10.1016/j.ejcts.2009.03.020.
37. Schermerhorn ML, Giles KA, Hamdan AD, Dalhberg SE, Hagberg R, Pomposelli F. Population-based outcomes of open descending thoracic aortic aneurysm repair. *J Vasc Surg.* 2008;48:821-7. doi:10.1016/j.jvs.2008.05.022.

38. Knipp BS, Deeb GM, Prager RL, Williams CY, Upchurch GR Jr, Patel HJ. A contemporary analysis of outcomes for operative repair of type A aortic dissection in the United States. *Surgery.* 2007;142:524-8. doi:10.1016/j.surg.2007.07.012.
39. Committee for Scientific Affairs, Kazui T, Osada H, Fujita H. An attempt to analyze the relation between hospital surgical volume and clinical outcome. *Gen Thorac Cardiovasc Surg.* 2007;55:483-92. doi:10.1007/s11748-007-0172-0.
40. Rigberg DA, McGory ML, Zingmond DS, Maggard MA, Agustin M, Lawrence PF, Ko CY. Thirty-day mortality statistics underestimate the risk of repair of thoracoabdominal aortic aneurysms: a statewide experience. *J Vasc Surg.* 2006;43:217-22. doi:10.1016/j.jvs.2005.10.070.
41. Narayan P, Caputo M, Rogers CA, Alwair H, Mahesh B, Angelini GD, Bryan AJ. Early and mid-term outcomes of surgery of the ascending aorta/arch: is there a relationship with caseload? *Eur J Cardiothorac Surg.* 2004;25:676-82. doi: 10.1016/j.ejcts.2004.01.011.
42. Cowan JA Jr, Dimick JB, Henke PK, Huber TS, Stanley JC, Upchurch GR Jr. Surgical treatment of intact thoracoabdominal aortic aneurysms in the United States: hospital and surgeon volume-related outcomes. *J Vasc Surg.* 2003;37:1169-74. doi:10.1016/S0741-5214(03)00085-5.
43. Derrow AE, Seeger JM, Dame DA, Carter RL, Ozaki CK, Flynn TC, Huber TS. The outcome in the United States after thoracoabdominal aortic aneurysm repair, renal artery bypass, and mesenteric revascularization. *J Vasc Surg.* 2001;34:54-61. doi: 10.1067/mva.2001.115596.
44. Albrink MH, Rodriguez E, England GJ, McKeown PP, Hurst JM, Rosemurgy AS 2nd. Importance of designated thoracic trauma surgeons in the management of traumatic aortic transection. S*outh Med J.* 1994;87:497-501.