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.

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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)

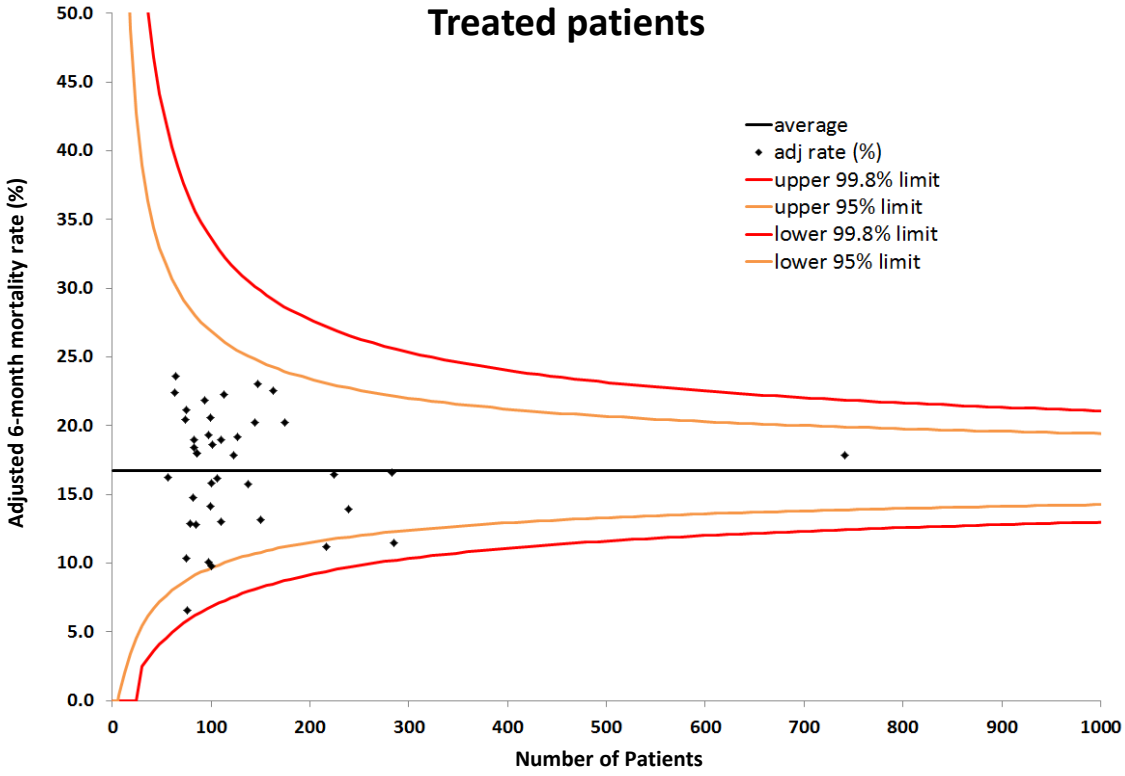
Miyata et al,[36] 2009	Hierarchical mixed-effects logistic regression model	clinical risk factors, procedure year, clinical events (beta-blocker usage), range of replacement (root, ascending, arch, distal aorta, descending, thoracoabdominal, abdominal) hospital procedural volume, and surgeon volume were 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)

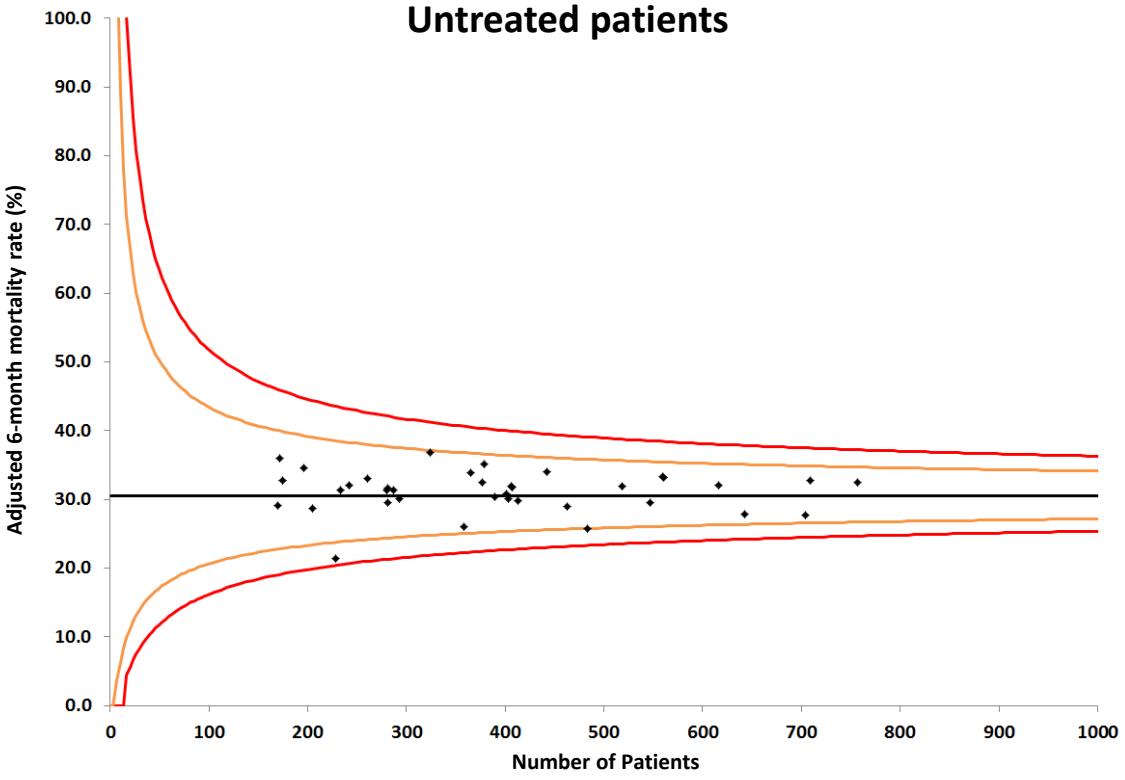
Abbreviations: BSA, body surface area; CABG, coronary artery bypass grafting; CI, confidence interval; HV, high volume; IABP, intra-aortic balloon pump; LV, low volume; n/a, not available; NYHA, New York Heart Association; OR, Odds ratio.

*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)

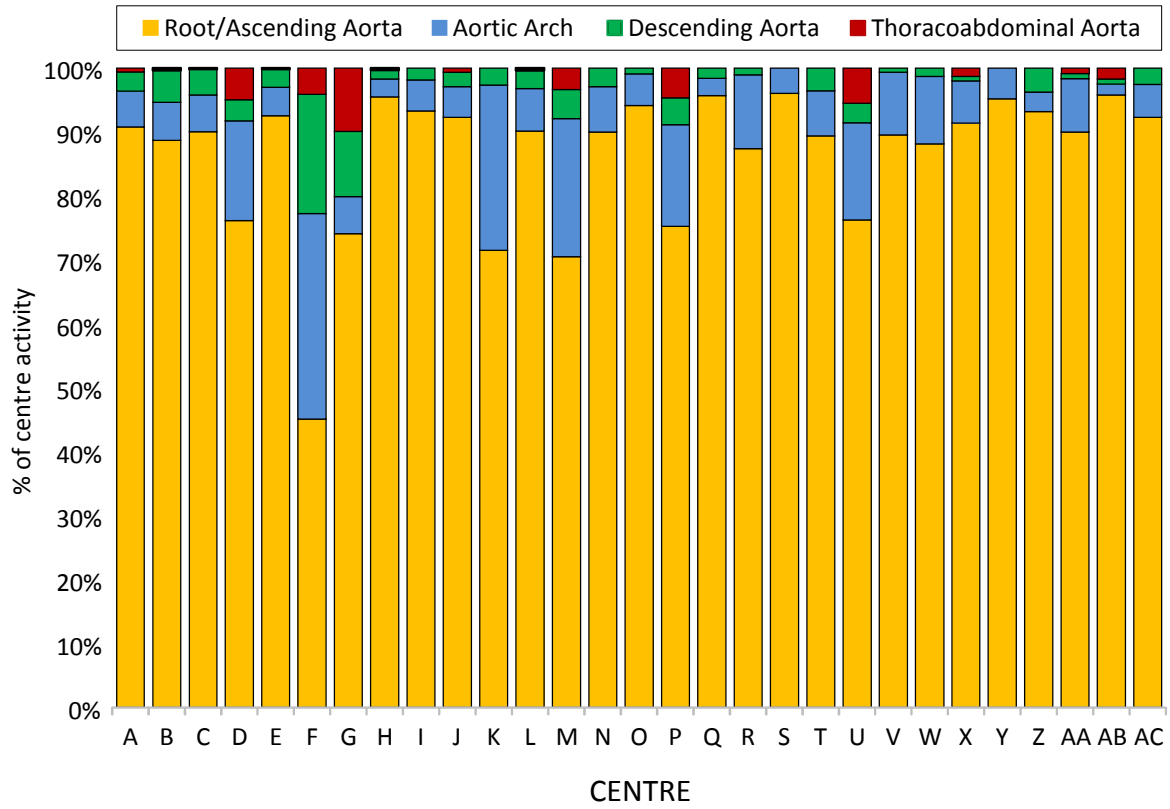
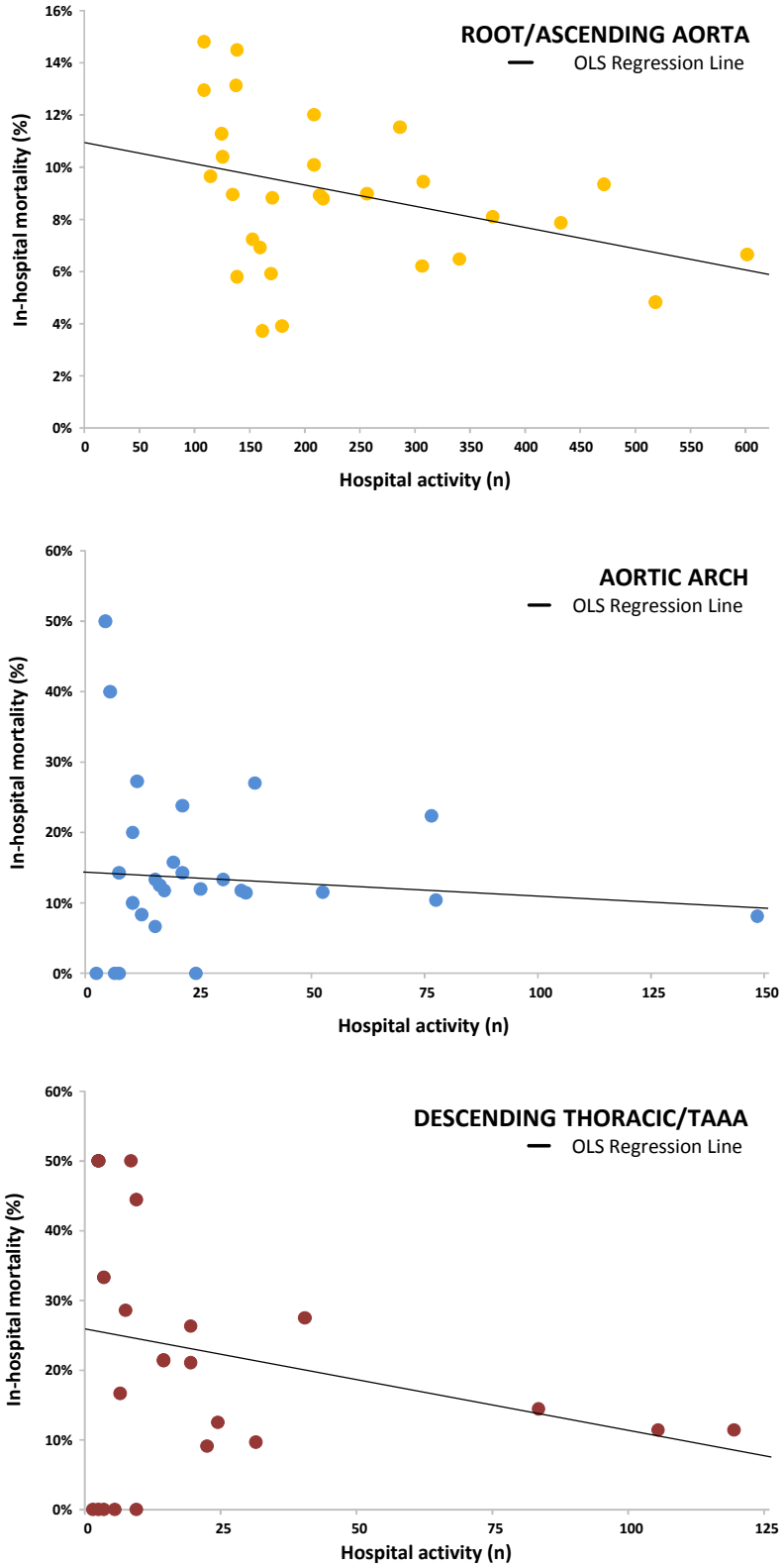


Figure S3. Correlation between the hospital activity (number of cases) and in-hospital mortality (NACSA dataset)



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]

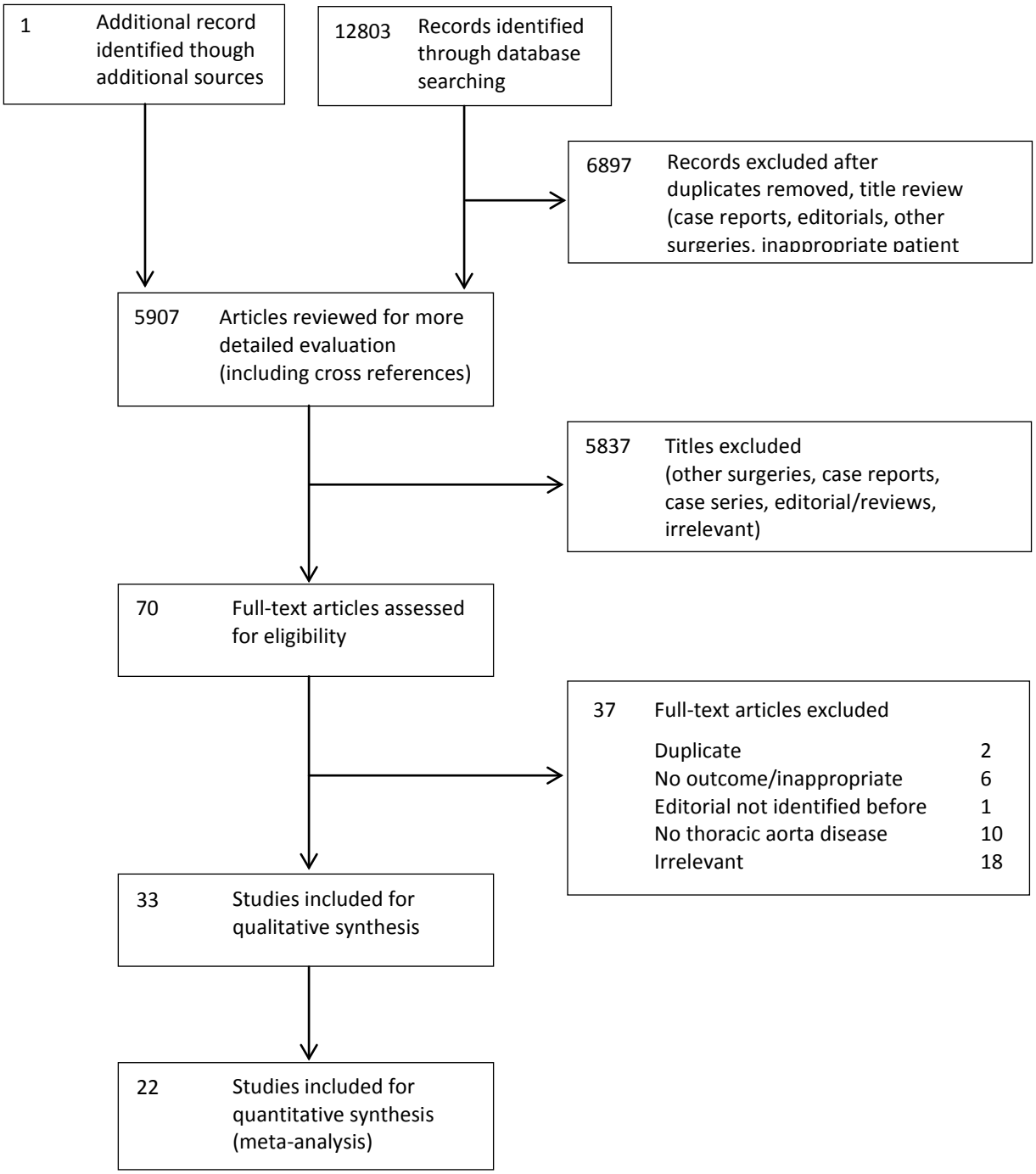


Figure S5. Funnel plots showing the absence of publication bias

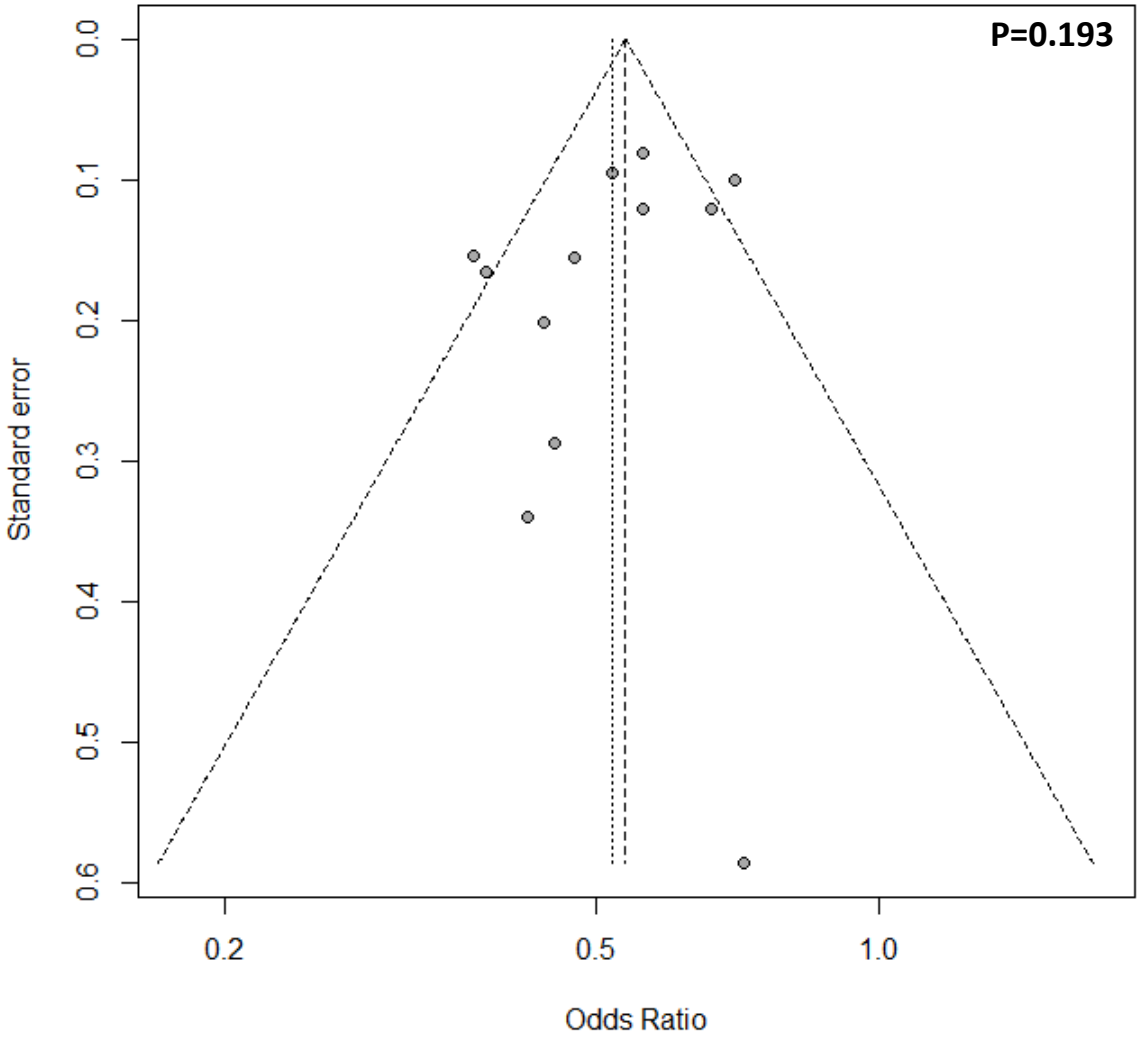
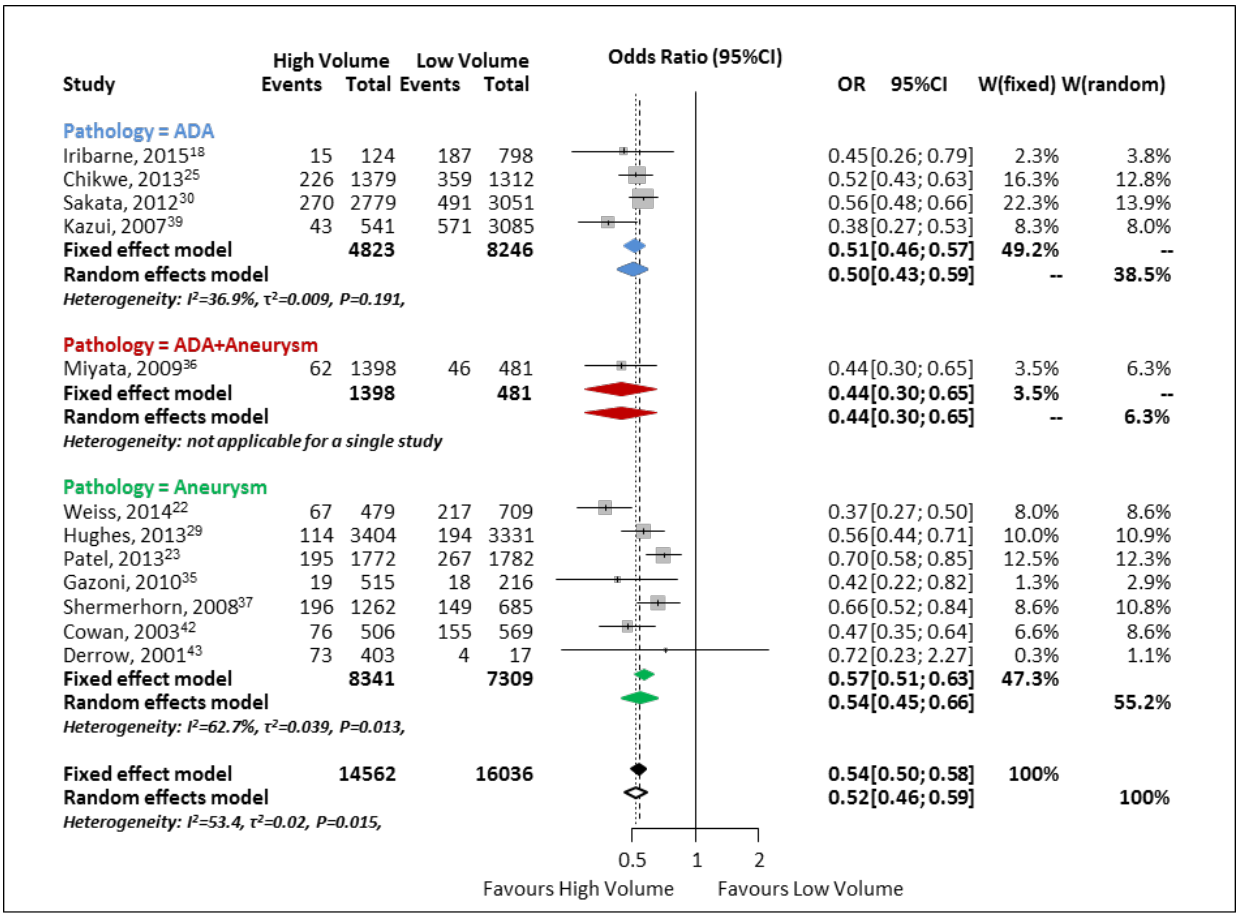
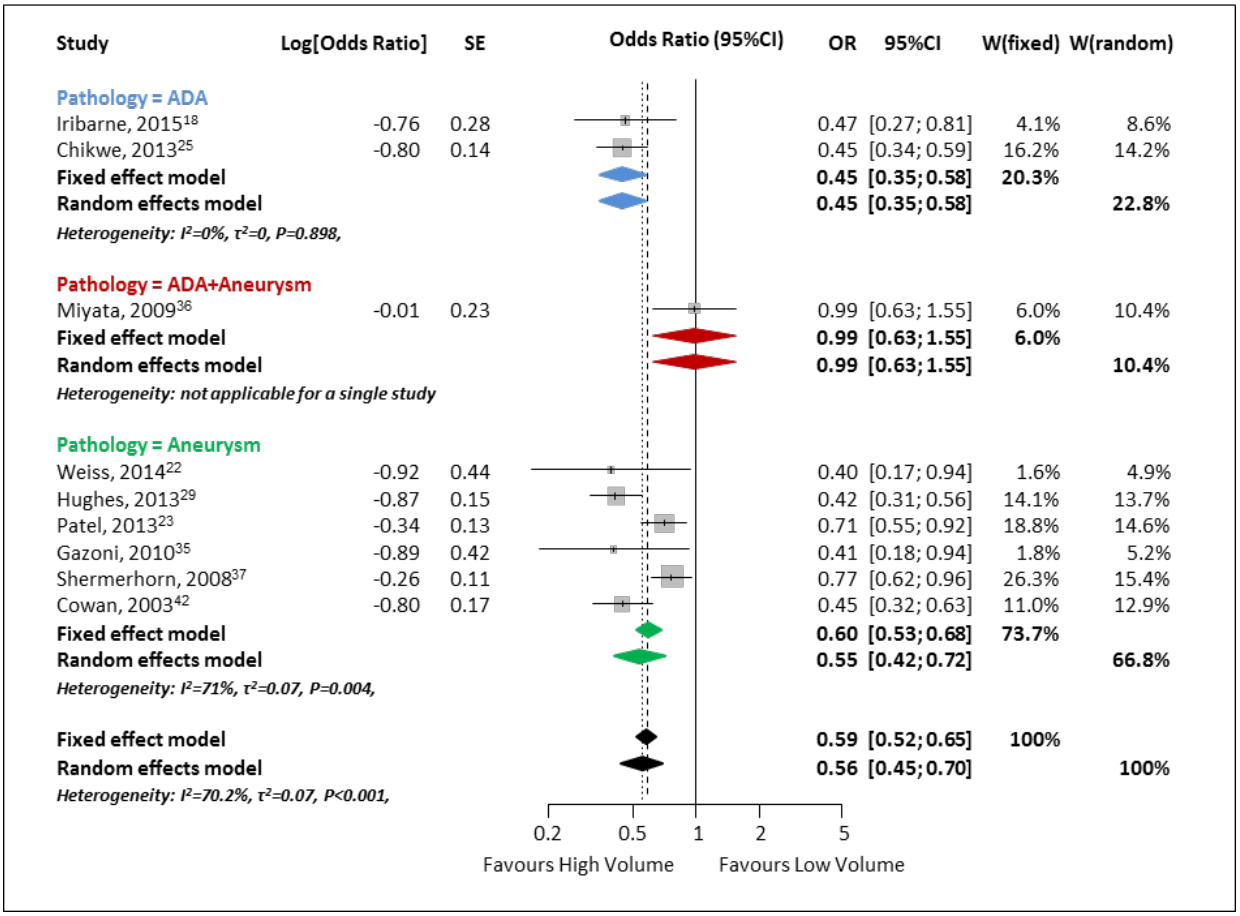


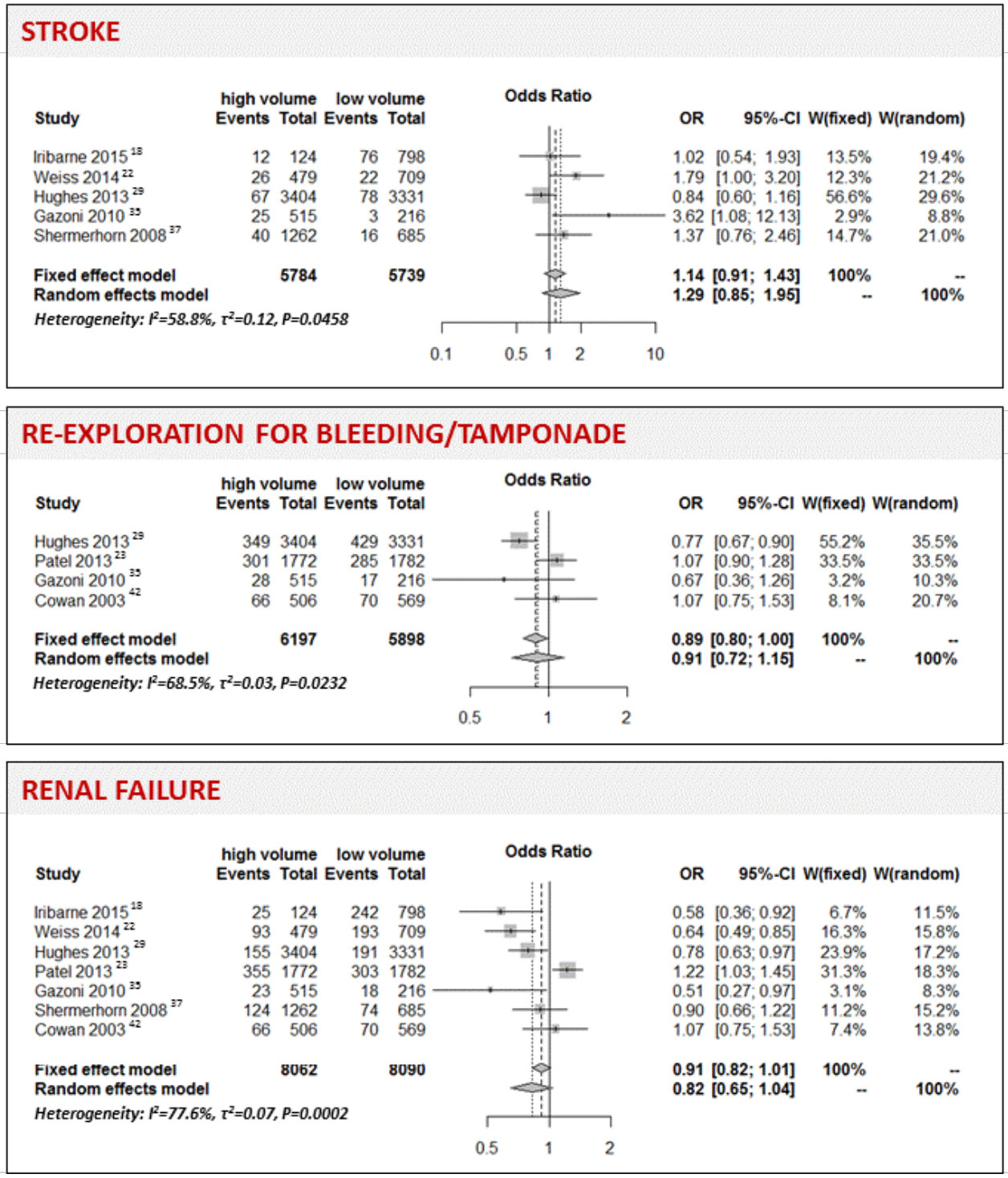
Figure S6. Forest plot for high-volume *versus* low-volume hospitals on operative mortality according to the primary aortic pathology (upper panel), and forest plot reporting risk adjusted estimates for high- *versus* low-volume hospitals on operative mortality according to the primary aortic pathology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





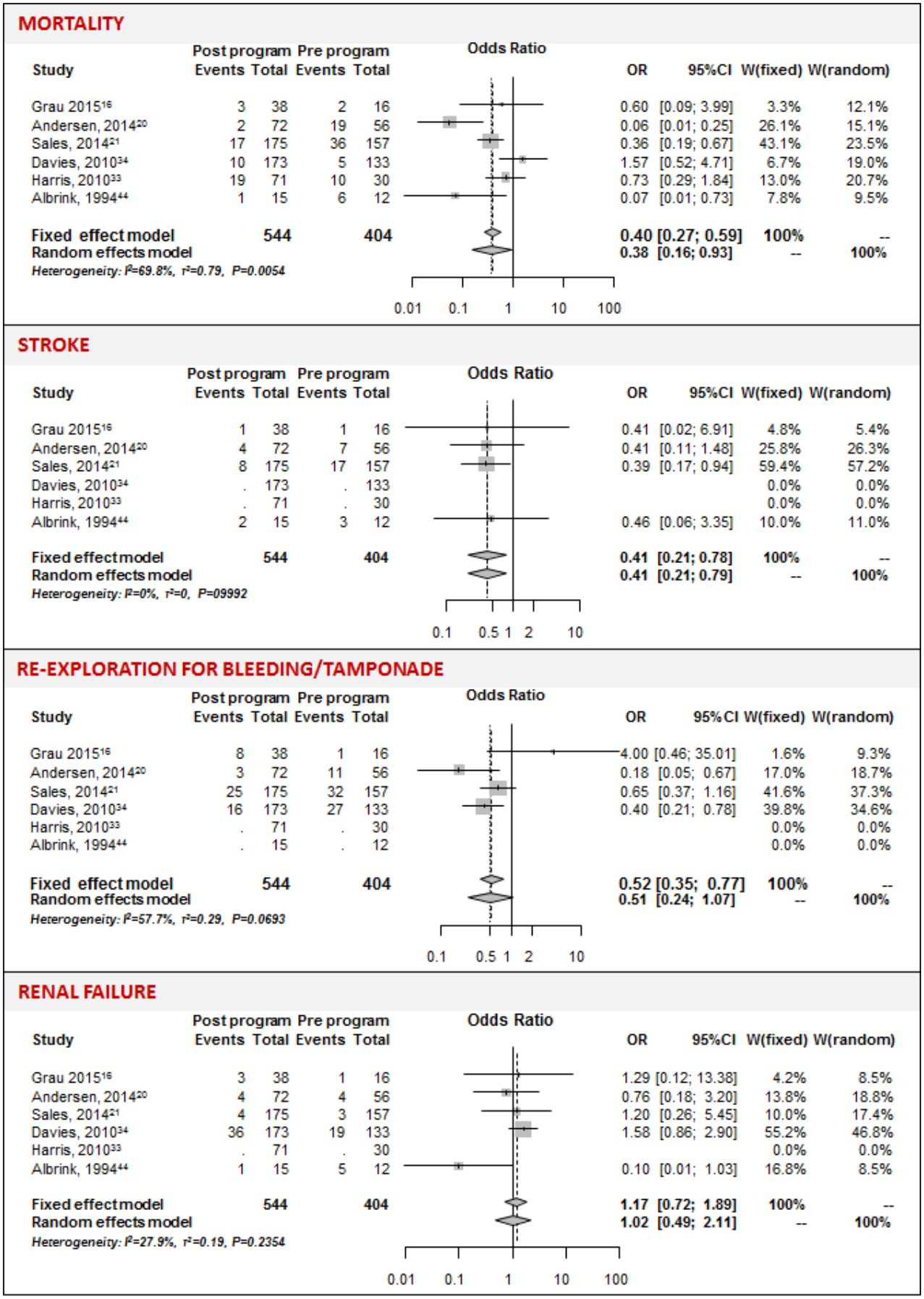
Abbreviations: ADA, acute aortic dissection; CI, confidence interval; OR, odds ratio.

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



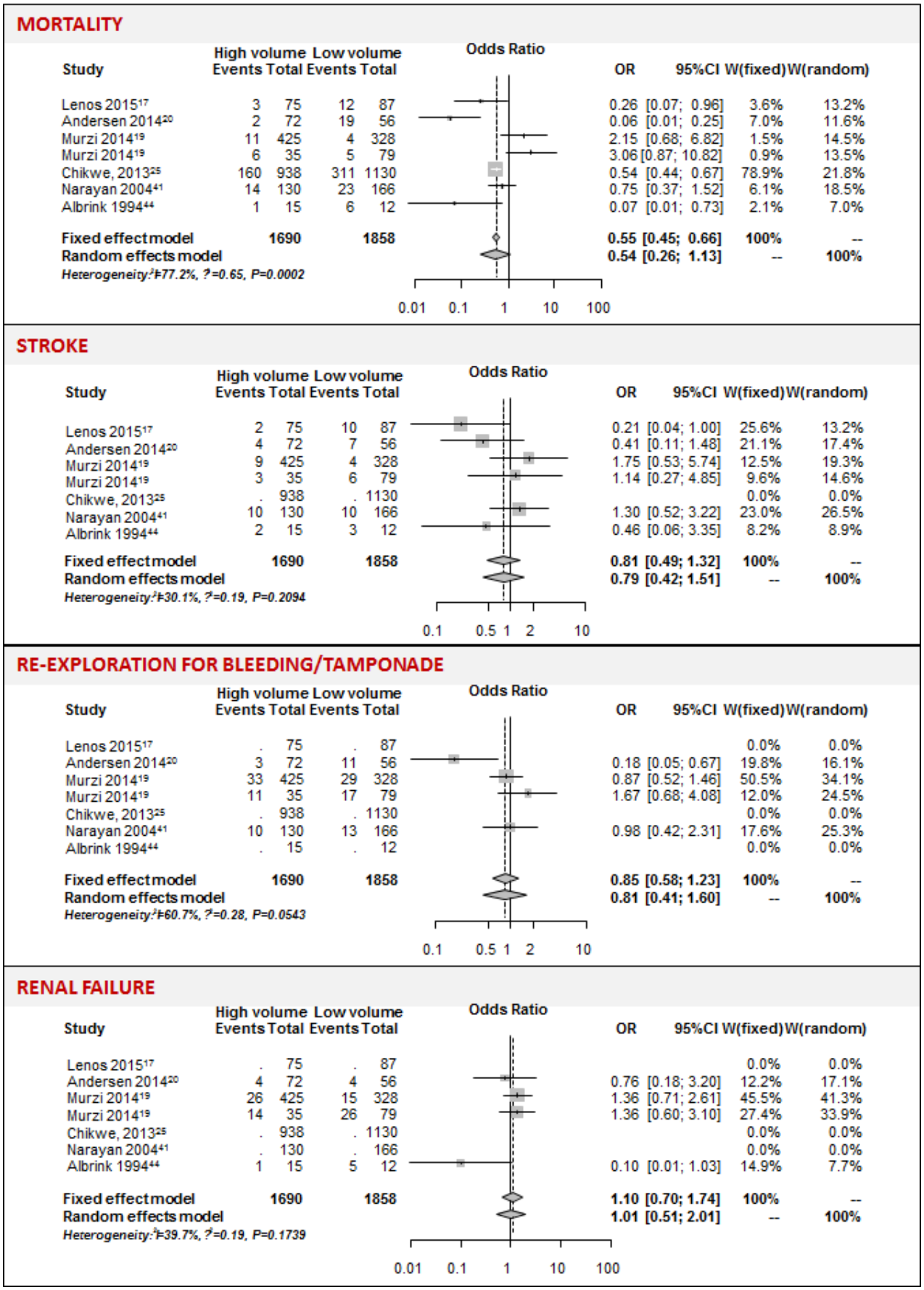
Abbreviations: CI, confidence interval; OR, odds ratio.

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



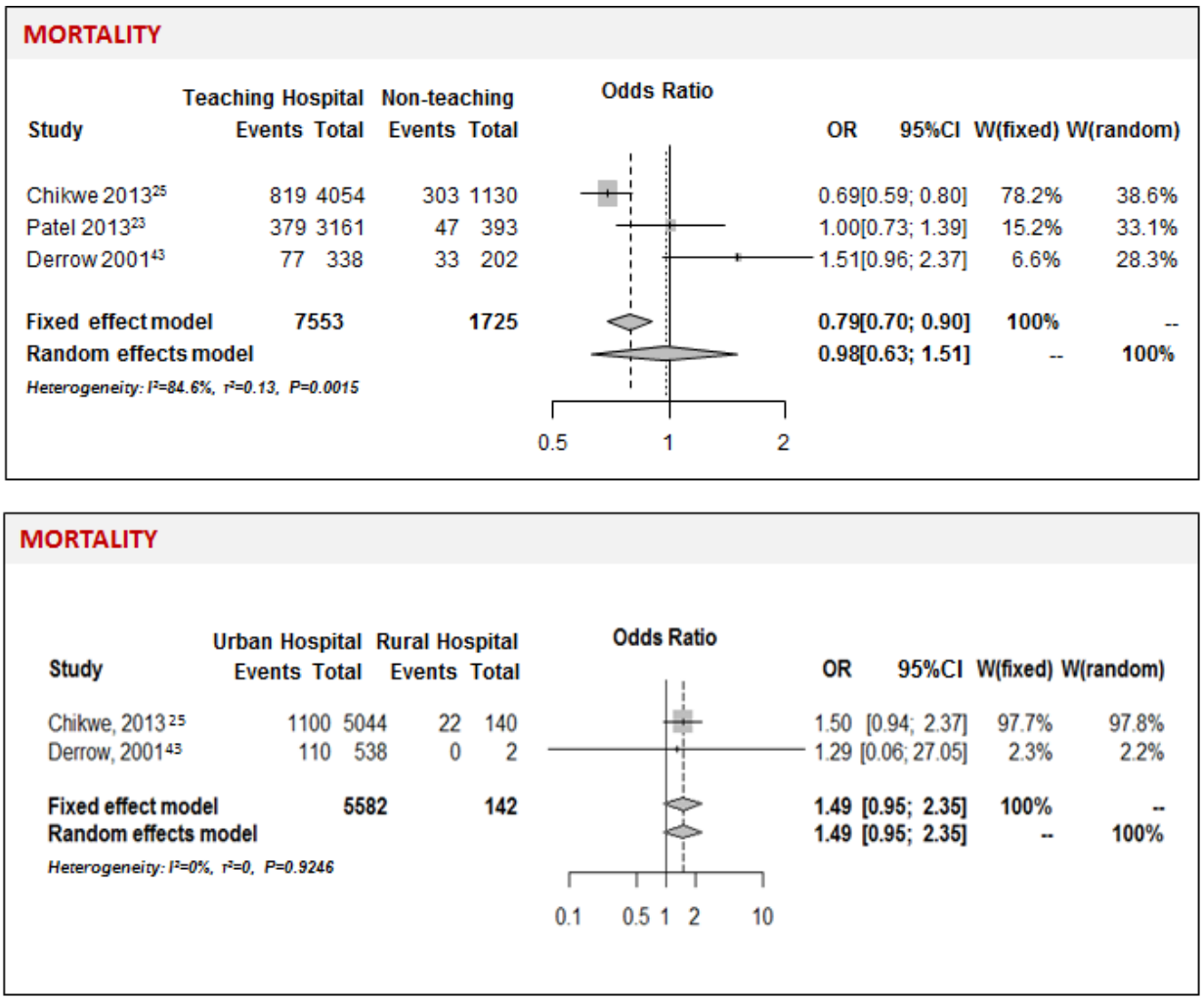
Abbreviations: CI, confidence interval; OR, odds ratio.

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.

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