2017

REPORT

A SYSTEMATIC REVIEW

Patient volume and quality in vascular surgery

Norwegian Institute of Public Health

Title	Patient volume and quality in vascular surgery: a systematic review
Norwegian title	Pasientvolum og kvalitet i karkirurgi: en systematisk oversikt
Publisher	Norwegian Institute of Public Health (Folkehelseinstituttet) Camilla Stoltenberg, *Director-General*
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ISBN	978-82-8082-813-2
Project number	1063
Type of report	Systematic Review
Pages	72 (286 including appendices)
Client	South-Eastern Norway Regional Health Authority
Subject heading (MeSH)	Patient volume, case volume, quality, vascular surgery
Citation	Austvoll-Dahlgren A, Underland V, Straumann GH, Forsetlund L. Patient volume and quality in vascular surgery: a systematic review. 2017. Oslo: Norwegian Institute of Public Health, 2017.

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Key messages

Vascular surgery are procedures related to diseases of the blood vessels, i.e. the arteries and veins of the circulatory system of the body. Typically, this includes surgery of the aorta, carotid arteries, and vessels of the lower extremities. The quality of these procedures is thought to be dependent on patient volume, based on the assumption that complicated procedures are best performed by those who do it often, and that "practice makes perfect".
We conducted a systematic review of studies exploring the relationship between patient volume and quality in vascular surgery. We included 89 observational studies. We found that:

- higher volume had a possible impact on quality when evaluated on both surgeon and hospital level.
- higher volume had a possible impact on quality for both open and endovascular surgery.
- higher patient volume possibly reduces mortality for patients with abdominal aortic aneurysms, thoracic abdominal aortic aneurysms, carotid artery stenosis, peripheral vascular disease and renal artery disease.
- higher patient volume also possibly reduces complications in patients with abdominal aortic aneurysms, carotid artery disease and peripheral vascular disease, and length of stay (hospital days) in patients with abdominal aortic aneurysms and carotid artery disease.
- there is a need for more studies evaluating the volume-quality relationship for patients with acute admissions, and for studies assessing outcomes such as length of stay and cost.

Title:
Patient volume and quality in vascular surgery: a systematic review
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Type of publication:
Systematic review
A review of a clearly formulated question that uses systematic and explicit methods to identify, select, and critically appraise relevant research, and to collect and analyse data from the studies that are included in the review. Statistical methods (meta-analysis) may or may not be used to analyse and summarise the results of the included studies.

Doesn't answer everything:
Estimates of recommended patient volume cut-off

Publisher:
Norwegian Institute of Public Health

Updated:
Last search for studies:
December 2015.

Internal peer review:
Brynjar Fure
Rigmor Berg

External peer review:
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Executive summary

Background

Vascular surgery includes procedures related to diseases of the blood vessels, i.e. the arteries and veins of the circulatory system of the body. Typically, this includes surgery of the aorta, carotid arteries, and vessels of the lower extremities. The quality of these procedures is thought to be dependent on patient volume, based on the assumption that complicated procedures are best performed by those who do it often, and that "practice makes perfect". We conducted a systematic review of studies exploring the relationship between patient volume and quality in vascular surgery.

Method

We performed systematic searches of relevant databases. We searched for systematic reviews, as well as randomized and observational studies comparing institutions or surgeons with high volume of vascular surgery with lower patient volume. We summarized the results descriptively and assessed the certainty of the overall evidence using GRADE for each outcome.

Results

We included 89 observational studies that evaluated the relationship between patient volume and vascular surgery on quality indicators. The studies included patients from USA, Canada, UK, Finland, Germany, Australia, Norway, Japan and France. The smallest study included 155 patients and the largest 491 779 patients. Thresholds for volume varied between studies and procedures, for example, median low volume for elective open surgery for abdominal aortic aneurysms was <9 procedures, and > 35 for high volume. Overall, we judged the evidence to be of moderate to very low certainty. For this summary we describe outcomes judged to be of moderate to low certainty.

Abdominal aortic aneurysms

For all surgery, there is:

- possibly lower 30-day mortality in high volume hospitals and for high volume surgeons.
- possibly less in-hospital mortality and fewer complications in high volume hospitals.

For open surgery, there is:

- possibly lower 30-day mortality in high volume hospitals, and possibly also for acute admissions.
- possibly less in-hospital mortality in high volume hospitals.

  - probably less in-hospital mortality for high volume surgeons, and possibly also for acute admissions.
  - possibly less complications in high volume hospitals.
  - possibly fewer days in hospital in high volume hospitals (elective patients).

- For endovascular surgery, there is:
  - possibly lower 30-day mortality in high volume hospitals
  - possibly less in-hospital mortality in high volume hospitals (elective patients).
  - possibly less complications in high volume hospitals (elective patients).

Thoracic and abdominal aortic aneurysms

- For open surgery, there is:
  - possibly lower 30-day mortality in high volume hospitals
  - probably less in-hospital mortality in high volume hospitals
  - possibly less in-hospital mortality for high volume surgeons (elective patients).
- For endocvascular surgery, there is:
  - possibly lower 30-day mortality in high volume hospitals, and lower risk of in-hospital mortality and complications for high-volume surgeons.

Carotid artery disease

- For open surgery, there is:
  - possibly lower 30-day mortality in high volume hospitals and for high volume surgeons.
  - possibly less in-hospital mortality in high volume hospitals and for high volume surgeons.
  - possibly less complications for high volume surgeons (including patients with severe carotid artery disease).
  - possibly fewer hospital days for for high volume surgeons (including patients with severe carotid artery disease).
- For endovascular surgery, there is:
  - possibly lower 30-day mortality and fewer complications in high volume hospitals and for high volume surgeons (elective patients). For surgeon volume, this also includes patients with severe carotid artery disease.
  - possibly less in-hospital mortality and complications combined for high volume surgeons (elective patients).
  - possibly fewer hospital days for for high volume surgeons.

Peripheral artery disease (aorto-iliac arteries and lower extremities)

- For all surgery, there is:
  - possibly less in-hospital mortality and complications combined for high volume surgeons.
- For open surgery, there is:

- possibly lower 30-day mortality and less in-hospital mortality in high volume hospitals.
  - possibly fewer complications in high volume hospitals and for high volume surgeons (elective patients).
- For endovascular surgery, there is:
  - possibly less in-hospital mortality in high volume hospitals.

Renal artery disease

- For open surgery, there is:
  - possibly less in-hospital mortality in high volume hospitals.

Discussion

We considered the evidence to be of moderate to very low certainty. In particular, there was insufficient evidence about the relationship between volume and quality for acute admissions, and for quality measures such as length of stay and costs. This is mainly due to few studies evaluating certain outcomes (precision), and that effect-estimates and measures of variance for several outcomes were not reported in the studies. There is also uncertainty as to some of the outcomes due to variability in results across studies. We judged two outcomes to be of moderate certainty, and which showed evidence of a strong association between volume and in-hosptial mortality. Both outcomes were measured for patients undergoing open elective surgery. The first evaluated surgeon volume for abominal aortic aneurysms and the second hospital volume for patients with thoracic and abdominal aortic aneurysms.

In addition to patient volume, patient related or system factors can also affect patient outcomes as well as resource use. Most of the included studies adjusted for such confounding patient factors, but in many studies, the baseline patient characteristics per volume group (high-volume vs. low-volume) were not reported. However, it is important to emphasize that in spite of these weaknesses, the studies included a large number of patients and with consistent conclusions across countries and health systems. Although many of the studies were from contexts with much larger populations, the median volume thresholds were comparable to those in smaller populations such as Norway.

Conclusion

Overall, we found that higher volume had a possible impact on quality when evaluated on both surgeon and hospital level. The available evidence also suggest that volume has an impact on quality for both open and endovascular surgery.

Higher patient volume possibly reduces mortality for patients with abdominal aortic aneurysms, thoracic and abdominal aortic aneurysms, carotid artery stenosis, peripheral vascular disease and renal artery disease. We also found that higher patient volume possibly reduces complications in patients with abdominal aortic aneurysms, carotid artery disease and peripheral vascular disease, and length of stay (hospital days) in patients with abdominal aortic aneurysms and carotid artery disease. More studies are needed evaluating the volume-quality relationship for patients with acute admissions, and for outcomes such as length of stay and cost.

The association was stronger and more certain for in-hospital mortality for patients with abdominal aortic aneurysms (hospital volume) and thoracic- and abdominal aortic aneurisms (surgeon volume) undergoing open elective surgery.

There are many other factors at the local level, including chance, which may explain quality of care associated with surgical procedures. This means that the results from this review cannot be generalized to the individual hospital or surgeon. Instead, this systematic review is intended as a general decision support for informing decisions about the organization of health services.

Hovedbudskap (norsk)

Karkirurgi omfatter kirurgiske inngrep knyttet til sykdommer i blodårene, dvs. arterier og vener i sirkulasjonssystemet i kroppen. Typisk omfatter dette abdominale aortaneurismer, karotidarterier og blodårer i nedre ekstremiteter. Pasientvolum kan tenkes å påvirke kvalitet basert på antakelsen om at kompliserte prosedyrer best gjøres av de som gjør det ofte og at «øvelse gjør mester». Vi har utført en systematisk oversikt over forskningen på sammenhengen mellom pasientvolum og kvalitet i karkirurgi. Vi inkluderte 89 observasjonelle studier. Vi fant

- en sammenheng mellom volum og kvalitet på både kirurgnivå og når sammenhengen ble målt på sykehus/ foretaksnivå.
- en sammenheng for både åpne og endvaskulære prosedyrer.
- at høyere pasientvolum gir muligens lavere 30-dagers dødelighet samt mindre sykehusdødelighet for pasienter med abdominal aortaaneurismer, torakale og abdominale aortaaneurismer, karotisstenose, perifer karsykdom og nyrearteriestenose.
- at høyere pasientvolum gir muligens færre komplikasjoner og kortere sykehusopphold for pasienter med abdominale aortaaneurismer og karotisstenose.
- at det er behov for studier som evaluerer volum-kvalitet sammenhengen for de sykeste pasientene, samt studier som måler kvalitetsindikatorer som dager på sykehus, og kostnader.

Tittel:
Pasientvolum og kvalitet ved karkirurgi: en systematisk oversikt
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Publikasjonstype:
Systematisk oversikt
En systematisk oversikt er resultatet av å
- innhente
- kritisk vurdere og
- sammenfatte

relevante forskningsresultater ved hjelp av forhåndsdefinerte og eksplisitte metoder.

Svarer ikke på alt:
Gir ingen anbefalinger eller vurdering av relevante pasientvolumterskler
----
Hvem står bak denne publikasjonen?
Kunnskapssenteret har gjennomført oppdraget etter forespørsel fra Helse Sør-Øst
----
Når ble litteratursøket utført?
Søk etter studier ble avsluttet desember 2015.

Eksterne fagfeller:
Arne Seternes, Overlege, St. Olavs hospital
Øystein Hovi Rognerud, Overlege Sykehuset i Vestfold og sekretær Norsk karkirurgisk forening

Sammendrag (norsk)

Innledning

Karkirurgi omfatter kirurgiske inngrep knyttet til sykdommer i blodårene, dvs. arterier og vener i sirkulasjonssystemet i kroppen. Typisk omfatter dette abdominale aortaneurismer, karotidarterier og blodårer i i nedre ekstremiteter. Pasientvolum er tenkt å påvirke kvalitet basert på antakelsen om at kompliserte prosedyrer best gjøres av de som gjør det ofte og at «øvelse gjør mester». Vi har utført en systematisk oversikt over forskningen på sammenhengen mellom pasientvolum og kvalitet i karkirurgi.

Metode

Vi utførte systematiske søk etter litteratur i relevante databaser. Vi søkte etter systematiske oversikter, og randomiserte og observasjonelle studier som sammenliknet institusjoner eller kirurger med høyt pasientvolum med lavere pasientvolum for karkirurgi. Vi har oppsummert resultatene deskriptivt og vurdert kvaliteten på den samlede dokumentasjonen ved bruk av GRADE for hvert utfall.

Resultat

Vi inkluderte 89 observasjonelle studier som så på sammenhengen mellom pasientvolum og kvalitet for karkirurgi. Studiene omfattet pasienter fra USA, Canada, Storbritannia, Finland, Tyskland, Australia, Norge, Japan og Frankrike. Den minste studien inkluderte 155 pasienter og den største 491 779 pasienter. Terskelverdier for volum varierte mellom studier og prosedyrer, eksempelvis var median lavvolum for elektive åpne operasjoner for abdominale aortaaneurismer <9 inngrep, og >35 for høyvolum. Vi vurderte dokumentasjonen til å være av moderat til svært lav kvalitet. I dette sammendraget oppsummerer vi utfallene vi vurderte å være av moderat og lav kvalitet.

Abdominale aortaaneurismer

For all kirurgi er det

- muligens lavere 30-dagers dødelighet i høyvolumsykehus og for høyvolumkirurger.
- muligens lavere sykehusdødelighet og færre komplikasjoner i høyvolumsykehus.

For åpen kirurgi er det

- muligens lavere 30-dagers dødelighet i høyvolumsykehus, også for akutte innleggelser.
- muligens lavere sykehusdødelighet i høyvolumsykehus.

- trolig lavere sykehusdødelighet for høyvolumkirurger, muligens også for akutte innleggelser.
- muligens færre komplikasjoner i høyvolumsykehus.
- muligens færre liggedøgn på sykehus i høyvolumsykehus (elektive pasienter).

- For endovaskulær kirurgi er det
  - muligens lavere 30-dagers dødelighet i høyvolumsykehus.
  - muligens lavere sykehusdødelighet i høyvolumsykehus.
  - muligens færre komplikasjoner i høyvolumsykehus (elektive pasienter).

Torakale og abdominale aortaaneurismer

- For åpen kirurgi er det
  - muligens lavere 30-dagers dødelighet i høyvolumsykehus.
  - trolig lavere sykehusdødelighet i høyvolumsykehus (elektive pasienter).
  - muligens lavere sykehusdødelighet for høyvolumkirurger (elektive pasienter).
- For endovaskulær kirurgi er det
  - muligens lavere 30-dagers dødelighet i høyvolumsykehus, og lavere sykehusdødelighet og komplikasjoner kombinert for høyvolumkirurger.

Karotisstenose

- For åpen kirurgi er det
  - muligens lavere 30-dagers dødelighet i høyvolumsykehus og for høyvolumkirurger.
  - muligens mindre sykehusdødelighet i høyvolumsykehus og for høyvolumkirurger.
  - muligens færre komplikasjoner for høyvolumkirurger (også for de med alvorlig symptomatisk karotisstenose).
  - muligens færre liggedøgn for alle grupper pasienter operert av høyvolumkirurger (også for de med alvorlig symptomatisk karotisstenose).
- For endovaskulær kirurgi er det
  - muligens mindre 30-dagers dødelighet og komplikasjoner i høyvolumsykehus og for høyvolumkirurger (elektive pasienter). For kirurgvolum gjelder dette også pasienter med alvorlig symptomatisk karotisstenose.
  - muligens mindre sykehusdødelighet og komplikasjoner kombinert for høyvolumkirurger (elektive pasienter).
  - muligens færre liggedøgn for høyvolumkirurger.

Perifer karsykdom (i bekken og ben)

- For all kirurgi er det
  - muligens mindre sykehusdødelighet og komplikasjoner kombinert for høyvolumkirurger.
- For åpen kirurgi er det

- muligens lavere 30-dagers dødelighet samt sykehusdødelighet i høyvolumsykehus.
- muligens færre komplikasjoner i høyvolumsykehus og for høyvolumkirurger (elektive pasienter).

- For endovaskulær kirurgi er det
  - muligens avere 30-dagers dødelighet i høyvolumsykehus.

Nyrearteriestenose

- For åpen kirurgi er det
  - muligens lavere sykehusdødelighet i høyvolumsykehus.

Diskusjon

Vi vurderte dokumentasjonen til å være av moderat til svært lav kvalitet. Særlig er dokumentasjonsgrunnlaget mangelfullt for sammenhengen mellom volum og kvalitet for akutte innleggelser, og for enkelte mål på kvalitet som dager på sykehus, og kostnader. Dette skyldes i hovedsak for få studier for noen av utfallene (altså lav presisjon), samt at tall og statistiske spredningsmål ikke var rapportert for en del utfall. Det er også knyttet usikkerhet til noen av utfallene grunnet variasjon i resultater på tvers av studiene. Vi vurderte dokumentasjonen for to utfall å være av moderat kvalitet. Vi fant at det trolig var en sterk sammenheng mellom volum og sykehusdødelighet for to grupper pasienter som gjennomgikk åpen elektiv kirurgi: kirurgvolum for abdominale aortaaneurismer og sykehusvolum for torakale og abdominale aortaaneurismer. I tillegg til pasientvolum, kan pasient-eller systemfaktorer påvirke kvaliteten av tjenestene. De fleste av de inkluderte studiene justerte for slike mulige forvekslingsfaktorer, men i mange studier er pasient-og systemkarakteristika per volumgruppe ikke rapportert. Det er imidlertid viktig å understreke at på tross av disse svakhetene omfattet de inkluderte studiene et stort antall pasienter, og med sammenfallende konklusjoner på tvers av mange land og helsesystemer.

Fordi det er mange andre faktorer på lokalt nivå, blant annet tilfeldigheter, som kan forklare forskjeller i kvalitet ved kirurgiske inngrep, betyr det at resultatene fra denne oversikten ikke kan generaliseres til det enkelte sykehus eller den enkelte kirurg. I stedet er denne rapporten ment som en generell beslutningsstøtte i organisering av helsetjenesten.

Konklusjon

Vi vurderte tilliten til dokumentasjonen for de ulike utfallene til å være av moderat tilsvært lav kvalitet. Vi fant en sammenheng mellom volum og kvalitet både på kirurgnivå og sykehusnivå. Sammenhengen ble funnet for både åpne og endovaskulære prosedyrer.

Høyere pasientvolum gir muligens lavere 30-dagers dødelighet samt mindre sykehusdødelighet for pasienter med abdominale aortaaneurismer, torakale og abdominaleaortaaneurismer, karotisstenose, perifer karsykdom og nyrearteriestenose. Vi fant også at høyere pasientvolum muligens gir færre komplikasjoner og kortere sykehusopphold for pasienter med abdominale aortaaneurismer og karotisstenose.

Sammenhengen var sterkere og mer sikker for sykehusdødelighet for elektive pasienter som fikk åpen kirurgi for abdominale aortaaneurismer (kirurgvolum) og torakale og abdominale aortaaneurismer (sykehusvolum).

Det er behov for studier som undersøker sammenhengen mellom volum og kvalitet for de sykeste pasientene ved akutte innleggelser, samt for enkelte utfallsmål som dager på sykehus og kostnader.

Preface

This report was commissioned by the South-Eastern Norway Regional Health Authority. The purpose of this report is to conduct a systematic review of studies that have evaluated the relationship between patient volume and quality for vascular surgery. Vascular surgery comprises procedures related to diseases of the blood vessels, i.e. the arteries and veins of the circulatory system of the body. The quality of these procedures is thought to be dependent on patient volume, based on the assumption that "practice makes perfect".

We would like to thank all those who have provided us with advice and feedback throughout this process, including Anne Karin Lindahl, Kristoffer Yunpeng Ding, Brynjar Fure, Rigmor Berg and Marit Johansen, as well as our external peer-reviewers of the protocol (Jørgen J. Jørgensen (1947-2017) and Arne Seternes) and full report (Arne Seternes and Øystein Hovi Rognerud). All authors of this report and peer-reviewers have filled out a form that map potential conflicts of interest. None of the above reported to have conflicts of interests.

This report builds on previous reports published by the Norwegian Knowledge Center for the Health Services, evaluating the association of case-volume and quality in surgical treatment for abdominal aortic aneurysms, carotid artery disease and peripheral artery disease. The working group has consisted of:

- Astrid Austvoll-Dahlgren, Senior researcher, Norwegian Institute of Public Health
- Vigdis Underland, Researcher, Norwegian Institute of Public Health
- Gyri Hval Straumann, Research librarian, Norwegian Institute of Public Health
- Louise Forsetlund, Senior researcher, Norwegian Institute of Public Health

Signe Agnes Flottorp	Gunn E. Vist	Astrid Austvoll-Dahlgren
Department Director	*Unit Director*	*Project Coordinator*

Introduction

Patient volume is assumed to affect the quality of surgical treatments based on the assumption that complicated procedures are best performed by those who do it often, and that "practice makes perfect" (1). The underlying idea is that practice makes perfect, and that this can lead to fewer deaths, less morbidity, and more rational use of resources. Consequently, this may have implications for how vascular surgery should be organized, and it may indicate a centralization of such procedures in specialized high volume units. In contrast stands the argument about the importance of patients' access to treatment at their local hospital; both in consideration of practical challenges such as extended commute for patients and their next of kin, but also because some conditions may require immediate care.

Vascular disease and surgery

Vascular surgery includes procedures related to diseases of the blood vessels, i.e. the arteries and veins of the circulatory system of the body. Typically, this includes surgery of the aorta, carotid arteries, and arteries and veins in the lower extremities. Based on estimates by the Norwegian Vascular Surgery Registry (NORKAR) for 2015, 748 operations were performed for abdominal aortic aneurysms (of which 91 was for ruptured aneurysms), 492 operations were registered for carotid surgery, and 2736 operations for peripheral disease in the lower extremities (2). However, it is worth mentioning that the NORKAR-registry only covers 61 to 84% of all operations, and consequently these esitmates should be interpreted with caution (2).

Surgical procedures for vascular disease include open surgery and percutaneous, catheter-based techniques, or a combination thereof (3). Although more patients in Norway are treated with open surgery, use of endovascular techniques is increasing (3). Generally, endovascular procedures are assumed to provide less operation trauma than open surgery and are often more suitable for high-risk patients (4-6). Using these methods, however, depends on access to expertise and access to necessary equipment. Furthermore, for anatomical reasons, not all patients can be treated with endovascular procedures. For example, in case of endovascular treatment of abdominal aortic aneurysm, it is estimated that approximately 50-60% of the patients will need open surgery (4).

The mortality associated with vascular surgery varies by diagnoses. In Norway, the mortality for intact abdominal aortic aneurysm in 2015 was 3.1% (of 319 patients) for open surgery and 1.8% (of 338 patients) for endovascular procedures (2). For ruptured abdominal aortic aneurysm, the mortality was 41.9% (of 74 patients) for open surgery and 29.4% (of 17 patients) for endovascular procedures. Following carotid surgery, 2.9% (of 408 patients) died or had a stroke (2).

Defining and measuring volume and quality

There is no consensus on how patient volume is best defined (1, 7). Patient volume is typically estimated per surgeon or per unit. This distinction is not always clear-cut, given that within a high-volume institution, there may be both high and low-volume surgeons. Furthermore, presumably, patient outcomes, use of resources and costs will not only depend on the surgeon and the actual procedure, but also on what other care is given to the patient and how this is organized before and after the procedure (18). It is also worth noting that what is defined as "high" and "low" volume varies across studies and procedures, and is usually based on pragmatic cut-offs such as dividing patient volume by institution or surgeon into quartiles or quintiles (1, 7).

In Norway, the overall volume for Norwegian hospitals providing data to the NORKAR registry in 2015, ranged from: 1 to 117 operations for abdominal aortic aneurysms, 5 to 46 for carotid surgery and 2 to 330 for peripheral vascular disease in the lower extremities (2).

When it comes to measuring quality, this is usually operationalized as different measures of mortality, including both in-hospital mortality and 30-day mortality, as well as complications, resource use and costs.

Other underlying or moderating variables

In addition to patient volume, other patient ("case-mix") or hospital factors may have an impact on quality of care. For example, the patients' health status, such as the severity of disease or comorbidities may affect outcomes (7). There may also be differences between the regions as a consequence of patients' socio-demographic background or system factors such as differences in how hospitals are organized and resources available.

High- and low-volume institutions may also attract different patient groups. For example, in some countries including Norway, many people live in rural areas and may not have immediate access to high-volume hospitals. Considering that some vascular conditions requires urgent treatment, many patients rely on their local hospital in case of an emergency. This may explain why some studies report that low-volume hospitals see more urgent admissions than high-volume institutions (7, 8).

These issues are examples of selection bias that can be expected in non-randomized trials. Thus, to make judgements about an observed association between volume and quality, it is important to have information about other baseline differences and whether adjustments were made to control for confounding factors.

Previous research

The Norwegian Knowledge Centre for the Health Services has previously summarized the available research on the relationship between patient volume and quality for cardiovascular surgery (9-11). The authors of these reports found that volume had an impact on quality in surgery for abdominal aortic aneurysms, while the association was judged to be uncertain in surgical treatment of atherosclerosis/narrowing of the carotid artery and in the lower extremities (9, 10). Systematic reviews in this area are essential to inform policy makers, health professionals and others in decisions about the organization or choice of treatment location. Following a request from South-Eastern Norway Regional Health Authority in 2014, we performed an update of this evidence base by conducting a systematic review of research on the relationship between patient volume and quality in vascular surgery.

Method

This report is a systematic review of primary studies. The report was conceptualized and conducted based on the Knowledge Center's method of systematic reviews (12). For a detailed description of our methods, please consult our method book which can be found on our website http://www.kunnskapssenteret.no/verktoy/slik-oppsummerer-vi-forskning

Inclusion criteria

In preparing the protocol to this systematic review, we judged it unlikely that we would find randomized studies evaluating the relationship between patient volume and quality. We based this on a scoping search we performed early in the process, but also based on a judgement that the impact of patient volume on quality would be difficult to study using experimental designs.

Therefore, we applied more generous inclusion criteria encompassing also observational studies for this systematic review. Observational studies potentially have a higher risk of bias compared to randomized studies, particularly when it comes to controlling for unknown confounders due to selection bias. However, when conducted properly, observational studies are well suited to explore this kind of research question, and may provide evidence of high certainty. In case the research question had already been addressed in a recent systematic review, or was in progress, we also searched for systematic reviews. Our inclusion criteria are further presented in frame 1.

Study designs:	Systematic reviews, randomised trials and other experimental designs, observational studies with two or more units in each group
Population:	Patients undergoing vascular surgery
Intervention:	Higher volume (per hospital, surgeon or other unit)
Comparison:	Lower volume (per hospital, surgeon or other unit)
Outcome:	All clinical outcomes such as mortality, complications, as well as use of resources and costs
Language:	No restrictions

Frame 1. Inclusion criteria

Literature search

We searched for systematic reviews in Epistemonikos, Cochrane Library (CDSR, DARE, and HTA), MEDLINE (Ovid) and EMBASE (Ovid) from 2010 to December 2015. We searched for primary studies in the Cochrane Library (CENTRAL), MEDLINE (Ovid) and EMBASE (Ovid). We also searched for ongoing studies in clinicaltrials.gov, and for gray literature in Open Grey and GreyLit. We used a combination of text words and Mesh terms for procedures, volume and relevant study designs, and combined these three components. The full search strategy can be found in Appendix 1. A research librarian (GHS) designed the search strategy with input from the working group, and another research librarian (MJ) reviewed this search strategy.

Article selection

All references were assessed independently by two authors using the predetermined inclusion criteria (AA, VU, GHS and LF). All references that were judged to possibly meet these criteria, were assessed in full-text by at least two authors (AA, VU, GHS and LF). In case of disagreement, a third author was consulted to reach consensus. In some cases were the cut-off between types of procedures was unclear for example between vascular and cardiac procedures, we conferred with an expert in vascular surgery (AKL).

Assessment of included studies and risk of bias

All full-text papers that were judged to meet the inclusion criteria were assessed for risk of bias using the Knowledge Center' s own checklist for observational studies (12). In this assessment, we took into consideration whether the study' author had adjusted for patient and hospital factors.

Data extraction

One author (AA) extracted data from all included papers, and another author quality assured this (VU, GHS or LF). We extracted data on unit of volume (hospital or surgeon), type of diagnosis, type of procedure, setting (country), number of patients/ procedures, volume cut-offs used, included outcomes and the results on these outcomes.

All data were entered into Excel, and volume-comparisons were sorted by the following criteria: diagnosis, severity of disease (acute/elective/all patients), type of procedure (endovascular/open/all procedures), unit of which volume was determined (hospital/ surgeon), and type of outcome (mortality/complications/length of stay/costs/process measures).

Analyses

After we had extracted the data, a statistician reviewed the data for potential meta-analysis, but the studies were considered too heterogeneous. There were two main reasons for this: the difference in volume-cut offs used and that a variety of statistical methods were performed across studies. Consequently, all results were summarized and reported descriptively. Data was entered as reported by the study authors into an Excel sheet, relying on adjusted results when available. We did not make any attempts to reanalyze the data.

Assessment of certainty of evidence

We assessed the certainty of the evidence using the GRADE approach. This is a system for rating the certainty of a body of evidence in systematic reviews and other evidence syntheses, such as health technology assessments, and guidelines and grading recommendations in health care (12).

The GRADE approach relies on judgments about grading the evidence down or up considering the following excplicit criteria to determine our confidence in the findings. Criteria that are used to potentially downgrade the evidence are study design, risk of bias, inconsistency of results, indirectness of evidence, imprecision and publication bias. There are also factors that can increase our confidence in the certainty of the evidence; these include large effects, dose-response gradients and effect of plausible residual confounding.

Based on these criteria, the certainty of evidence is graded to fall into one of four categories: “high”, “medium”, “low” or “very low” certainty. In cases were the certainty is judged to be “very low”, the evidence base is so uncertain that it does not provide a reliable basis to make conclusions.

Results

Description of studies

Results of literature search

Our search resulted in 2365 articles. In addition to the reviews previously conducted by the Knowledge Center, fourteen of these articles were systematic reviews that included vascular diseases; however, these were either outdated or only partly relevant. Consequently, none of these was included; see Appendix 2 for a list of these reviews. We included 89 studies that evaluated the relationship between patient volume and vascular surgery on quality (see Figure 1 and Appendix 3). Some of these studies evaluated the impact of volume on more than one diagnosis in separate analyses. We also identified five potentially relevant conference abstracts (13-17).

We excluded studies that did not meet our inclusion criteria. In most cases, this was because the studies did not include vascular surgery as part of their analysis, or if the evaluations included too few sites (see Appendix 4 for a list of examples).

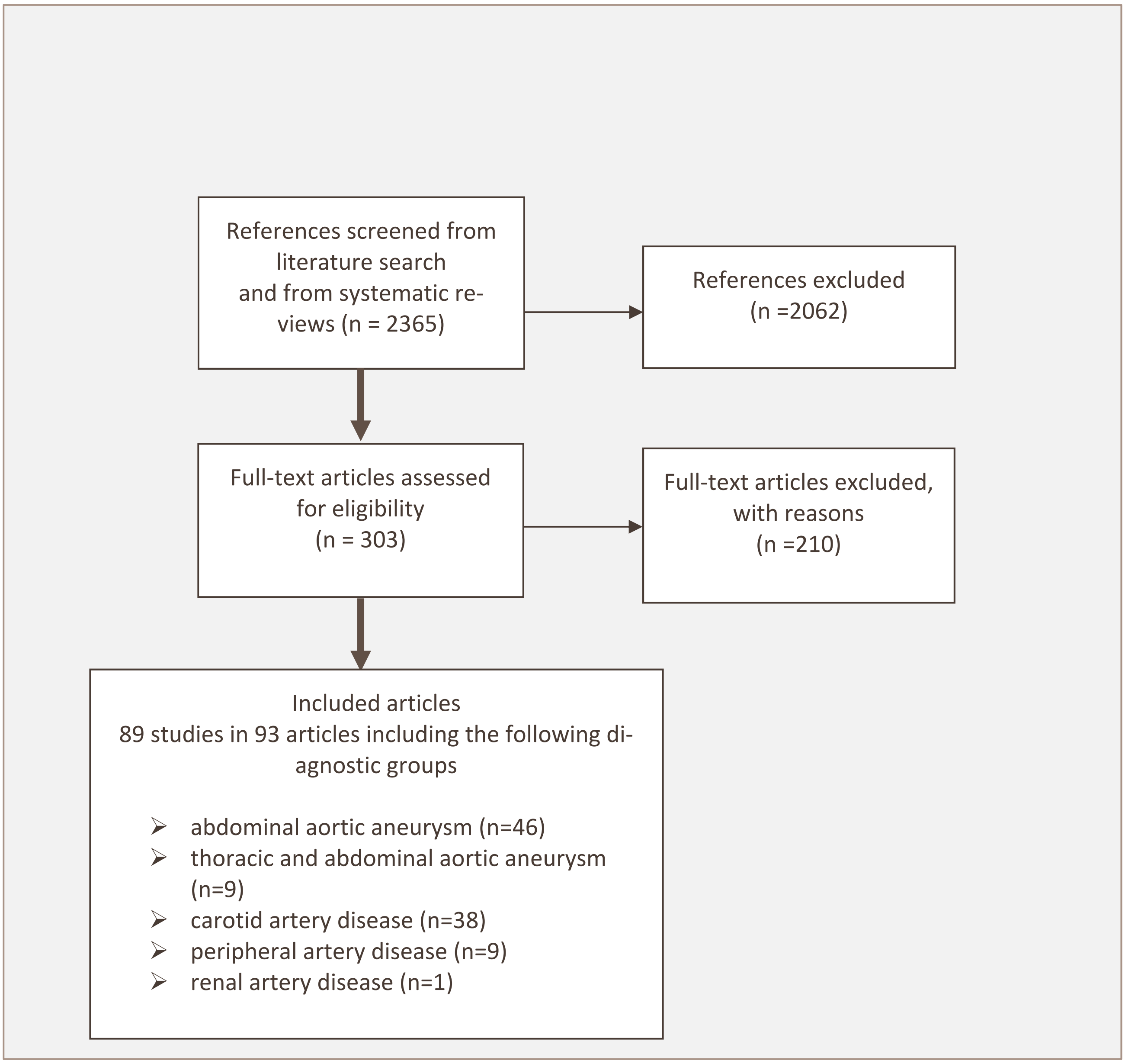

Figure 1. Flowchart of literature search and identification of relevant studies

Context, conceptualization of volume and outcomes

The studies were conducted in a range of settings, and in most cases drawing upon large and diverse samples. Overall, the studies were conducted in USA (69 studies), Canada (6 studies), UK (4 studies), Finland (3 studies), Germany (2 studies), Australia (1 study), Norway (1 study), Japan (1 study), one study included samples from both USA and UK, and one study was an international study including samples from France, Germany, and England. The smallest study included 155 patients and the largest study included 491 779 patients. Across studies, the data collection took place from 1982 to 2011.

The majority of the studies evaluated the volume-quality relationship by hospital level; however, some also assessed this relationship on the surgeon level.

Outcomes evaluated were consistent across studies, and included mortality (84 studies), complications (including also combined measures of complications and mortality)

(41 studies), length of stay (days in intensive care and days in hospital) (23 studies), and costs (resource use) (12 studies).

Risk of bias in the included studies

All the included studies used observational designs. The studies had mainly two weaknesses: in many cases, patient factors and other confounders were not reported per group at baseline, and not all studies reported whether they had taken these factors into account in their analyzes (see table 1). Overall, we judged 13 studies to have low risk of bias, 62 studies to have unclear risk of bias and 14 studies to have high risk of bias (see Appendix 5). Although all of these studies included data of the volume-quality relationship over time drawn, in most cases they were analysed as cross-sectional studies. Despite this, we used the checklist for cohort studies and not for cross-sectional studies when assing the risk of bias of the included studies. The reason for this is that the cohort study checklist also includes important criteria related to differences in baseline and adjustments not captured by the cross-sectional study checklist.

Diagnostic groups and procedures evaluated

The included studies evaluated the impact of volume on quality for the following diagnostic groups: abdominal aortic aneurysms (46 studies), thoracic and abdominal aortic aneurysms (9 studies), carotid artery disease (38 studies), peripheral vascular disease (aorto-iliac arteries and lower extremities) (9 studies) and renal artery disease (1 study).

Aortic aneurysms

We included studies addressing two types of aortic aneurysm: abdominal aortic aneurysms (part of aorta in the abdomen) (46 studies) and thoracic aortic aneurysms (part of aorta in the chest) (9 studies). Aneurysm sometimes occur in a blood vessel and is characterized as as an abnormal distention of the blood vessel. Aneurysms can form in any artery, but most commonly occur in the aorta, which is the main blood vessel leading from the heart (5, 18). The likelihood of rupture increases with the size of the aneurysm and can be life threatening. People with aneurysms are also at risk of having a blood clot (thrombus), and of plaque forming at the site of the aneurysm (5).

Carotid artery disease, peripheral vascular disease and renal artery disease

We included studies addressing atherosclerosis/ stenosis of the carotid arteries (38 studies), of the lower extremities (9 studies) and renal arteries (1 study). Fat and cholesterol deposits may build up in the arteries (the blood vessels outside the heart) and cause the arteries to harden and narrow over time (atherosclerosis). These deposits on the inside of the artery walls of fat and cholesterol (called plaque), may narrow the artery over time, and lead to inadequate blood flow to the body's tissue (ischemia)(6, 19).

Narrowing of the internal carotid arteries (two of four major blood vessels that supply blood to the brain) may lead to stroke or death (6). If plaque builds up in the major arteries that supply oxygen-rich blood to the legs, arms, and pelvis, peripheral artery disease is established. A blockade of the arteries in the legs can cause pain, cramps, change of skin colour, sores and ulcers and discomfort. In worst case, a blockage of these arteries can cause gangrene and loss of limb (amputation)(20). Narrowing of the renal arteries that supply blood to one or more of the kidneys may lead to hypertension and kidney damage (21).

Thresholds used for patient volume

The included studies used a variety of different cut-off values for determining volume categories. An overview of median thresholds in the included studies can be seen in Table 1, the full overview of thresholds by study can be found in Appendix 11.

Table 1. Annual median thresholds by diagnosis and procedure

	Low volume	**High volume**
Abdominal aortic aneurysms: hospital volume open surgery		
Elective	<9	>35
Acute	<9	>18
Abdominal aortic aneurysms: hospital volume endovascular procedures		
Elective	<9	>50
Acute	<4	>10
Abdominal aortic aneurysms: surgeon volume open surgery		
Elective	<2	>11
Acute	<3	>11
Abdominal aortic aneurysms surgeon volume endovascular procedures		
Elective*	<4	>24
Thoracic and abdominal aortic aneurysms: hospital volume open surgery		
Elective	<3	>5
Acute	<2	>4
Thoracic and abdominal aortic aneurysms: surgeon volume open surgery		
Elective*	<2	>3
Thoracic and abdominal aortic aneurysms: surgeon volume endovascular procedures		
Elective*	<5	>16
Carotid artery disease: hospital volume open surgery		
Elective	<20	>100
Carotid artery disease: hospital volume endovascular procedures		
All	<40	>150
Carotid artery disease: surgeon volume open surgery		
All	<7	>35
Carotid artery disease: surgeon volume endovascular procedures		
All	<20	>55
Peripheral artery disease: hospital volume open surgery		
All	<25	>88
Peripheral artery disease: hospital volume endovascular procedures		
All*	<36	>126
Peripheral artery disease: surgeon volume endovascular procedures		
All*	<17	>17
Renal artery disease: hospital volume open surgery		
All*	<2	>5
*Only one study		

We present the results below sorted by diagnosis and procedure based on the summary of findings tables resulting from the GRADE approach for assessing the certainty of the evidence. The complete result tables per diagnosis group can be seen in Appendices 6 to 10. It is important to note that for some of the studies there was an overlap in time and of samples drawn from the same databases. In such cases we have included the studies with the lowest risk of bias and/ or those that had the greatest samples into the summary of findings tables. For each group of diagnoses, we present the results by outcome, sorted by type of admission (all patients/ elective admissions/ acute admissions), type of volume (hospital/ surgeon).

Abdominal aortic aneurysms

We included 46 studies evaluating the volume-quality relationship for abdominal aortic aneurysms. Thirty-six studies were conducted in USA (7, 22-56), four in the UK (England) (26, 57-59), four in Canada (60-63), one in Finland (64, 65), one in Germany (66), and one in Norway (67). One study reported from samples in two settings (USA and UK). The number of patients per study ranged from 434 to 182 843. All results can be found in Appendix 6, the summary of findings is presented below.

All surgery for abdominal aortic aneurysms

The summary of findings is based on fourteen studies including a range of 224 401 to 2601 patients conducted in USA (7, 22, 24-26, 32, 34, 35, 43, 44, 54, 68), Canada (60-62) and UK (England)(26, 59) (see Table 2).

Overall, there are possibly fewer deaths within 30 days among patients treated at high-volume hospitals or by high-volume surgeons in studies including both acute and elective patients, and in studies examining elective admissions separately. There is also possibly lower incidence in 30-day mortality in acute patients treated by high-volume surgeons. We judged the certainty of the evidence for these outcomes to be low.

For the relationship between hospital volume and 30-day mortality for acute admissions, the certainty of the evidence is very low.

We found that patients treated at high-volume hospitals possibly have lower risk of hospital mortality and fewer complications for all patient groups. We assessed the certainty of the evidence for these outcomes to be low.

We judged the impact of patient volume on days of hospitalization and costs, to be of very low certainty.

Table 2. The association between patient volume and quality for all surgery

Population: patients with abdominal aortic aneurysms
Intervention: higher volume of patients
Comparison: lower volume of patients
Context: USA, Canada and England

Outcomes	Results	Summary of estimate of effects («←» in favour of low volume, «→»in favour of high-volume «?» uncertainty)	Number of participants (studies)	Certainty of the evidence (GRADE)
Mortality (30-days) (hospital volume)	**All patients** Gonzalez 2014: odds of death was higher in low-volume compared to high-volume (OR 1.80, 95% CI 1.56 to 2.07) (n=20 690)	→ **In favour of high volume**	20 690 patients (1 study)	⊕⊕⊖⊖ **Low**[1,2]
	Elective admissions Birkmeyer 2002: odds for death was lower in high-volume compared to low-volume (OR 0.58, 95% CI 0.53 to 0.65) (n=140 577) Bush 2006: odds for death was higher in low-volume compared to high-volume (OR 1.89, 95% CI 1.19 til 2.98, p< 0.006) (n=1 904) Dueck 2004: reported as not statistically significant, estimates not available (n=13 701) Massarweh 2011: little or no difference in both time points (year 1: -0.05%, p=0.58, and year 2: 1.2%, p=0.12) (n=7 724) Reames 2014: odds for death was higher in low-volume compared to high-volume, range over time points from OR 1.59 (95% CI 1.35 to 1.88) to OR 1.28 (95% CI 1.07 to 1.52) (approximately n= 54 216) Urbach 2004: the odds for death was lower in high-volume compared to lower volume (OR 0.62, 95% CI 0.46 to 0.83) (n=6 279)	→ **In favour of high volume**	224 401 patients (6 studies)	⊕⊕⊖⊖ **Low**[1]
	Acute admissions Dueck 2004: reported as not statistically significant, estimates not available (n=2 601)	? **Uncertain**	2 601 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,3]
Mortality (30-days) (surgeon volume)	**Elective admissions** Birkmeyer 2003: odds for death was higher in low-volume compared to high-volume (OR 1.55, 1.36 to 1.77) (n=39 794) Dueck 2004: odds for death was lower in high-volume (hazard ratio 0.91, 95% CI 0.88 to 0.94) (n=13 701)	→ **In favour of high volume**	54 495 patients (2 studies)	⊕⊕⊖⊖ **Low**[1]

	Acute admissions Dueck 2004: odds for death was lower in high-volume compared to low-volume (hazard ratio 0.87, 95% CI 0.81 to 0.94) (n=2 601)	→ **In favour of high volume**	2 601 patients (1 study)	⊕⊕⊖⊖ **Low**[1,2]
In-hospital mortality (hospital volume)	**All patients** Gonzalez 2014: odds for failure to rescue was higher in low-volume compared to high-volume (OR 1.38, 95% CI 1.16 to 1.64) (n=20 690) Hernandez-Boussard 2012: lower mortality in high-volume compared to low-volume (-2.43%, p<0.0001 (n=182 843) Jibawi 2006: higher volume was associated with lower mortality (Pearson's correlation coeffisient -0.447, p<0.001), the threshold for little or no difference in mortality was found to be 14 yearly elective procedures per year (n=31 078)	→ **In favour of high volume**	234 611 patients (4 studies)	⊕⊕⊖⊖ **Low**[1]
	Elective admissions Hill 2008: odds for death was lower in high-volume compared with low-volume (OR 0.6, 95% CI 0.5 to 0.7) (n=46 901)	→ **In favour of high volume**	46 901 patients (1 study)	⊕⊕⊖⊖ **Low**[1,2]
	Acute admissions Kartikesalingam 2014 (UK): numbers not reported, only p-value for the association of hospital volume with in-hospital mortality (p<0.0001) (n=11 799) Kartikesalingam 2014 (USA): numbers not reported, only p-value for the association of hospital volume with in-hospital mortality: (p<0.0001) (n=23 838)	?→ **Uncertain/ in favour of high volume**	35 637 patients (2 studies)	⊕⊕⊖⊖ **Low**[1,3]
In-hospital mortality (surgeon volume)	Not reported		-	-
Complications (hospital volume)	**All patients** Hernandez-Boussard 2012: there were fewer patients with one or more complications in high-volume compared to low-volume (-1.61%, p<0.001) (n=18 2843) Gonzalez 2014: odds for complications were higher in low-volume compared to high-volume (OR 1.18, 95% CI 1.09 to 1.27) (n=20 690)	→ **In favour of high volume**	203 533 patients (2 studies)	⊕⊕⊖⊖ **Low**[1]

	Elective admissions Allareddy 2010: odds for complications were lower in high-volume compared to low-volume (OR 0.89, 95% CI 0.81 to 0.98) (n=35104) Bush 2006: the association is uncertain (p=0.17) (n=1904) Masserweh 2011: two time points, the association is uncertain in the first time point (-3.1%, p=0.93), but there were fewer complications in high-volume at the second time point (-6.2%, p=0.03) (n=7724) Regenbogen 2012: there were fewer complications in high-volume compared to low-volume (-3%, p<0.0001) (n=69 141)	→ **In favour of high volume**	113 873 patients (4 studies)	⊕⊕⊖⊖ **Low**[1]
Complications (surgeon volume)	Not reported		-	-
Length of stay (hospital volume)	**Elective admissions** Masserweh 2011: two time points, the association was uncertain for both years (year 1: -2.1%, p=0.93, and year 2: -0.1%, p=0.82) (n=7724)	? **Uncertain**	7 724 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,3,4]
Length of stay (surgeon volume)	Not reported		-	
Costs (hospital volume)	**Elective admissions** Regenbogen 2012: higher costs in low-volume for home health (20.59%), physician services (15.1%), post-discharge ancillary care (29.5%), readmissions (10.5%) and nursing services (31.2%). Lower costs in outpatient care for low-volume (-18%) (n=69 141)	?→ **Uncertain/ In favour of high volume**	69 141 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,3,4,5]
Costs (surgeon volume)	Not reported		-	-

1. Observational studies
2. We decided not to downgrade because of one study because of consistency with other studies on same outcome for abdominale aortic aneurysms
3. Effect estimate or measures of uncertainty not reported
4. Imprecision: one study
5. Directness: relevance difficult to assess

Open surgery for abdominal aortic aneurysms

The summary of findings is based on 25 studies including 155 to 78 257 patients of which 18 were conducted in USA (27-30, 36, 39-41, 45-48, 50-53, 55, 56, 69), one in Norway (67), one in Finland (64, 65), two in UK (England)(57, 58), one in Germany (66) and two in Canada (63, 70) (see table 3).

For acute and elective admissions undergoing open surgery overall, there are possibly fewer deaths within 30 days among those who were treated at high-volume hospitals. We assessed the certainty of the evidence for this outcome as low.

For elective admissions and acute admissions assessed separately for hospital volume, the relationship with 30-day mortality is uncertain. There is also considerable uncertainty about the relationship between surgeon volume and 30-day mortality. We assessed the certainty of the evidence for these outcomes as very low.

When it comes to hospital mortality, there is probably a lower incidence in patients treated at high-volume hospitals (low certainty) or by high-volume surgeons for all patient groups (moderate certainty- upgraded for large effect).

For all patients admitted, we found a possibly lower incidence of complications in high volume institutions. For the association between surgeon volume and days of hospitalization there is possibly little or no association. We assessed the certainty of the evidence for these outcomes to be low.

We judged the certainty of the evidence to be very low for the relationship between patient volume and mortality for elective and acute admissions evaluated separately, as well as for complications for people with acute admissions, and for days of hospitalization and costs for all patient groups.

Table 3. The association between patient volume and quality for open surgery

Population: patients with abdominal aortic aneurysms
Intervention: higher volume of patients
Comparison: lower volume of patients
Context: USA, Norway, Finland, Germany, UK (England) and Canada

Outcomes	Results	Summary of estimate of effects («←» in favour of low volume, «→»in favour of high volume «?» uncertainty)	Number of participants (studies)	Certainty of the evidence (GRADE)
Mortality (30-days) (hospital volume)	**All patients** Dimick 2008: odds of death was higher in low-volume compared to high-volume (OR 1.52, 95% CI 1.35 to 1.72) (n=54 203)	→ **In favour of high volume**	54 203 patients (1 study)	⊕⊕⊖⊖ **Low**[1]
	Elective admissions Amundsen 1990: odds of death was higher in low-volume compared to high-volume (OR 2.7, p=0.04) (n=279) Kantonen 1997: reported as no association (numbers not available) (n=929) Khuri 1999: lower volume did not predict mortality, based on logistic regression (-0.02844 (SE 0.02), p=0.10) (n=3 767) Landon 2010: lower mortality with higher volume with an absolute reduction of 3 percentage points (n=78 257)	? **Uncertain**	83 232 patients (4 studies)	⊕⊖⊖⊖ **Very low**[1,2]

	Acute admissions Amundsen 1990: odds of death was higher in low-volume compared to high-volume, but the estimate is uncertain (OR 1.9, p=0.14), (n=155) Kantonen 1997: reported as no association (numbers not available) (n=610)	? **Uncertain**	765 patients (2 studies)	⊕⊖⊖⊖ **Very low**[1,2]
Mortality (30-days) (surgeon volume)	**Elective admissions** Huber 2001: lower mortality in higher volume compared to low-volume (-3.5%) (n=unclear)[3] Kantonen 1997: lower mortality in higher volume compared to low-volume (p<0.01) (n=929)	→ **In favour of high volume**	>929 patients (2 studies)	⊕⊖⊖⊖ **Very low**[1,2]
	Acute admissions Kantonen 1997: reported as no association (numbers not available) (n=610)	? **Uncertain**	610 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,2]
In-hospital mortality (hospital volume)	**All patients** Pronovost 1999: odds of death was higher in low-volume compared to high-volume (OR 1.7, 95% CI 1.3 to 2.3) (n=2 606) Glance 2007: volume was not found to be an important predictor of mortality (n=8 855)	?→ **Uncertain / in favour of high volume**	11 461 patients (2 studies)	⊕⊕⊖⊖ **Low**[1]

Elective admissions Brooke 2008: the association is uncertain (rate of ratios based on two time points RR 0.80 (95% CI 0.44 to 1.45) (n=6 406) Dardik 1998: the association is uncertain (-7.1%, p=0.53). Not evaluated in multivariate analysis (n=3 293) Dimick 2002b: odds of death was higher in low-volume compared to high-volume (OR 1.71, 95% CI 1.37 to 2.14) (n=7 980) Eckstein 2007: odds of death was higher in low-volume compared to high-volume (OR 1.90, 95% CI 1.12 to 3.22) (n=10 163) Holt 2007: odds of death was lower in high compared to low-volume (OR 0.92, 95% CI 0.88 to 0.96) (n=15 515) Holt 2009: odds of death was lower in high compared to low-volume (OR 0.99, 95% CI 0.989 to 0.999) (n=5 668) Manheim 1998: odds of death was lower in high compared to low-volume (OR 0.84, p<0.001) (n=unclear)[,3] McPhee 2011: odds of death was higher in low-volume compared to high-volume, but the estimate is uncertain (OR 1.6, 95% CI 0.98 to 2.7) (n=unclear)[,3] Rutledge 1996: more people survived in high-volume compared to low-volume, but the estimate is uncertain (p=0.59) (n=12 658) Tu 2001: odds of death was higher in low-volume compared to high-volume (OR 1.83, 95% CI 1.01 to 3.32, p< 0.04) (n=5 878) Vogel 2011: odds of death was higher in low-volume compared to high-volume (OR 1.22, 95% CI 1.04 to 1.44) (n=17 210) Wen 1996: mortality decreased by 10 additional volume units (OR 0.94, 95% CI 0.88 to 0.99) (n=5 492)	→ **In favour of high volume**	>90 263 patients (12 studies)	⊕⊕⊖⊖ **Low**[1]

	Acute admissions Dardik 1998: the association is uncertain (-1.5%, p=0.8). Not evaluated in multivariate analysis (n=527) Dimick 2002b: odds of death was higher in low-volume compared to high-volume (OR 1.43, 95% CI 1.15 to 1.78) (n=5 907) Holt 2007: little or no association for patients with rupture (OR 0.98, 95% CI 0.95 to 1.02) (n=6462) / odds of death was lower in high-volume compare to low-volume for acute admissions (OR 0.94, 95% CI 0.90 to 0.99) (n=4 845) Manheim 1998: odds of death was lower in high-volume compared to low-volume (OR 0.49, p<0.001) (n=unclear) [,3] McPhee 2009: odds of death was higher in low-volume compared to high-volume (OR 1.24, 95% CI 1.01 to 1.52) (n=unclear) [,3] Rutledge 1996: more people survived in high-volume compared to low-volume, the association is uncertain (p=0.23) (n=1 480) Wen 1996: little or no association (OR 0.97, 95% CI 0.91 to 1.03) (n=1 203)	?⟶ **Uncertain / in favour of high volume**	>13 962 patients (7 studies)	⊕⊖⊖⊖ **Very low**[1,2]
In-hospital mortality (surgeon volume)	**All patients** Pronovost 1999: reported as not statistical significant (n=2 606)	? **Uncertain**	2 606 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,2]
	Elective admissions Dimick 2003: higher volume was associated with a 40% reduction in mortality (95% CI 12% to 60%, p<0.01) (n=3 912) McPhee 2011: odds of death was higher in low-volume compared to high-volume (OR 2.0, 95% CI 1.3 to 3.1) (n=unclear) [,3] Pearce 1999: a doubling in surgeon volume was associated with a risk reduction of 11% (coefficient relative risk ratio 0.9, p=0.0002) (n=13 415)	⟶ **In favour of high volume**	>17 327 patients (3 studies)	⊕⊕⊕⊖ **Moderate**[1,4]
	Acute admissions Dardik 1998: odds of death was lower in high-volume compare to low-volume (OR 0.54, 95% CI 0.33 to 0.88, p<0.014) (n=527) Modrall 2011: little or no association between abdominal aortic aneurysm procedure volume and mortality, but surgeons with a higher vascular surgery volume overall had a lower odds of death (OR 0.94, 95% CI 0.992 to 0.996, p<0.0001) (n=22 986) Rutledge 1996: an association between higher volume and survival was found (p-value for logistic regression is 0.025) (n=1 480)	?⟶ **Uncertain / in favour of high volume**	24 993 patients (3 studies)	⊕⊕⊖⊖ **Low**[1]

Complications (hospital volume)	**All patients** Dimick 2002a: lower risk of complications in higher volume; lung failure (RR 0.45, 95% CI 0.36 to 0.55), reintubation (RR 0.53, 95% CI 0.44 to 0.64), pneumonia (RR 0.74, 95% CI 0.55 to 0.99), heart complications (RR 0.63, 95% CI, 0.51 to 0.78), and shock (RR 0.27, 95% CI 0.10 to 0.78) (n=2 987)	→ **In favour of high volume**	2 987 patients (1 study)	⊕⊕⊖⊖ **Low**[1 5]
	Elective admissions Holt 2007: reported as no association (n=15 515) Eckstein 2007: reported as little or no association, not evaluated in multivariate analysis (n=10 163) Vogel 2011: reported as no statistical significant association for most complications with the exception of sepsis (OR 1.36, 95% CI 1.11 to 1.68) and pneumonia (OR 1.23, 95% CI 1.08 to 1.40) (n=17 210)	? **Uncertain**	42 888 patients (3 studies)	⊕⊖⊖⊖ **Very low**[1,2]
	Acute admissions Holt 2007: little or no association for patients with rupture (n=6 462) or acute admissions (n=4 845). Kantonen 1997: reported as little or no association (n=610)	? **Uncertain**	11 917 patients (2 studies)	⊕⊖⊖⊖ **Very low**[1,2]
Complications (surgeon volume)	Not reported		-	-
Length of stay (hospital volume)	**All patients** Dimick 2002a: reported as no statistical significant association (n=2 987) Pronovost 1999: 6% longer hospital stay for patients in low-volume, but the association is uncertain (95% CI -3% to 15%) (n=2 606)	? **Uncertain**	5 593 patients (2 study)	⊕⊖⊖⊖ **Very low**[1,2]
	Elective admissions Brooke 2008: reported as no statistical significant association (n=6 406) Dimick 2002b: reported as no statistical significant association (n=7 980) Eckstein 2007: four days (median) longer stay in low-volume (p<0.001), not evaluated in multivariate analysis (n=10 163) Holt 2007: longer length of stay in low-volume (p<0.001) (n=15 515) Vogel 2011: 0.34 mean days longer length of stay in low-volume (p<0.004) (n=17 210) Wen 1996: with 10 more additional cases, there was a reduction in length of stay in high-volume compared to low-volume (OR 0.29, 95% CI 0.22 to 0.35) (n=5 492)	?→ **Uncertain / in favour of high volume**	62 766 patients (5 studies)	⊕⊕⊖⊖ **Low**[1]

	Acute admissions Dardik 1998: the association is uncertain (-2.4%, p=0.15), not evaluated in multivariate analysis (n=527) Dimick 2002b: reported as no statistical significant association (n=5 907) Holt 2007: longer length of stay for acute admissions in higher volume (p<0.041)(n=4845), little or no association for patients with rupture (p=0.806) (n=6 462) Wen 1996: little or no association (-0,12 days, 95% -0.46 to 0.22) (n=1 203)	? **Uncertain**	18 944 patients (4 studies)	⊕⊕⊖⊖ **Low**[1]
Length of stay (surgeon volume)	**Acute admissions** Dardik 1998: the association is uncertain (11.7 days in low-volume versus 12.4 in high volume p=0.46), not evaluated in multivariate analysis (n=527)	? **Uncertain**	527 patients (1 study)	⊕⊕⊖⊖ **Low**[1,5]
Costs (hospital volume)	**Elective admissions** Vogel 2011: lower hospital costs in high-volume -9768 USD, and for equipment -2037 USD (p<0.0001) (n=17 210)	→ **In favour of high volume**	17 210 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,6,7]
	Acute admissions Dardik 1998: lower hospital costs per patient in high-volume but the association is uncertain (-5481 USD, p=0.10), not evaluated in multivariate analysis (n=527)	? **Uncertain**	527 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,6,7]
Costs (surgeon volume)	**Acute admissions** Dardik 1998: lower hospital costs per patient in high-volume (-3622 USD, p=0.018), not evaluated in multivariate analysis (n=527)	→ **In favour of high volume**	527 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,6,7]

1. Observational studies
2. Effect estimate or measures of uncertainty not reported
3. Total number of patients is reported in Appendix 3, number of patients per comparison unclear
4. Upgraded for large effect
5. We decided not to downgrade because of one study because of consistency with other studies on same outcome for abdominale aortic aneurysms
6. Imprecision: one study
7. Directness: relevance difficult to assess

Endovascular surgery for abdominal aortic aneurysms

The summary of findings is based on seven studies including 42 155 to 1645 patients of which six were conducted in USA (29, 39-41, 45, 47) and one in UK (England) (58) (see table 4).

For endovascular surgery, there are possibly fewer deaths within 30 days among those treated at high-volume hospitals for both elective and acute admissions combined. We assessed the certainty of the evidence for this outcome as low. For elective admissions studied separately, the certainty of the evidence was very low.

For patients treated in high-volume hospitals there is possibly a lower incidence of hospital mortality overall, as well as for elective patients considered separately. There is also possibly fewer deaths for acute admissions evaluated separately, but the confidence interval was wide and also included possible benefits for patients treated at low-volume institutons. This is also the case for relationship between surgeon volume and hospital mortality for elective patients. We assessed the certainty of the evidence for these outcomes to be low.

For the relationship between hospital volume and complications, there are possibly fewer complications among elective patients treated at high-volume hospitals.

There is insufficient evidence on the relationship between hospital volume and days of hospitalization, as well as for costs, and the relationship between surgeon volume and relevant outcomes for endovascular surgery.

Table 4. The association between patient volume and quality for endovascular surgery

Population: patients with abdominal aortic aneurysms
Intervention: higher volume of patients
Comparison: lower volume of patients
Context: USA and UK (England)

Outcomes	Results	Summary of estimate of effects («←» in favour of low volume, «→»in favour of high volume «?» uncertainty)	Number of participants (studies)	Certainty of the evidence (GRADE)
Mortality (30-days) (hospital volume)	**All patients** Dimick 2008: odds of death was higher in low-volume compared to high-volume (OR 1.68, 95% CI 1.32 to 2.22) (n=2 750)	→ **In favour of high volume**	2 750 patients (1 study)	⊕⊕⊖⊖ **Low**[1,2]
	Elective admissions Landon 2010: mortality by quintile, after adjustment, showed a substantial decrease by higher volume between the first and second quintile (2.5% versus 1.6%), with continued minor decreases over quintiles 3 to 5 (n=29 390)	→ **In favour of high volume**	29 390 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,3]
Mortality (30-days) (surgeon volume)	Not reported		-	
In-hospital mortality (hospital volume)	**All patients** Holt 2009: odds of death was lower in higher volume compared to low-volume (OR 99, 95% CI 0.98 to 1.00) (n=2 750)	→ **In favour of high volume**	2 750 patients (1 study)	⊕⊕⊖⊖ **Low**[1,2]

	Elective admissions Brooke 2008: lower risk of death in high-volume but the estimate is uncertain, (ratio of rate ratio of two time points RR 0.39, 95% CI 0.07 to 1.80 (n=3 120) McPhee 2011: odds of death was higher in low-volume compared to high-volume, but the estimate is uncertain (OR 2.3, 95% CI 0.96 to 5.3) (n=8 121) Vogel 2011: odds of death was higher in low-volume compared to high-volume (OR 1.35, 95% CI 1.08 to 1.68) (n=42 155)	?→ **Uncertain/ in favour of high volume**	53 396 patients (3 studies)	⊕⊕⊖⊖ **Low**[1]
	Acute admissions McPhee 2009: the association is uncertain (OR 1.06, 95% CI 0.85 to 1.32) (n= unclear) [4]	? **Uncertain**	Unclear (1 study)	⊕⊕⊖⊖ **Low**[1,2]
In-hospital mortality (surgeon volume)	**Elective admissions** McPhee 2011: odds of death was higher in low-volume compared to high-volume, but the estimate is uncertain (OR 1.6, 95% CI 0.76 to 4.4) (n=unclear) [4]	? **Uncertain**	Unclear (1 study)	⊕⊕⊖⊖ **Low**[1,2]
Complications (hospital volume)	**Elective admissions** Vogel 2011: fewer complications overall in high-volume compared to low-volume (-0.4%), in the multivariate analysis lower volume predicted pneumonia (OR 1.34, 95% CI 1.11 to 1.63) and sepsis (OR 1.44, 95% CI 1.03 to 2.01) (n=42 155)	→ **In favour of high volume**	42 155 patients (1 study)	⊕⊕⊖⊖ **Low**[1,2]
Complications (surgeon volume)	Not reported		-	-
Length of stay (hospital volume)	**All patients** Holt 2009: median hospital days was lower in high-volume compared to low-volume, with 7.25 days in the highest volume quintile compared to 10.2 days in the remaining quintiles (-2.95 days) (n=1 645)	→ **In favour of high volume**	1 645 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,3]
	Elective admissions Brooke 2008: reported as not statistical significant (n=3 120) Vogel 2011: fewer hospital days in low-volume compared to high-volume (-0.27 days, p<0001) (n=42 155)	? **Uncertain**	45 275 patients (2 studies)	⊕⊖⊖⊖ **Very low**[1,3]
Length of stay (surgeon volume)	Not reported		-	
Costs (hospital volume)	Not reported		-	
Costs (surgeon volume)	Not reported		-	

1. Observational studies
2. Decided not to downgrade because of consistency with other studies on same outcome
3. Effect estimate or measures of uncertainty not reported
4. Total number of patients is reported in Appendix 3, number of patients per comparison unclear

Thoracic and abdominal aortic aneurysms

We included nine studies evaluating the volume-quality relationship for thoracic and abdominal aortic aneurysms. Most of the studies adressed several diagnostic groups, including both thoracic and abdominal aortic surgery. Consequently, for pragmatic reasons we decided to treat these studies witihin the same comparisons. However, we would like to remind the reader that the results of each inidvidual study and associated diagnostic codes are reported in appendix 7. Eight studies were conducted in USA (38, 71-77) and one in Japan (78). The summary of findings is presented below.

All surgery for thoracic and abdominal aortic aneurysms

The summary of findings is based on two studies including 731 to 2 875 patients from USA (75) and Japan (78) respectively (see table 5).

The studies evaluated the association of mortality, complications, length of stay and costs with hospital volume. We judged the certainty of the evidence for all of these outcomes to be very low.

Table 5. The association between patient volume and quality for all procedures

Population: patients with thoracic and abdominal aortic aneurysms
Intervention: higher volume of patients
Comparison: lower volume of patients
Context: USA, Japan

Outcomes	Results	Summary of estimate of effects («←» in favour of low volume, «→»in favour of high volume «?» uncertainty	Number of participants (studies)	Certainty of the evidence (GRADE)
Mortality (30-days) (hospital volume)	**All patients** Miyata 2009: the odds of death was lower in high-volume compared to low-volume (OR 0.98 to 0.99, p=0.03) (n= 2 875)	→ **In favour of high volume**	2 875 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,2]
	Elective admissions Gazoni 2010: the odds of death was lower in high-volume compared to low-volume (OR 0.41, 95% CI 0.18 to 0.92, p=0.03) (n= 731)	→ **In favour of high volume**	731 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,2]

Mortality (30-days) (surgeon volume)	**All patients** Miyata 2009: the odds of death was lower in high-volume compared to low-volume (OR 0.99 to 1.01, p=0.3) (n= 2 875)	? **Uncertain**	2 875 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,2]
In-hospital mortality hospital volume)	Not reported	-	-	
In-hospital mortality (surgeon volume)	Not reported	-	-	
Complications (hospital volume)	**Elective admissions** Gazoni 2010: there were fewer complications in high volume hospitals, such as renal failure (23/515 (4.5%) in high and 18/216 (8.3%) in low, p=0.05), prolonged ventilation (86/515 (16.7%) in high-volume and 55/216 (25.5%) in low-volume, p<0.01), and in permanent stroke (25/515 (4.8%) in high and 39/216 (1.4%) in low-volume, p<0.01). There were also fewer cases of reoperation of bleeding (28/515 (5.4%) in high, and 17/216 (7.9%) in low-volume, p=0.23) and pneumonia (34/515 (6.6%) in high and 9/216 (4.2%) in low-volume, p=0.23), but these results were more uncertain (n= 731)	⟶ **In favour of high volume**	731 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,2]
Complications (surgeon volume)	Not reported	-	-	
Length of stay (hospital volume)	**All patients** Gazoni 2010: decreased length of stay with higher volume (OR 0.96, 95% CI 0.94 to 0.95, p=0.001) (n=731)	⟶ **In favour of high volume**	731 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,2,3]
Length of stay (surgeon volume)	Not reported	-	-	
Costs (hospital volume)	**Elective admissions** Gazoni 2010: mean overall cost was lower in high-volume centers compared to low-volume centers (USD -8560, p<0.04).	⟶ **In favour of high volume**	731 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,2,3]
Costs (surgeon volume)	Not reported	-	-	

1. Observational study/ies
2. High risk of bias
3. Imprecision: one study

Open surgery for thoracic and abdominal aortic aneurysms

The summary of findings is based on six studies including 12 573 to 1 188 patients in USA (38, 71-73, 76, 77) (see table 6)

There is possibly lower 30-day mortality in high-volume hospitals for elective and acute patients assessed together. There are also fewer in-hospital deaths in high-volume hospitals for elective and acute patients assessed together, as well as for elective patients considered alone. We considered the certainty of the evidence for these outcomes as low.

For elective patients, there are also fewer deaths during stay for patients treated by high-volume surgeons (moderate certainty- upgraded for large effect).

The certainty of the evidence is very low for in-hospital mortality for acutely admitted patients by hopsital volume.

For complications, length of stay and costs, the certainty of the evidence is also very low.

Table 6. The association between patient volume and quality for open surgery

Population: patients with thoracic and abdominal aortic aneurysms
Intervention: higher volume of patients
Comparison: lower volume of patients
Context: USA

Outcomes	Results	Summary of estimate of effects («←» in favour of low volume, «→»in favour of high volume «?» uncertainty	Number of participants (studies)	Certainty of the evidence (GRADE)
Mortality (30-days) (hospital volume)	**All patients** Goodney 2013: lower risk of death in high-volume compared to low (OR 0.5, 95% CI 0.4 to 0.6, p<0.001) (n=12 573)	→ **In favour of high volume**	12 573 patients (1 study)	⊕⊕⊖⊖ **Low**[1,5]
Mortality (30-days) (surgeon volume)	Not reported	-	-	-
In-hospital mortality (hospital volume)	**All patients** Schermerhorn 2008: higher risk of death in low-volume compared to high-volume (OR 1.3, 95% CI 1.1 to 1.6, <0.05) (n=2 549) Weiss 2014: higher volume had less odds for death compared to low-volume (OR 0.40, 0.17 to 0.96) (n=1 188)	→ **In favour of high volume**	3 737 patients (2 studies)	⊕⊕⊖⊖ **Low**[1]
	Elective admissions Christian 2003: higher risk of death in low-volume compared to high-volume (OR 1.67, 95% CI 1.32 to 2.11, p<0.0001) (n=9 869) Cowan 2003a: higher risk of death in low-volume compared to high-volume (OR 2.2, 95% CI 1.6 to 3.1,p<0.001) (n=1542)	→ **In favour of high volume**	11 411 patients (2 studies)	⊕⊕⊕⊖ **Moderate**[1,6]

	Acute admissions Cowan 2003b: reported as no statistical significant association, numbers not reported (p=0.398) (n=unclear)[4]	? **Uncertain**	>unclear number of patients (1 study)	⊕⊖⊖⊖ **Very low**[1, 4]
In-hospital mortality (surgeon volume)	**Elective admissions** Cowan 2003a: higher risk of death in low-volume compared to high-volume (OR 2.6, 95% CI 1.7 to 4.1, p<0.001) (n=1 542)	→ **In favour of high volume**	1 542 patients (1 study)	⊕⊕⊖⊖ **Low**[1,5]
Complications (hospital volume)	**All patients** Schermerhorn 2008: there was little or no difference between volume categories for complications: % all complications was 44.4 in low and 44.5 in high, p=0.33. % stroke was 2.3 in low, 2.5 in medium and 3.2 in high, p=0.5. % neuro non-stroke was 2.2 in low, 1.3 in medium and 1.3 in high, p=0.26. % respiratory was 12.4 in low, 13.3 in medium and 13.9 in high, p=0.66. % acute renal failure was 10.8 in low, 11.3 in medium and 9.8 in high, =0.58. Variable not explored in multivariate analysis (n=2549) Weiss 2014: the results were very uncertain (OR 1.17 (95% CI 0.74 to 1.86, p=0.51) (n=1 188)	? **Uncertain**	3737 patients (2 studies)	⊕⊕⊖⊖ **Low**[1]
	Elective admissions Cowan 2003a: on average, high-volume hospitals had a higher rate of complications compared to low-volume of 6%, although there was large uncertainty associated with this estimate (p=0.08) (n=1 542)	? **Uncertain**	1542 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,3]
Complications (surgeon volume)	Not reported	**-**	-	
Length of stay (hospital volume)	**All patients** Schermerhorn 2008: patients treated in higher volume had a median 4 days longer stay (p<0.01). Not evaluated in multivariate analysis. (n=2 549)	← **In favour of low volume**	2549 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,3]
	Elective admissions Cowan 2003a: length of stay was one day more in high-volume compared to low-volume (p<0.004) (n=1 542)	← **In favour of low volume**	1542 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,3]
Length of stay (surgeon volume)	Not reported	**-**	-	
Costs (hospital volume)	Not reported	**-**	-	
Costs (surgeon volume)	Not reported	**-**	-	

1. Observational study/ies
2. Imprecision: estimates of uncertainty or numbers not reported
3. Imprecision: one study
4. Number of patients only reported for the complete sample, not by severity or volume unit. See table of included studies.
5. Decided not to downgrade because of consistency with other studies/ dose –response
6. Upgraded for large effect

Endovascular surgery for thoracic and abdominal aortic aneurysms

The summary of findings is based on two studies including >2 013 patients (74, 77) (see table 7).

For high-volume hospitals, there is possibly lower 30-day mortality for all patients. Likewise, for high-volume surgeons, there are possibly lower in-hospital mortality and complications combined for elective patients. We judged the certainty of the evidence to be low for both of these outcomes.

The association between patient volume and quality for endovascular surgery

Population: patients with thoracic and abdominal aortic aneurysms
Intervention: higher volume of patients
Comparison: lower volume of patients
Context: USA

Outcomes	Results	Summary of estimate of effects («←» in favour of low volume, «→»in favour of high volume «?» uncertainty	Number of participants (studies)	Certainty of the evidence (GRADE)
Mortality (30-days) (hospital volume)	**All patients** Goodney 2013: fewer deaths in higher volume, but there were large uncertainties associated with these estimates. (OR 0.7, 95% CI 0.5 to 1.1 p=0.15) (n=2013)	?→ **Uncertain/ in favour of high volume**	2013 patients (1 study)	⊕⊕⊖⊖ **Low**[1,2]
Mortality (30-days) (surgeon volume)	Not reported	-	-	
In-hospital mortality (hospital volume)	Not reported	-	-	
In-hospital mortality and complications (surgeon volume)	**Elective admissions** Modrall 2014: the risk of death was lower in high-volume compared to low-volume (OR 0.85, 95% CI 0.75 to 0.97, <0.02) (n= unclear)[3]	→ **In favour of high volume**	Unclear number of patients (1 study)	⊕⊕⊖⊖ **Low**[1,2]
Complications (hospital volume)	Not reported	-	-	

Complications (surgeon volume)	Not reported	-	-
Length of stay (hospital volume)	Not reported	-	-
Length of stay (surgeon volume)	Not reported	-	-
Costs (hospital volume)	Not reported	-	-
Costs (surgeon volume)	Not reported	-	-

1. Observational study/ies
2. Decided not to downgrade because of consistency with other studies for this outcome

Carotid artery disease

We included 38 studies evaluating the volume-quality relationship for carotid artery disease. Thirty-one studies were from USA (7, 22, 31, 36, 43, 50, 56, 69, 71, 79-91), two were from Canada (92, 93), one from Germany (94), one from Australia (95), one from Finland(96), one study from UK (England)(97) and one study included an international sample including people from France, Germany and UK (England)(98). All results can be found in Appendix 8; the summary of findings is presented below. Please note that the results also includes patients with severe and moderate symptoms, and those with acute admissions to hospitals. These have been sorted under the common heading “Patients with severe and moderate symptoms“ in the summary of findings tables below.

Open surgery for carotid artery disease

The summary of findings is based on 20 studies conducted in USA (7, 22, 43, 50, 69, 71, 80, 82, 85-89, 99-105), one from UK (England) (97) and one from Australia (95) (see table 8).

For hospital and surgeon volume there are possibly lower 30-day mortality and in-hospital mortality in higher volume hospitals based on studies assessing this outcome for all patients. Likewise, there is possibly lower in-hospital mortality for elective patients treated in high-volume hospitals, but the association is uncertain for patients with severe symptoms. There are fewer complications for elective patients and for those with severe symptoms by surgeon volume. We judged the certainty of these outcomes as low.

For length of stay and complications, the certainty of the evidence for hospital volume is very low. For surgeon volume, there is a possibly shorter length of stay for patients treated by high-volume surgeons for all patient groups. We considered this outcome to be of low certainty.

We judged the certainty of the evidence for the relationship between costs and hospital volume to be of very low certainty.

Table 8. The association between patient volume and quality for open surgery

Population: patients with atherosclerosis/ narrowing of the common carotid artery or internal carotid artery
Intervention: higher volume of patients
Comparison: lower volume of patients
Context: UK (England), USA, Australia

Outcomes	Results	Summary of estimate of effects («←» in favour of low volume, «→»in favour of high volume «?» uncertainty	Number of participants (studies)	Certainty of the evidence (GRADE)
Mortality (30-days) (hospital volume)	**All patients** Birkmeyer 2002: there was lower risk of death in all quintiles compared to the lowest volume category (the odds of mortality in highest versus lowest volume category was OR 0.88, 95% CI 0.80 to 0.96) (n=479 289). Khuri 1999: lower volume was not found to be an important predictor of mortality (in logistic regression 0.00357 (SE 0.01, p= 0.72) (n= 10 173) Middleton 2002: reported as no association, numbers not reported (n=666) Reames 2014: there was higher odds of death in low-volume except for year 4 (four time points) OR (95% CI) year 1: 1.32 (1.12–1.56) year 2: 1.31 (1.11 to 1.52) year 3: 1.38 (1.14 to 1.69) year 4: 1.17 (.965 to 1.43) year 5: 1.28 (1.08 to 1.53) (n=mean 125 753) Wennberg 1998: there was lower risk of death in high-volume compared to low. Rate in high-volume was 1.7% (95% CI 1.6% to 1.8%), and low 2.5% (95% 2.0% to 2.9%), p<0.001 (n=113 300)	?→ **Uncertain/ in favour of high volume**	729 181 patients (5 studies)	⊕⊕⊖⊖ **Low**[1]
Mortality (30-days) (surgeon volume)	**All patients** Birkmeyer 2003: lower volume had higher odds of death (OR 1.70, 95% CI 1.51 to 1.91) (n=136 049) Kumamaru 2015: the increased relative risk of 30-day mortality for low-volume surgeons remained statistically significantly higher compared with higher past-year case-volume surgeons. Numbers not reported (n= 454 717) Middleton 2002: there was higher odds of death in high-volume compared to low-volume (OR 4.96, 05% CI 1.00 to 23.57) (n= 666)	?→ **Uncertain/ in favour of high volume**	591 432 patients (3 studies)	⊕⊕⊖⊖ **Low**[1]

In-hospital mortality (hospital volume)	**All patients** Cowan 2002: low-volume hospitals did not have a statistically significant effect, numbers not reported (n=35 821) Hannan 1998: there were lower odds of death in high-volume (OR 0.94, 95% CI 0.74 to 1.19) than in low-volume (OR 1.28, 95% CI 1.13 to 1.45). All compared to statewide mean mortality rate (n= 28 207) Manheim 1998: there was lower odds of death in high-volume compared to low (OR for high versus low 0.86 and very high versus low 0.66, p<0.001) (n=106 493) Nazarian 2008: high-volume hospitals had an odds ratio of death of 0.945 per additional procedure, or 0.055 decrease in the odds of death (p< 0.013), whereas low-volume hospitals had an odds ratio of 0.998 (p=0.563) (n=22 772) Roddy 2000: the association was uncertain, death rates in high-volume was 0.38% versus 0.91% in low-volume (n=10 211) Westvik 2006: rates of in-hospital mortality in high was 0.3%, medium was 0.7%, and low was 0.9%. P-value from the Chi-square test was 0.0008. Results for in-hospital mortality alone was not reported for the multivariate analysis (n=14 288)	?→ **Uncertain/ in favour of high volume**	217 792 patients (6 studies)	⊕⊕⊖⊖ **Low**[1]
	Elective admissions Christian 2003: there was higher mortality in lower volume, but with large uncertainties OR 1.53, 95% CI .860 to 2.72, p=0.15) (n= 17 015) Holt 2007: higher volume had lower odds of death (OR 0.898, 95% CI 0.808 to 0.99, p= 0.047) (n=16 759)	?→ **Uncertain/ in favour of high volume**	33 774 patients (2 studies)	⊕⊕⊖⊖ **Low**[1]
	Patients with severe and moderate symptoms Holt 2007: the association was uncertain (OR 0.97, 95% CI 0.79 to 1.19, p= 0.8) (n=1 489)	? **Uncertain**	1 489 patients (1 study)	⊕⊕⊖⊖ **Low**[1]
In-hospital mortality (surgeon volume)	**All patients** Cowan 2002: there was higher odds of death in low-volume (OR 1.9, 96% CI 1.4 to 2.5) (n=35 821) Hannan 1998: there were lower odds of death in high (OR 1.11, 95% CI 0.99 to 1.25) than in low-volume volume (OR 1.89, 95% CI 1.43 to 2.46). All compared to statewide mean mortality rate (n= 28 207) Nazarian 2008: higher volume surgeons had lower estimated odds of death. Odds of death per additional procedure per year for low-volume was 0.802 (95% CI 0.505 to 1.275) p<0.351, for medium volume 0.935 (95% CI 0.887 to 0.986) p<0.013, for high-volume 0.997 (95% CI 0.987 to 1.006) p<0.485 (n= 22 772) O'Neill 2000: the association is uncertain, reported as not statistical significant (n= 14 439)	→ **In favour of high volume**	101 239 patients (4 studies)	⊕⊕⊖⊖ **Low**[1]

Complications (hospital volume)	**All patients** Khuri 1999: lower volume was not found to be a strong predictor of mortality (in logistic regression -0.00338 (SE 0.006), p=0.60) (n=10 173) Matsen 2006: the volume association with stroke was reported as not statistical significant, numbers not available from adjusted analysis (n=23 237) Mayo 1998: patients treated in low-volume hospitals had a stroke rate of 3.3% compared with a rate of 2.3% among high-volume hospitals. The association was reported as not statistical significant (n=341) Perler 1998: higher rates of neurologic complications in low-volume compared with low (6.1% versus 1.8%, p<0.001) (n= 9 981) Roddy 2000: the association was uncertain, complication rates in high-volume was 1.41% versus 0.23% in low-volume (n=10 211) Westvik 2006: adj OR for cardiac complications in high compared to low was 0.49 (95% CI 0.20 to 1.24; p=0.134). Rates of stroke in high was 1.0%, medium was 1.6%, and high was 2.1%. P-value from the Chi-square test was 0.006. Results for stroke alone was not reported for the multivariate analysis (n=14 288)	? **Uncertain**	68 231 patients (6 studies)	⊕⊝⊝⊝ **Very low**[1,3]
	Elective admissions Holt 2007: the association was reported as not statistical significant, numbers not reported (p=0.275) (n=16 759)	? **Uncertain**	16 759 patients (1 study)	⊕⊝⊝⊝ **Very low**[1,3]
	Patients with severe and moderate symptoms Holt 2007: the association was reported as not statistical significant, numbers not reported (p=0.181) (n=1 489)	? **Uncertain**	1 489 patients (1 study)	⊕⊝⊝⊝ **Very low**[1,3]
Complications (surgeon volume)	**All patients** Mayo 1998: low-volume surgeons had a stroke rate of 1.7%. The stroke rate among patients of high-volume surgeons was 2.4% and reported as not statistically significant (n=341) Matsen 2006: association with stroke was uncertain, reported as not statistical significant (n=23 237) O'Neill 2000: the lowest volume category predicted bad outcome with a regression of 4.758 (SE 1.904), p<0.013 (n= 14 439)	? **Uncertain**	38 017 patients (3 studies)	⊕⊝⊝⊝ **Very low**[1,3]
	Elective admissions Cowan 2002: lower rates of stroke in high-volume: % postoperative stroke was 1.78 for low-volume and 1.02 for high-volume, p<0.001. Not evaluated in multivariate analysis (n= 26 149)	→ **In favour of high volume**	26 149 patients (1 study)	⊕⊕⊝⊝ **Low**[1,6]
	Patients with severe and moderate symptoms Cowan 2002: lower rates of stroke in high-volume: % postoperative stroke was 2.50 for low-volume and 1.51 for high-volume, p<0.014. Not evaluated in multivariate analysis (n= 9 672)	→ **In favour of high volume**	9 672 patients (1 study)	⊕⊕⊝⊝ **Low**[1,6]

Length of stay (hospital volume)	**All patients** Perler 1998: higher volume was associated with shorter length of stay with 4.22 days (SEM 0.06) in high-volume versus 6.25 (SEM 0.50) in low-volume (p<0.0045) (n=9 981) Roddy 2000: the association was uncertain. The intensive care length of stay was 1.25 in high-volume, and 1.13 in low. Length of stay in hospital days were in high-volume 3.74 and in low 3.89 (n=10 211)	? **Uncertain**	20 192 patients (2 studies)	⊕⊝⊝⊝ **Very low**[1,3,4]
	Elective admissions Glaser 2014: the association was reported as not statistical significant, numbers not reported (n= 8 860)	? **Uncertain**	8 860 patients (1 study)	⊕⊝⊝⊝ **Very low**[1,2,3]
Length of stay (surgeon volume)	**All patients** Boudourakis 2009: higher volume was associated with increased length of stay for low-volume hospitals (two time points): year one coefficient 1.4, 95% CI 1.0 to 1.8 and year 2 coefficient 0.9, 95% CI 0.5 to 1.3 (n>5327) Ruby 1996: the prolonged stay rate (> 7 days) was associated with lower volume (lowest quintile had 30.2%, and highest quintile had a rate of 10.9% (n=3 997)	?→ **In favour of high volume**	>9324 patients (2 studies)	⊕⊕⊝⊝ **Low**[1]
	Elective admissions Cowan 2002: fewer % prolonged length of stay (>4 days) in hospitals in high-volume: 16.8% in low-volume and 8.6% in high-volume, p<0.001. Not evaluated in multivariate analysis (n= 26 149) Glaser 2014: low-volume surgeons had patients with longer days of stay (>1 day) (OR 3.1, 95% CI 1.9 to 5.0; p<0.01) (n= 8 860)	→ **In favour of high volume**	35 009 patients (2 studies)	⊕⊕⊝⊝ **Low**[1]
	Patients with severe and moderate symptoms Cowan 2002: fewer % prolonged length of stay (more than four days) in hospitals in high-volume: 56.8% in low-volume and 41.4% in high-volume, p<0.001. Not evaluated in multivariate analysis (n= 9 672)	→ **In favour of high volume**	9 672 patients (1 study)	⊕⊕⊝⊝ **Low**[1,6]
Costs (hospital volume)	**All patients** Perler 1998: mean hospital charges were lower in high-volume institutions when compared with low-volume hospitals. High USD 6294 (SEM 66) and low USD 7824 (SEM 401) (p<0.0004 compared to high-volume) (n=9 981) Roddy 2000: the association was uncertain, overall costs with direct medical expense per category was high-volume USD 6475 and for low-volume USD 6239 (n=10 211)	? **Uncertain**	20 192 patients (2 studies)	⊕⊝⊝⊝ **Very low**[1,3,4]
Costs (surgeon volume)	Not reported	-	-	

1. Observational study/ies
2. Imprecision: one study
3. Imprecision: estimates of uncertainty or numbers not reported
4. High risk of bias
5. Number of patients only reported for the complete sample, not by severity or volume unit. See table of included studies.
6. We decided not to downgrade because of consistency with other studies on same outcome for carotid artery disease

Endovascular surgery for carotid artery disease

The summary of findings is based on five studies conducted in USA (74, 83, 90, 91, 106), one from Germany (94) and an international study conducted in France, Germany and UK (England) (98)(see table 9).

For elective patients treated in high-volume hospitals or by high-volume surgeons, there are possibly lower 30-day mortality and complications combined. For patients with severe symptoms treated by high-volume surgeons, there are possibly lower 30-day mortality and complications combined. We considered the certainty of the evidence for these outcomes to be of low certainty.

For the association of hospital and surgeon volume with 30-day mortality and complications including all patients, we judged the certainty of the evidence to be very low.

For the combined measure of in-hospital mortality and complications, the association with hospital volume varies by type of complication, and an association is present for cerebral ischemic event but not for mortality and stroke combined. For surgeon volume, there are fewer in-hospital deaths and complications for elective patients treated by high-volume surgeons. Furthermore, patients treated by high-volume surgeons possibly have fewer days in hospital. We considered the certainty of the evidence for these outcomes to be of low certainty.

We judged the certainty of the evidence for the association between surgeon volume and costs to be very low.

Table 9. The association between patient volume and quality for endovascular surgery

Population: patients with atherosclerosis/ narrowing of the common carotid artery or internal carotid artery
Intervention: higher volume of patients
Comparison: lower volume of patients
Context: USA, Germany as well as an international study

Outcomes	Results	Summary of estimate of effects («←» in favour of low volume, «→»in favour of high volume «?» uncertainty	Number of participants (studies)	Certainty of the evidence (GRADE)
Mortality and complications combined (30-days) (hospital volume)	**All patients** Shishebor 2014: the association is uncertain for mortality, stroke and myocardial infarction (OR 1.01, 95% CI 0.60 to 1.69; p< 0.98) (n= 5 240)	? **Uncertain**	5 240 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,3]
	Elective admissions Gray 2011: an inverse relationship between mortality/ stroke and patient volume was found in the linear regression: (y) 4.43, 0.74*log(x), with p value for slope 0.0001, and r2=0.53 (n= 3 388)	→ **In favour of high volume**	3 388 patients (1 study)	⊕⊕⊖⊖ **Low**[1,2]
Mortality and complications combined (30-days) (surgeon volume)	**All patients** Shishebor 2014: the association was uncertain for mortality, stroke and myocardial infarction (OR 1.39, 95% CI 0.55 to 3.50; p< 0.48 (n= 5 240)	? **Uncertain**	5 240 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,3]
	Elective admissions Gray 2011: an inverse relationship between mortality/ stroke and patient volume was found in the linear regression: log(y) 4.71- 0.85*log(x), with p value for slope 0.0001, and r2=0.81 (n= 3 388)	→ **In favour of high volume**	3 388 patients (1 study)	⊕⊕⊖⊖ **Low**[1,2]
	Patients with severe and moderate symptoms Calvet 2013: the relative risk of mortality and stroke was higher in low-volume compared to high-volume (RR 2.30, 95% CI 1.36 to 3.87) (n= 1 679)	→ **In favour of high volume**	1 679 patients (1 study)	⊕⊕⊖⊖ **Low**[1,2]
In-hospital mortality and complications combined (hospital volume)	**All patients** Staubach 2014: lower odds of in-hospital mortality or cerebral ischemic event in high-volume compared to low-volume (4^{th} quartile compared with 1^{st}: OR 0.62 (95% CI 0.46 to 0.88); p< 0.05). For mortality and stroke the association was uncertain (4^{th} quartile compared with 1^{st} 0.77 (95% CI 0.48 to 1.25; p< 0.54 (n=5 535)	? **Uncertain**	5 535 patients (1 study)	⊕⊕⊖⊖ **Low**[1,2]
In-hospital mortality and complications combined (surgeon volume)	**Elective admissions** Modrall 2014: higher volume was associated with lower risk of mortality and stroke (OR 0.84, 95% CI 0.74 to 0.94, p<0.0003) (n=11 535)	→ **In favour of high volume**	11 535 patients (1 study)	⊕⊕⊖⊖ **Low**[1,2]

Complications (surgeon volume)	**All patients** Sgroi 2015: the risk of stroke was lower in high-volume (OR 0.97, 95% CI 0.94 to 0.99; p<0.021), but the association was uncertain for myocardial infarction (OR 0.99, 95% CI 0.96 to 1.02) (n=20 663) Vogel 2009d: the association with stroke was uncertain. Higher volume surgeons had a stroke rate of 1.92% compared with the 3.80% (p<0.641) stroke rate for low-volume surgeons (n=625)	? **Uncertain**	21 288 patients (2 studies)	⊕⊖⊖⊖ **Very low**[1,4]
Length of stay (hospital volume)	Not reported	**-**	-	
Length of stay (surgeon volume)	**All patients** Sgroi 2015: higher volume was associated with shorter stay (mean days difference -0.05, 95% CI -0.06 to -0.04, p<0.001) (n=20 663) Vogel 2009d: high-volume (mean 1.7 days) had lower length of stay than low-volume (mean 2.4 days; p<0.0422) (n=625)	→ **In favour of high volume**	21 288 patients (2 studies)	⊕⊕⊖⊖ **Low**[1]
Costs (hospital volume)	Not reported	**-**	-	
Costs (surgeon volume)	**All patients** Sgroi 2015: the association with total hospital charges was uncertain (mean USD 98.39, 95% CI -55.77 to 252.55) (n=20 663) Vogel 2009d: the total hospital costs per volume category showed mixed results. High-volume specialists had higher total costs of USD 13193 (SD 9095) compared to medium USD 8442 (SD 3983; p<0.0971) but were lower than for low-volume USD 19325 (SD 19,236; p<0.004). Similarly, the medical supplies costs per volume category showed mixed results. High-volume specialists had higher total costs compared to medium-volume USD 4496 (SD 5692) and USD 3060 (SD 2372, respectively; p<0.31), but were lower than in low-volume USD 8800 (SD 9043; p<0.0001). (n=625)	? **Uncertain**	21 288 patients (2 studies)	⊕⊖⊖⊖ **Very low**[1,4]

1. Observational study/ies
2. We decided not to downgrade because of consistency with other studies on same outcome for carotid artery disease
3. High risk of bias
4. Heterogeneity

Peripheral artery disease

We included nine studies evaluating the volume-quality relationship for peripheral artery disease in the lower extremities and in the aorto-iliac arteries. Eight studies were conducted in USA (7, 50, 56, 107-111), and one study was done in Finland (112). All results can be found in Appendix 9, the summary of findings is presented below.

All surgery for peripheral artery disease

The summary of findings is based on one study conducted in USA including 31 172 patients (56). The study evaluated the relationship between hospital volume and in-hospital mortality for all patients, and concluded that there was little or no association (see Table 10). The same study also looked at the relationship between surgeon volume and in-hospital mortality and complications overall and found that the risk was lower for those treated by high-volume surgeons. We considered both of these outcomes to be of low certainty.

Table 10. The association between patient volume and quality for all procedures

Population: patients with lower extremity peripheral artery disease
Intervention: higher volume of patients
Comparison: lower volume of patients
Context: USA

Outcomes	Results	Summary of estimate of effects («←» in favour of low volume, «→»in favour of high volume «?» uncertainty)	Number of participants (studies)	Certainty of the evidence (GRADE)
Mortality (30-days) (hospital volume)	Not reported	-	-	-
Mortality (30-days) (surgeon volume)	Not reported	-	-	-
In-hospital mortality (hospital volume)	**All patients** Pearce 1999: there was little or no association (Coefficient Relative risk ratio 0.98, p=0.60) (n= 31 172)	? **Uncertain**	31 172 patients (1 study)	⊕⊕⊖⊖ **Low**[1]
In-hospital mortality and complications (surgeon volume)	**All patients** Pearce 1999: a doubling of surgeon volume was associated with 8% reduction in risk of hospital death, myocardial infarction and cerebrovascular accident (Coefficient Relative risk ratio 0.91, p=0.0001)(n= 31 172)	→ **In favour of high volume**	31 172 patients (1 study)	⊕⊕⊖⊖ **Low**[1]

Complications (hospital volume)	Not reported	-	-	-
Complications (surgeon volume)	Not reported	-	-	-
Length of stay (hospital volume)	Not reported	-	-	-
Length of stay (surgeon volume)	Not reported	-	-	-
Costs (hospital volume)	Not reported	-	-	-
Costs (surgeon volume)	Not reported	-	-	-

1. Observational study/ies
2. Decided not to downgrade because of consistency with other studies on same outcome

Open surgery for peripheral artery disease

The summary of findings includes four studies conducted in USA (7, 50, 110, 111), and one study from Finland (112)(see table 11). The number of patients ranged from 263 580 to 1 761.

There is a possible lower 30-day mortality in high-volume hospitals for elective and acute patients assessed overall. We considered this outcome to be of low certainty. For elective patients considered separately, the certainty of the evidence is very low for 30-day mortality by both hospital and surgeon volume.

We found a possible lower risk in in-hospital mortality in high-volume hospitals for elective and acute admissions considered together. We judged the certainty of this outcome to be of low certainty.

For the relationship between high-volume hospitals and complications for elective and acute admissions assessed overall, we judged the certainty of the evidence to be very low. For elective patients considered separately, there was a possible lower risk of complications for patients treated in high-volume hospitals or by high-volume surgeons.

For the relationship between hospital volume and days of hospitalization for all patients, we considered the certainty of the evidence for this outcome to be of very low certainty.

Table 11. The association between patient volume and quality for open surgery

Population: patients with peripheral artery disease in the lower extremities and/ or aorto-iliac arteries
Intervention: higher volume of patients
Comparison: lower volume of patients
Context: USA, Finland

Outcomes	Results	Summary of estimate of effects («←» in favour of low volume, «→»in favour of high volume «?» uncertainty	Number of participants (studies)	Certainty of the evidence (GRADE)
Mortality (30-days) (hospital volume)	**All patients** Birkmeyer 2002: higher volume was associated with lower mortality (OR 0.81, 95% CI 0.74 to 0.88) (n= 263 580) Feinglass 2009: lower volume was associated with higher mortality (OR 1.77, 95% CI 1.37 to 2.28 (n>28 000).	→ **In favour of high volume**	>263 580 patients (2 studies)	⊕⊕⊖⊖ **Low**[1]
	Elective admissions Kantonen 1998: the association is uncertain, reported as not statistical significant (n= 1 761)	? **Uncertain**	1 761 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,3]
Mortality (30-days) (surgeon volume)	**Elective admissions** Kantonen 1998: the association is uncertain, reported as not statistical significant (n= 1 761)	? **Uncertain**	1 761 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,3]
In-hospital mortality (hospital volume)	**All patients** Dimick 2003: higher volume was associated with lower mortality. Highest compared to lowest volume, the odds for mortality was OR 0.58; 95% CI 0.34-0.97; p=0.04) (n=3 073) Manheim 1998: higher volume was associated with lower mortality. Highest compared to lowest volume, the odds for mortality was OR 0.67 (p<0.001) (n=100 963)	→ **In favour of high volume**	104 036 patients (2 studies)	⊕⊕⊖⊖ **Low**[1]
In-hospital mortality (surgeon volume)	Not reported	-		-
Complications (hospital volume)	**All patients** Feinglass 2009: amputation varied inversely by hospital volume level. The highest volume hospitals had lower 30-day amputations (1.8%) compared with low-volume (3.0%). There was little or no difference in stroke and myocardial infarction by hospital volume level. The highest volume hospitals had 2.4% compared with high-volume 2.5%, medium volume 2.3% and low-volume 1.9% (confidence intervals or p-value not reported) (n>28 000)	? **Uncertain**	>28 000 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,3]
	Elective admissions Kantonen 1998: low-volume hospitals had higher rates of amputations than high-volume OR 1.49 (95% CI 1.00 to 2.25, p< 0.05) (n= 1 761)	→ **In favour of high volume**	1 761 patients (1 study)	⊕⊕⊖⊖ **Low**[1,2]

Complications (surgeon volume)	**Elective admissions** Kantonen 1998: low-volume surgeons had higher rates of amputations than high volume: OR 1.80 (95% CI 1.15 to 2.80, p<0.01) (n= 1 761)	→ **In favour of high volume**	1 761 patients (1 study)	⊕⊕⊖⊖ **Low**[1,2]
Length of stay (hospital volume)	**All patients** Dimick 2003: there was little or no difference in proportion of patients with prolonged length of stay at high-volume hospitals (24%) versus low-volume hospitals (25%) (p=0.30). In the multivariate analysis, volume was not a statistically significant predictor of length of stay (numbers were not reported) (n=3 073)	? **Uncertain**	3 073 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,3]
Length of stay (surgeon volume)	Not reported	**-**	-	-
Costs (hospital volume)	Not reported	**-**	-	-
Costs (surgeon volume)	Not reported	**-**	-	-

1. Observational study/ies
2. We decided not to downgrade because of consistency with other studies on same outcome for carotid artery disease
3. Figures or estimates of uncertainty not reported

Endovascular surgery for peripheral artery disease

The summary of findings is based on three studies with a range of 92 714 to 818 patients conducted in USA (107-109) (see table 12).

For patients treated in high-volume hospitals, there is possibly lower in-hospital mortality. Furthermore, for patients treated in high-volume hospitals, there was possibly a lower risk of complications. We judged the certainty of the evidence for these outcomes to be low.

The certainty of the evidence for the remaining outcomes, including in-hospital mortality, complications, length of stay and costs by surgeon volume, and length of stay by hospital volume was very low.

Table 12. The association between patient volume and quality for endovascular surgery

Population: patients with peripheral artery disease in the lower extremities and/ or aorto-iliac arteries
Intervention: higher volume of patients
Comparison: lower volume of patients
Context: USA

Outcomes	Results	Summary of estimate of effects («←» in favour of low volume, «→»in favour of high volume «?» uncertainty	Number of participants (studies)	Certainty of the evidence (GRADE)
Mortality (30-days) (hospital volume)	Not reported	-	-	-
Mortality (30-days) (surgeon volume)	Not reported	-	-	-
In-hospital mortality (hospital volume)	**All patients** Arora 2015: fewer deaths in higher volume compared to low (OR 0.65, 95% CI 0.52 to 0.82; p<0.022) (n= 92 714)	→ **In favour of high volume**	92 714 (1 study)	⊕⊕⊝⊝ **Low**[1,6]
In-hospital mortality (surgeon volume)	**All patients** Indes 2011: the association is uncertain, reported as not statistical significant, numbers not available (n=818)	? **Uncertain**	818 patients (1 study)	⊕⊝⊝⊝ **Very low**[1,4]
Complications (hospital volume)	**All patients** Arora 2015: fewer complications in higher volume. Highest compared to lowest volume, the odds for any complication was OR 0.85, 95% CI 0.73 to 0.97; p<0.001) (n= 92 714) Indes 2011: the association is uncertain. In the bivariate analysis, the rate of complications was 17.4% vs 13.9% for low-volume and high-volume hospitals; p=0.16). Variable not entered in the multivariate analysis (n=818)	? → **Uncertain/ in favour of high volume**	>93 532 patients (2 studies)	⊕⊕⊝⊝ **Low**[1,6]
Complications (surgeon volume)	**All patients** Indes 2011: high-volume physicians had fewer complications when compared with low-volume physicians (12.6% vs 18.7%; p=0.02). In the multivariate analysis, high-volume physicians were associated with significantly lower complication rates (n=818)	→ **In favour of high volume**	818 patients (1 study)	⊕⊝⊝⊝ **Very low**[1,4]
Length of stay (hospital volume)	**All patients** Indes 2011: in the bivariate analysis, high-volume hospitals had l ower length of stay compared with low-volume (2.8 vs 3.3 days; p=0.001). High-volume hospitals were also associated with a shorter length of stay in the multivariate analysis (n=818)	→ **In favour of high volume**	818 patients (1 study)	⊕⊝⊝⊝ **Very low**[1,2,4]

Length of stay (surgeon volume)	**All patients** Indes 2011: in the bivariate analysis, high-volume physicians had lower length of stay compared with low-volume (2.8 vs 3.3 days; p=0.001). Unclear if tested in multivariate analysis (n=818)	→ **In favour of high volume**	818 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,2]
Costs (hospital volume)	Not reported	**-**	-	-
Costs (surgeon volume)	**All patients** Indes 2011: reported as no statistically significant difference in volume on costs (n=818)	? **Uncertain**	818 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,2,4]
	Elective admissions Vogel 2009: low-volume surgeons were found to have higher charges than high-volume (USD 51 014 vs USD 41 730; p<0 .0001) (n=2 837)	→ **In favour of high volume**	2 837 patients (1 study)	⊕⊖⊖⊖ **Very low**[1,2,3,5]

1. Observational study/ies
2. Precision: only one study
3. High risk of bias
4. Imprecision: measures of uncertainty or estimates not reported
5. Directness: difficult to assess the relevance of this outcome
6. Decided not to downgrade because of consistency with other studies on same outcome

Renal artery disease

One study including 7 413 patients conducted in USA evaluated the volume-quality relationship for renal artery bypass to treat renal artery occlusive disease (113)(see table 13). All results can be found in Appendix 10, the summary of findings is presented below.

The study evaluated the association between in-hospital mortality and hospital volume.

There is possibly a slightly lower risk for those who were treated in high-volume institutions. We judged the certainty of the evidence for this outcome as low.

Table 12. The association between patient volume and quality for open surgery

Population: patients with renal artery disease
Intervention: higher volume of patients
Comparison: lower volume of patients
Context: USA

Outcomes	Results	Summary of estimate of effects («←» in favour of low volume, «→»in favour of high volume «?» uncertainty	Number of participants (studies)	Certainty of the evidence (GRADE)
Mortality (30-days) (hospital volume)	Not reported	-	-	-
Mortality (30-days) (surgeon volume)	Not reported	-	-	-
In-hospital mortality (hospital volume)	Modrall 2009: high-volume hospitals had a lower risk of mortality (OR; 0.98; CI 0.96 to 0.99; p=0.015) (n=7 413)	→ **In favour of high volume**	7 413 patients (1 study)	⊕⊕⊖⊖ **Low**[1,2]
In-hospital mortality (surgeon volume)	Not reported	-	-	-
Complications (hospital volume)	Not reported	-	-	-
Complications (surgeon volume)	Not reported	-	-	-
Length of stay (hospital volume)	Not reported	-	-	-
Length of stay (surgeon volume)	Not reported	-	-	-
Costs (hospital volume)	Not reported	-	-	-
Costs (surgeon volume)	Not reported	-	-	-

1. Observational study/ies
2. Decided not to downgrade because of consistency with other studies on same outcome

Discussion

Key findings summary

We included 89 observational studies that evaluated the relationship between patient volume in vascular surgery and quality. The studies included patients from USA, Canada, UK, Finland, Germany, Australia, Norway, Japan and France. The smallest study included 155 patients and the largest 491 779 patients. Using the GRADE approach, we judged the evidence to be of moderate to very low certainty.

Abdominal aortic aneurysms

For patients with abdominal aortic aneurysms for all surgery, there is possibly lower 30-day mortality in high-volume hospitals and for high-volume surgeons (low certainty). There is also possibly less in-hospital mortality and fewer complications in high-volume hospitals (low certainty).

For open surgery assessed separately, there is possibly lower 30-day mortality and less in-hospital mortality in high-volume hospitals (low certainty), and probably less in-hospital mortality for high-volume surgeons (moderate certainty). The latter including also acute admissions (low certainty). There are also possibly fewer complications in high-volume hospitals (low certainty). For elective patients, there are possibly fewer days in hospital in high-volume hospitals (low certainty).

For endovascular surgery assessed separately, there is possibly lower 30-day mortality in high-volume hospitals (low certainty), and less in-hospital mortality in high-volume hospitals for elective patients (low certainty). There are also possibly fewer deaths for acute admissions evaluated separately, but the confidence interval was wide and included potential benefit to those treated at low-volume institutions. This was also the case for surgeon volume and in-hospital mortality (low certainty). Furthermore, there were possibly less complications in high-volume hospitals for elective patients (low certainty).

Thoracic and abdominal aortic aneurysms

For patients with thoracic and abdominal aortic aneurysms undergoing open surgery, there is possibly lower 30-day mortality (low certainty) and probably less in-hospital mortality in high-volume hospitals (moderate certainty). There is also possibly less in-hospital mortality for high-volume surgeons for elective patients (low certainty). For endovascular procedures, there is possibly lower 30-day mortality in high-volume hospitals, and lower risk of in-hospital mortality and complications for high-volume surgeons (low certainty).

Carotid artery disease

For patients with carotid artery disease having open surgery, there is possibly lower 30-day mortality in high-volume hospitals and for high-volume surgeons (low certainty). There is also possibly less in-hospital mortality in high-volume hospitals and for high-volume surgeons (low certainty). There is also possibly fewer complications for elective patients and for patients with severe symptoms (low certainty). Furthermore, there is possibly fewer hospital days for for high-volume surgeons (including patients with severe carotid artery disease) (low certainty).

For endovascular surgery, there is possibly lower 30-day mortality and fewer complications in high-volume hospitals and for high-volume surgeons (low certainty). For surgeon volume, this also includes patients with severe carotid artery disease. There is also possibly less in-hospital mortality and complications combined for high-volume surgeons for elective patients (low certainty). For high-volume surgeons and complications, as well as for costs, the certainty is very low.

Peripheral artery disease

For patients with peripheral artery disease for all surgery there is possibly less in-hospital mortality and complications combined for high-volume surgeons (low certainty). There was possibly little or no association between hospital volume and in-hospital mortality (low certainty).

For open surgery, there is possibly lower 30-day mortality and less in-hospital mortality in high-volume hospitals (low certainty), and less complications in high-volume hospitals (low certainty, and for high-volume surgeons for elective patients (low certainty).

For endovascular surgery, there is possibly less in-hospital mortality and complications in high-volume hospitals (low certainty).

Renal artery disease

For patients with renal artery disease undergoing open surgery, there is possibly less in-hospital mortality in high-volume hospitals (low certainty).

Strengths and weaknesses

Decisions about health or healthcare should be informed by systematic reviews of the available evidence, whether such interventions are organisational or patient directed. A single comparison of interventions rarely provides conclusive evidence and results are often available from other studies. These other comparisons may have different results or may help to provide more reliable and precise estimates of the effects of interventions. We used systematic and explicit criteria for searching, assessing and summarizing the available evidence on the impact of patient volume on quality for vascular surgery. Each step of this process was performed by at least two researchers quality assuring the process.

Decision makers should also take the certainty of the evidence into account (the extent to which the research provides a good indication of the likely effects of interventions). How certain the evidence is depends on the fairness of the comparisons (the risk of bias), the risk of being misled by the play of chance, and judgements about the relevance of the evidence. We judged the certainty of the evidence for these many outcomes as low due to weaknesses in the study design, and in some cases very low in cases where a certain outcome was only assessed in one study or because of insufficient reporting of results. This was particularly the case for studies where the relationship between patient volume and an outcome was found to be not statistically significant, and were the effect estimates and measures of uncertainty typically were not reported. This is a form of selective reporting that provides too little information to make any conclusions about the patient-volume assocation, and which can result in biased conclusions of systematic reviews because "negative" results are underreported. However, it is important to emphasize that in spite of these weaknesses, the studies included a large number of patients and with much of the same conclusions particularly for mortality outcomes, across different countries and health systems. In two instances, we also upgraded the certainty of the evidence due to large effects.

The majority of the studies had unclear risk of bias. As mentioned introductory, in addition to patient volume, patient- or system factors can also affect patient outcomes as well as resource use. For example, the patient's health status, such as the severity of the disease, or socio-demographic or other differences between hospitals may influence results. Most of the included studies adjusted for such possible confounding patient factors, but in many studies, the baseline patient characteristics per volume group (high-volume vs. low-volume) were not reported.

Finally, although our search for studies was extensive, there is always the risk that we may have missed relevant studies. However, considering the large number of studies included in this review, this is unlikely to change our conclusions.

Consistency with other studies or reviews

This review is an update of prevous reports evaluating the impact of patient volume on quality for cardiovascular disease (9, 10). Our systematic review concludes in line with previous reviews that volume has an impact on selected quality measures for abdominal aortic aneurysms (1, 10, 114-119). But also that there is more uncertainty associated with outcomes for patients undergoing acute admissions (120).

This review also contributes with additional evidence on the volume-quality relationship in surgical treatment for atherosclerosis/ narrowing of the carotid arteries and peripheral artery disease of the lower extremities. Our findings for carotid artery surgery are consistent with previous reviews in that higher volume possibly results in less mortality and complications (116-118, 121). Although our review presents a more updated evidence base for the volume-quality association for peripheral disease in the lower extremities, we conclude consistently with earlier findings in that although there seems to be an impact of patient volume on outcomes such as mortality and complications, the available evidence remains scarce (116-118, 122).

Implication of results

There are many other factors at the local level, including chance, which may explain differences in quality of care associated with surgical procedures.

This means that the results from this review cannot be generalized to the individual hospital or surgeon. Instead, this systematic review is intended as a general decision support for informing decisions about the organization of health services. Furthermore, in line with evidence-based practice, decisions about health and health care should also be informed by practitioner expertise, and with the characteristics, state, needs, values and preferences of those who will be affected. This should be done in consideration of the environment or the setting in relevance to the decision, such as the geographical location, available resources, legislation and policies that may play into the decision. For example, an important factor to take into consideration is that any potential discontinuation of vascular surgery in low-volume hopsitals also implies that there is no emergency service available to patients who may be in need of emergency care.

Furthermore, for this review, we report the median threshold cut-offs for each group of diagnoses, however we have not made any assumptions based on these to provide recommendations on the minimum volume thresholds. This should be addressed in other analyses for implemention purposes.

The included studies used a variety of different cut-off values for determining volume categories. Such estimates are often pragmatic, and as previously mentioned, there is no agreement on how volume categories are best defined (1, 7, 8). Although the range of thresholds within volume categories and the number of volume categories used varied in the included studies, and that many of the studies were from contexts with much larger populations, the median volume thresholds were comparable to those in smaller populations such as Norway.

Of the 89 studies we included, one of these was conducted in Norway (67). This study assessed the relationship between volume and mortality and with findings in concordance with the conclusion of this review, in that the odds of death was higher for elective patients treated in low-volume institutions, but that the association was uncertain for patients who were admitted acute. This uncertainty can probably be explained by that this study had a small sample size.

Need for further research

A limitation in many of the included studies we identified was suboptimal reporting of baseline person and system factors. Future studies on the impact of volume on quality should make sure to report their baseline values, as well as patient and system characteristics for all volume categories compared. This is likely to improve judgements about risk of bias and may improve our confidence in the results. Furthermore, we encourage researchers to report effect estimates and associated confidence intervals for all outcomes, including those that are found to be not statistical significant. This will improve transparency, and enable interpretation and inclusion of all results coming out of these evaluations.

The majority of the studies we identified were based in the USA. To improve relevance and to gain knowledge about the impact of volume on quality in smaller health systems, more studies conducted in European or Scandinavian settings would provide useful knowledge.

We judged the outcomes addressed in the included studies to be consistent and relevant, but for length of stay and costs - the results varied or were inconclusive. Consequently, more evidence is needed for these outcomes to reduce this uncertainty. There is also need for more evidence on the impact of patient volume for patients who are admitted acute.

In decisions about organization of healthcare, evidence is needed on the appropriate minimum volume thresholds for the specific context.

Conclusion

Overall, we judged the evidence to be of moderate to very low certainty. We found that higher volume had a possible impact on quality when evaluated on both surgeon and hospital level. The available evidence also suggest that volume has an impact on quality for both open and endovascular surgery.

Higher patient volume possibly reduce mortality for patients with abdominal aortic aneurysms, thoracic and abdominal aortic aneurysms, carotid artery stenosis, peripheral vascular disease and renal artery disease. We also found that higher patient volume possibly reduces complications in patients with abdominal aortic aneurysms, carotid artery disease and peripheral vascular disease, and length of stay (hospital days) in patients with abdominal aortic aneurysms and carotid artery disease.

There is a need for more studies evaluating the volume-quality relationship for patients with acute admissions, and for quality measures such as length of stay and cost.

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Appendices

Appendix 1. Search strategy

Database: Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations, Ovid MEDLINE(R) Daily, Ovid MEDLINE(R) and Ovid OLDMEDLINE(R) 1946 to Present Search date: 17.12.2015

#	Searches	Results
1	(((endovascular or microvascular or vascular or intravascular or fontan or blood vessel or great vessel or small vessel) adj (reconstruct* or repair or surg* or procedur* or technique* or grafting)) or (bypass* adj1 (grafting or sta mca or arterial or extracranial or intracranial or aortacoronary or coronary or artery or arteries or heart)) or embolectom* or thromboendarterectom* or endarterectom* or angioplast* or endoluminal repair* or atherectom* or angioscop* or (catheterization* adj2 (venous or vein* or peripher* or arter* or bronchial or swan-ganz)) or ((intervention* or revascularization*) adj2 (cerebral or brain or (coronar* adj1 percutaneous))) or (limb* adj2 salvag*) or ((peritoneovenous or peritoneo venous or leveen or arteriovenous or pulmonary or cavopulmonary or portasystemic or portacaval splenoral) adj2 shunt*) or thrombectom* or mechanical thrombolysis or blalock taussig or ((vascular or blood vessel) adj1 implantation*) or ((heart or cavopulmonary or artery) adj1 (anastomoses or anastomosis)) or venous cutdown* or venostom* or vein cutdown*).ti,ab.	151771
2	exp Vascular Surgical Procedures/	203483
3	exp Vascular Diseases/su [Surgery]	166429
4	exp Arteries/su [Surgery]	67283
5	exp Veins/su [Surgery]	30670
6	or/1-5	388339
7	((high or low) adj volume).ti,ab.	12365
8	((surgeon or physician or hospital or annual or unit) adj3 (caseload or case load or number or frequency or volume)).ti,ab.	17249
9	(surg* adj experience).ti,ab.	5772

10	clinical competence/	71746
11	hospitals, high-volume/ or hospitals, low-volume/	523
12	or/7-11	104564
13	systematic review.kw.	3040
14	meta-analysis.mp,pt.	102020
15	review.pt.	2087937
16	((systematic* or literature) adj3 (overview or review*)).ti,ab.	273290
17	or/13-16	2243824
18	clinical trial.mp.	626192
19	clinical trial.pt.	509366
20	random:.mp.	1023041
21	randomized controlled trial.pt.	418428
22	controlled clinical trial.pt.	92318
23	multicenter study.pt.	200474
24	pragmatic clinical trial.pt.	236
25	(pre-post or "pre test$" or pretest$ or posttest$ or "post test$" or (pre adj5 post)).ti,ab.	78230
26	("quasi-experiment$" or quasiexperiment$ or "quasi random$" or quasirandom$ or "quasi control$" or quasicontrol$ or ((quasi$ or experimental) adj3 (method$ or study or trial or design$ or controlled))).ti,ab,hw.	117533
27	("time series" or "time points").ti,ab,hw.	75494
28	(effect or impact or trial or intervention).ti.	1093106
29	repeated measure*.ti,ab.	31459
30	((before adj5 after) or control group*).ti,ab.	602041
31	(pretest-posttest study or pretesting or pre-post tests or quasi experimental design or quasi experimental study or quasi experimental study design or repeated measurement or repeated measurements or repeated measures or time series).kw.	327
32	or/18-31	2892443
33	6 and 12 and 17	443
34	limit 33 to yr="2010-Current"	171
35	6 and 12 and 32	1073
36	34 or 35	1199

Database: Embase 1974 to 2015 December 16
Search date: 17.12.2015

#	Searches	Results
1	exp vascular surgery/	363182
2	exp vascular disease/su [Surgery]	213121
3	exp artery/su [Surgery]	12463
4	exp vein/su [Surgery]	5212
5	(((endovascular or microvascular or vascular or intravascular or fontan or blood vessel or great vessel or small vessel) adj (reconstruct* or repair or surg* or procedur* or technique* or grafting)) or (bypass* adj1 (grafting or sta mca or arterial or extracranial or intracranial or aortacoronary or coronary or artery or arteries or heart)) or embolectom* or thromboendarterectom* or endarterectom* or angioplast* or endoluminal repair* or atherectom* or angioscop* or (catheterization* adj2 (venous or vein* or peripher* or arter* or bronchial or swan-ganz)) or ((intervention* or revascularization*) adj2 (cerebral or brain or (coronar* adj1 percutaneous))) or (limb* adj2 salvag*) or ((peritoneovenous or peritoneo venous or leveen or arteriovenous or pulmonary or cavopulmonary or portasystemic or portacaval splenoral) adj2 shunt*) or thrombectom* or mechanical thrombolysis or blalock taussig or ((vascular or blood vessel) adj1 implantation*) or ((heart or cavopulmonary or artery) adj1 (anastomoses or anastomosis)) or venous cutdown* or venostom* or vein cutdown*).ti,ab.	208809
6	or/1-5	529654
7	high volume hospital/	578
8	low volume hospital/	359
9	clinical competence/	47734
10	((high or low) adj volume).ti,ab.	19018
11	((surgeon or physician or hospital or annual or unit) adj3 (caseload or case load or number or frequency or volume)).ti,ab.	23773
12	(surg* adj experience).ti,ab.	7744
13	or/7-12	95686
14	((systematic* or literature) adj3 (overview or review* or search*)).ti,ab.	359395
15	meta-analys*.ti,ab.	107312
16	systematic review/	99722
17	meta analysis/	103119
18	14 or 15 or 16 or 17	467667

19	clinical trial/	858699
20	randomized controlled trial/	393493
21	exp randomization/	69174
22	randomized.ti,ab.	495940
23	randomised.ti,ab.	99364
24	randomly.ti,ab.	311200
25	trial.ti,ab.	563545
26	controlled study/	4810504
27	time series analysis/	16334
28	pretest posttest design/	927
29	evaluation/	170426
30	intervention study/	26613
31	comparative study/	700546
32	experimental study/	17736
33	time series.ti,ab.	21849
34	(((pre adj test) or pretest) and ((post adj test) or posttest)).ti,ab.	9583
35	time point*.ti,ab.	113287
36	repeated measur*.ti,ab.	41777
37	effect.ti,ab.	3059826
38	impact.ti,ab.	827477
39	or/19-38 [RCT,CBA,ITS]	8825218
40	6 and 13 and 18	122
41	limit 40 to yr="2010 -Current"	70
42	6 and 13 and 39	1524
43	limit 41 to embase	58
44	limit 42 to embase	1323
45	43 or 44	1354

Database: Cochrane Library (CENTRAL, DARE, HTA, CDSR)
Search date: 17.12.2015

#1	(((endovascular or microvascular or vascular or intravascular or fontan or "blood vessel" or "great vessel" or "small vessel") next (reconstruct* or repair or surg* or procedur* or technique* or grafting)) or (bypass* near/1 (grafting or "sta mca" or arterial or extracranial or intracranial or aortacoronary or coronary or artery or arteries or heart)) or embolectom* or thromboendarterectom* or endarterectom* or angioplast* or (endoluminal next repair*) or atherectom* or angioscop* or (catheterization* near/2 (venous or vein* or peripher* or arter* or bronchial or swan-ganz)) or ((intervention* or revascularization*) near/2 (cerebral or brain or (coronar* near/1 percutaneous))) or (limb* near/2 salvag*) or ((peritoneovenous or "peritoneo venous" or leveen or arteriovenous or pulmonary or cavopulmonary or portasystemic or "portacaval splenoral") near/2 shunt*) or thrombectom* or "mechanical thrombolysis" or "blalock taussig" or ((vascular or "blood vessel") near/1 implantation*) or ((heart or cavopulmonary or artery) near/1 (anastomoses or anastomosis)) or (venous next cutdown*) or venostom* or vein cutdown*)	24155
#2	MeSH descriptor: [Vascular Surgical Procedures] explode all trees	13150
#3	MeSH descriptor: [Vascular Diseases] explode all trees and with qualifier(s): [Surgery - SU]	5457
#4	MeSH descriptor: [Arteries] explode all trees and with qualifier(s): [Surgery - SU]	1116
#5	MeSH descriptor: [Veins] explode all trees and with qualifier(s): [Surgery - SU]	730
#6	#1 or #2 or #3 or #4 or #5	26951
#7	((high or low) next volume)	499
#8	((surgeon or physician or hospital or annual or unit) near/3 (caseload or "case load" or number or frequency or volume))	2777
#9	(surg* next experience)	304
#10	MeSH descriptor: [Clinical Competence] this term only	2034
#11	MeSH descriptor: [Hospitals, High-Volume] this term only	7
#12	MeSH descriptor: [Hospitals, Low-Volume] this term only	5
#13	#7 or #8 or #9 or #10 or #11 or #12	5473
#14	#6 and #13 in Trials	158
#15	(((endovascular or microvascular or vascular or intravascular or fontan or "blood vessel" or "great vessel" or "small vessel") next (reconstruct* or repair or surg* or procedur* or technique* or grafting)) or (bypass* near/1 (grafting or "sta mca" or arterial or extracranial or intracranial or aortacoronary or coronary or artery or arteries or heart)) or embolectom* or thromboendarterectom* or endarterectom* or angioplast* or (endoluminal next repair*) or atherectom* or angioscop* or (catheterization* near/2 (venous or vein* or peripher* or arter* or bronchial or swan-ganz)) or ((intervention* or revascularization*) near/2 (cerebral or brain or (coronar* near/1 percutaneous))) or (limb* near/2 salvag*) or ((peritoneovenous or "peritoneo venous" or	21806

	leveen or arteriovenous or pulmonary or cavopulmonary or portasys-temic or "portacaval splenoral") near/2 shunt*) or thrombectom* or "mechanical thrombolysis" or "blalock taussig" or ((vascular or "blood vessel") near/1 implantation*) or ((heart or cavopulmonary or artery) near/1 (anastomoses or anastomosis)) or (venous next cutdown*) or venostom* or vein cutdown*):ti,ab,kw	
#16	#15 or #2 or #3 or #4 or #5	24881
#17	((high or low) next volume):ti,ab,kw	382
#18	((surgeon or physician or hospital or annual or unit) near/3 (caseload or "case load" or number or frequency or volume)):ti,ab,kw	1159
#19	(surg* next experience):ti,ab,kw	188
#20	#17 or #18 or #19 or #10 or #11 or #12	3722
#21	#6 and #13 Publication Year from 2010 to 2015, in Other Reviews and Technology Assessments	10
#22	#16 and #20 Publication Year from 2010 to 2015, in Cochrane Reviews (Reviews and Protocols)	1

Database: Epistemonikos
Search date: 17.12.2015

((title:((endovascular OR microvascular OR vascular OR intravascular) AND (surg* OR procedur* OR technique* OR reconstruct* OR repair)) OR abstract:((endovascular OR microvascular OR vascular OR intravascular) AND (surg* OR procedur* OR technique* OR reconstruct* OR repair))) AND (caseload OR "case load" OR frequency OR volume))
38

Database: clinicaltrials.gov
Search date: 17.12.2015

«vascular surgery» AND volume : 9

Database: OpenGrey
Search date: 17.12.2015

Vascular surgery volume : 9
Database: GreyLit
Search date: 17.12.2015

Vascular surgery volume : 0

Appendix 2. Systematic reviews

Study ID	Date of search	Relevance	Description
Abbotts 2012 (123)	2011	Obsolete	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery. Scoping review.
Amato 2013 (124)	2012	Obsolete	Vascular disease
Awopetu 2010 (122)	2009	Obsolete	Atherosclerosis/ lower limb
Henebiens 2007 (125)	2006	Obsolete	Abdominal aortic aneurysm
Holt 2007b (121)	Not reported	Obsolete	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery
Holt 2007c (119)	2006?	Obsolete	Abdominal aortic aneurysm
Karthikesalingam 2010 (117)	Unclear	Obsolete	Vascular disease
Killeen 2007 (118)	2005	Obsolete	Vascular disease
Marlow 2010 (1)	2007	Obsolete	Abdominal aortic aneurysm
McIntosh 2013 (120)	2011	Obsolete	Abdominal aortic aneurysm
Norderhaug 2007/ 2009 (10, 11)	2006	Obsolete	Vascular disease

Norderhaug 2009 (9)	2008	Obsolete	Athero-sclerosis/ narrowing of the common carotid artery or internal carotid artery
Pieper 2013 (116)	2012	Obsolete	Abdominal aortic aneurysm
Troeng 2008 (114)	2008	Obsolete	Abdominal aortic aneurysm
Wilt 2006 (126)	2006	Obsolete	Abdominal aortic aneurysm
Young 2007 (115)	Unclear	Obsolete	Abdominal aortic aneurysm

Appendix 3. Included studies

Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients	Data source (name of registry/ area/ time)	Measures to quality check registry data (for example cross-referencing with patient records)	Condition (diagnosis)	Patients or conditions excluded (diagnosis)	Procedure (open or endovascular)	Outcome(s)
Allareddy 2010 (and Allareddy 2007)	USA	1207 hospitals	35104 procedures	The Nationwide Inpatient Sample (NIS) for years 2000 through 2003	Unclear	Abdominal aortic aneurysm (codes not reported)	Patients <18 years. Included also diagnoses and procedures not meeting our inclusion criteria: coronary artery bypass graft (CABG), percutaneous coronary intervention (PCI), pancreatectomy (PAN), and esophagectomy (ESO. Emergency/ruptured)	Open and endovascular (ICD-9 codes 38.34, 38.44, 38.64, 39.71, 39.25)	Mortality and complications
Amundsen 1990	Norway	26 surgical units	279 patients, 155 patients (ruptured)	Unclear	Unclear	Abdominal aortic aneurysm and ruptured (codes not reported)	Patients dying from ruptured aneurysm at home or on their way to the hospital were not included.	Open (procedure codes not reported)	Mortality
Anderson 2014	USA	Hospitals, numbers unlcear	159333 patients	The Nationwide Inpatient Sample (NIS) from 1998 to 2010	Unclear	Abdominal aortic aneurysm and ruptured (codes not reported)	Patients <18 years, and patients with more than 1 procedure of interest during the same hospitalization were excluded.	Open and endovascular (procedure codes not reported)	Mortality

Arora 2015	USA	Hospitals, numbers unclear	Patients, numbers unclear	Healthcare Cost and Utilization Project Nationwide Inpatient Sample database (2006 to 2011)	Unclear	Peripheral artery disease (codes not reported. lower-extremity)	>18 patients, patients with missing age excluded.	Endovascular (ICD-9 codes 17.56, 39.90, 39.50)	Mortality, complications, costs
Birkmeyer 2002	USA	2819 hospitals, 3184 hospitals (LEB), 2990 hospitals (CEA)	140577 patients, 263580 patients (LEB), 479289 patients (CEA)	Data obtained from Medicare Provider Analysis and Review (MEDPAR) files and the denominator files from the Center for Medicare and Medicaid Services for the years 1994 to 1999.	Unclear	Abdominal aortic aneurysm , peripheral artery disease lower extremity), narrowing of the common carotid artery or internal carotid artery (codes not reported)	Ruptured AAA and thoraabdominal aneurysms. Patients <65 and >99 years of age. Includes diagnoses not meeting our inclusion criteria, such as coronary-artery bypass grafting, colectomy, gastrectomy, esophagectomy, pancreactic resection, nephrectomy, cystectomy, pulmonary resection	Possibly open and endovascular for AAA, open for CEA and LEB (procedure codes not reported)	Mortality
Birkmeyer 2003	USA	6276 surgeons (AAA), 8818 surgeons (CEA)	39794 patients (AAA)/ 136049 patients (CEA)	Data obtained from Medicare Provider Analysis and Review (MEDPAR) files and the denominator files from the Center for Medicare and Medicaid Services for the years 1998 to 1999.	Unclear	Abdominal aortic aneurysm, narrowing of the common carotid artery or internal carotid artery (codes not reported)	Ruptured AAA and thoraabdominal aneurysms. Patients <65 and >99 years of age. Includes diagnoses not meeting our inclusion criteria, such as coronary-artery bypass grafting, colectomy, gastrectomy, esophagectomy, pancreactic resection, nephrectomy, cystectomy, pulmonary resection	Possibly open and endovascular for AAA, and open for CEA (procedure codes not reported)	Mortality

Boudourakis 2009	USA	16,230 surgeons	Range 6301 to 4354	Health Care Utilization Project National Inpatient Sample (HCUP-NIS) administrative database. Representing a stratified 20% sample of acute care hospitals nationwide for the period 1999 and 2005	Unclear	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Patients <18 years and patients with secondary cardiac/ peripheral vascular procedure this included synchronous procedures on heart valves or vessels. The study included a range of diagnoses not meeting our inclusion criteria: colorectal procedures, esophagectomy, gastrectomy, pancreatectomy, thyroidectomy, coronary artery bypass graft surgery	Open (procedure codes not reported)	Mortality, length of stay
Brooke 2008	USA (California)	140 hospitals (81 endo and 103 open)	6406 open cases and 3120 endo cases	Hospital demographics collected by survey data 2001 to 2005 from Leapfrog Group Hospital Quality and Safety Surveys. Self-reported information. Outcomes collected from The California Office of Statewide Health Planning and Development (OHSPD) database	Unclear	Abdominal aortic aneurysm (codes not reported)		Open and endovascular (ICD-9 codes 38.34, 38.36, 38.44, 38.64, 39.25, 39.52, 39.71)	Mortality, length of hospital stay

Bush 2006	USA	123 hospitals	1904 patients of which 717 were endovascular and 1187 were open	Department of Veterans Affairs (VA) National Surgical Quality Improvement Program (NSQIP) database 2001 to 2003	Database includes detailed clinical data. Additional data collected by trained personnel.	Abdominal aortic aneurysm (ICD-9 codes 441.4)	Patients with secondary diagnostic codes for ruptured AAA or thoracic or thoracic abdominal aortic aneurysm were excluded from the analysis. CPT codes representing open repair after EVAR (34830, 34831, 34832) were also excluded.	Both (Open CPT codes 35081 and 35102 and EVAR CPT codes 34800, 34802, and 34804.	Mortality and complications
Calvet 2014	International study, including France, Germany and England	Surgeon, numbers unclear	1679 patients	The Carotid Stenting Trialists' Collaboration (CSTC) pooled individual patient data from the Endarterectomy Versus Angioplasty in patients with Symptomatic Severe Carotid Stenosis trial (EVA-3S), the Stent-Protected Angioplasty versus Carotid Endarterectomy trial (SPACE), and the International Carotid Stenting Study (ICSS).	Unclear but trial data so less likely to be systematic error in registry of data	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Asymptomatic patients	Endovascular (procedure codes not reported)	Mortality

Cebul 1998	USA, Ohio	115 hospitals/ 478 surgeons	Random sample of 678 patients	Ohio Medicare Provider Analysis and Review from 1993 to 1994.	Unclear	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 code not reported)		Open (ICD-9 code 38.12)	Mortality and stroke
Christian 2003	USA	Hospitals: AAA 99, CEA 102	AAA: 9869 patients, CEA: 17015	University Health System Consortium (UHC) Clinical Database (CDB). The UHC Clinical Database is a collection of all-payor hospital discharge abstracts from UHC members and their community teaching affiliates. From years 1999–2000	Unclear	Abdominal aortic aneurysm and thoracic abdominal aortic aneurysm (441.00, 441.02, 441.03-441.7, 441.9)/ Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery		AAA Open (ICD-9 codes 38.34, 38.44, 38.64)/ CEA 38.12, 38.32, 38.42	Mortality
Cowan 2002	USA	Hospitals, numbers unclear/ 2330 surgeons	26149 patients (elective), 9672 patients (emergent)	The National Inpatient Sample for 1996 and 1997	Unclear	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Patients <19 years	Open (ICD-9 code 38.12)	Mortality, complications, length of stay

Cowan 2003	USA	308 hospitals/ surgeons number unclear	1542 patients	Nationwide Inpatient Sample (NIS) from 1988 to 1998	Unclear	Thoracic abdominal aortic aneurysms and abdominal aortic aneurysms (ICD-9 441.0, 441.2, 441.4, 441.7, 441.9)	No restrictions on age	Open (ICD-9 38.44, 38.45)	Mortality, length of stay, complications
Cowan 2003b	USA	Hospitals, numbers unclear	321 patients, unclear how many had AAA or TAAA	Nationwide Inpatient Sample (NIS) from 1988 to 1998	Unclear	Abdominal aortic aneurysm (ICD-9 441.3, 441.5) and thoracic abdominal aortic aneurysms (ICD-9 441.1, 441.6)	No restrictions on age	Open (ICD-9 codes 38.44, 38.45)	Mortality
Dardik 1998	USA, Maryland	47 hospitals/ 45 hospitals (rupture)/ 226 surgeons	In total 3820 patients of which 527 were operations for ruptured	Maryland Health Services Cost review Commission (HSCRC) database from 1990 and 1995	Double checked by going through hospital records	Abdominal aortic aneurysm (ICD-9 code not reported and ruptured abdominal aortic aneurysm (ICD-9 codes 441.02 and) 441.3)	Patients undergoing other operations	Open (ICD-9 codes 38.34, 38.44, 38.64, 38.84, 39.54)	Mortality, length of stay, costs
Dimick 2002	USA	507 hospitals in 1996 and	Total patients 13887, of	Nationwide Inpatient Sample (NIS). Sample	Unclear	Abdominal aortic aneurysm (code not	Primary diagnosis of thoracic abdominal aneurysm, dissection of abdominal	Open (ICD-9 code 38.44)	Mortality, complica-

		536 in 1997	which 7980 were elective and 5907 were urgent/ emergent	taken between 1996 to 1997		reported), Ruptured or acute abdominal aortic aneurysm (ICD- 9 code 441.3)	aortic and rupture of thoracic abdominal aneurysm, patients younger than 40 years, and diagnostic codes associated with injury to a blood vessel.		tions, hospital length of stay
Dimick 2002 (case-mix) + 2004 (based on 2002 publication)	USA, Maryland	52 hospitals	2987 patients	Uniform Discharge Dataset managed by the Health Services Cost Review Commission (HSCRC) of Maryland. Sample taken from 1994 to 1996	Unclear	Abdominal aortic aneurysm (code not reported), Ruptured or acute abdominal aortic aneurysm (ICD- 9 code 441.3)	Patients with a diagnosis of blood vessel injury	Open (ICD-9 codes 38.44 and 39.25)	Mortality, complications, length of stay
Dimick 2003	USA	483 hospitals	3073 patients	Nationwide Inpatient Sample (NIS) for 1997	Unclear	Peripheral arterial disease (no code provided. aortoiliac occlusive disease)	Patients with a primary diagnosis of abdominal aortic aneurysms (ICD-9 444.4 and 4441.3)	Open (ICD-9 code 39.25)	Mortality, length of stay
Dimick 2003b (surgeon)	USA	536 hospitals, 879 surgeons	3912 patients	Nationwide Inpatient Sample (NIS). A database of hospital discharges, representative stratified sample of USA	Unclear	Abdominal aortic aneurysm (codes not reported)		Open (ICD-9 codes 38.44 and 39.25)	Mortality

				discharges. Sample taken from 1997					
Dimick 2008	USA	2301 hospitals, 1357 hospitals (endo)	54203 patients, 26750 patients (endo)	National Analytic files from the Center for Medicare Provider Analysis and Review (MEDPAR). Sample taken 2001 and 2003	Unclear	Abdominal aortic aneurysm (ICD-9 code 441.4) and ruptured (ICD-9 code 441.3)	Patients <65 years, and patients with ruptured AAA	Open and endovascular (ICD-9 codes 38.44 and 39.71)	Mortality
Dua 2014	USA	Hospitals, N unclear	630901 admissions of which approximately 558 347 admissions were elective, unclear how many of these were open/ endovascular	Nationwide Inpatient Sample (NIS). A database of hospital discharges, representative stratified sample of USA discharges. Sample taken between 1998 and 2011.	Unclear	Abdominal aortic aneurysm (ICD-9 code 441.4 and 441.9) and ruptured (ICD-9 code 441.3)		Open and endovascular (ICD-9 codes 38.34,38.44, 38.64, 39.52 and 39.71)	Mortality
Dueck 2004 + (Dueck 2004b)	Canada, Ontario	Hospitals and surgeons	13701 patients (elective)/ 2601 patients (rupture)	The Ontario Health Insurance Plan captures 95% of the physician billings in Ontario. Data was collected for the	Unclear	Abdominal aortic aneurysm (fee code R802, R816, and R817) and rupture (fee code E627).		Open and endovascular (procedure codes not reported)	Mortality

				period April 1992 to March 2001.					
Eckstein 2007	Germany	131 hospitals,	10163 patients	A surgeon-led registry to document representative data about indications, treatments and complications. Voluntary participation. This study evaluated data from January 1999 to December 2004 (six years).	Unclear	Abdominal aortic aneurysm (ICD-10 codes I173 or I174)	Hospitals that had not been part of the registry for the last 4 years and patients who underwent another procedure simultaneously. Patients with ruptured AAA.	Open (procedure codes not reported)	Mortality, complications, length of stay, process measures
Feasby 2002	Canada	Hospitals, numbers unclear/ 367 surgeons	14268 patients	Canadian administrative hospital discharge database for 1994 to 1997.	Unclear	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Patients who also underwent coronary artery bypass grafting. No age restrictions.	Open (Canadian classification of procedures 50.12)	Mortality, complications
Feinglass 2009	USA, California	345 hospitals	>28000 patients	State of California hospital discharge data from 1996 to 1999	OSHPD provided an encrypted patient identifier to link multiple discharges for the same patient over time. The sample was created to select all unique patients, aged >=35 years, undergoing a	Peripheral arterial disease (no codes. aortoiliac/ femoral)	Patients <35 years or 'with a principal diagnosis of aortic aneurysm' or with prior bypass surgery or amputation.	Open (ICD-9 codes 39.25 and 39.29)	Mortality, complications

					first aortoiliac-femoral (AI) or femoropopliteal-distal (FP) bypass graft surgery				
Finks 2011 (same authors as Birkmeyer 2002, but this sample continues from the Birkmeyer 2002)	USA	Hospitals, range from 1860 to 2339, Hospitals, range from 2341 to 2635 (CEA)	Patients, range from 56333 to 71170 (AAA), patients, range from 178070 to 232388 (CEA)	National Medicare data from 1999 through 2008	Unclear	Abdominal aortic aneurysm, narrowing of the common carotid artery or internal carotid artery (codes not reported)	Included also diagnoses and procedures not meeting our inclusion criteria: esophagectomy, pancreatectomy, lung resection, cystectomy, coronary-artery bypass grafting (CABG), and aortic-valve replacement. AAA patients with diagnosis code or procedure code indicating rupture of the aneurysm, the presence of a thoracic abdominal aneurysm, or both	Open and endovascular for AAA (ICD-9 codes 38.34, 38.44, 38.64, 39.25 and 39.71), and CEA ICD-9 code 38.12)	Mortality
Gazoni 2010	USA, Virginia	17 hospitals	731 procedures, number of patients unclear	The Virginia Cardiac Surgery Quality Initiative, a voluntary consortium of 17 hospitals. Data submitted by the Society of Thoracic Surgery database. Period 2004 and 2007	Unclear	Thoracic abdominal aortic aneurysms, ascending aneurysms, arch aneurysm, descending aneurysms	Unclear if there were age restrictions	Open and endo (procedure codes not reported)	Mortality, length of stay, complications, costs

Glance 2007	USA, California	301 hospitals	8855 patients	California State Inpatient Database, between 1998 to 2000	Unclear	Abdominal aortic aneurysm and ruptured (codes not reported)	The study included also diagnosis not meeting our inclusion criteria: coronary angioplasty and coronary artery bypass	Open (ICD-9 codes 38.34, 38.44 and 38.64)	Mortality
Glaser 2014	USA, New Jersey	Hospitals/ surgeons, numbers unclear	8860 patients	The Vascular Study Group of New England (VSGNE) database was used. This database and this study have been approved by the Institutional Review Board at each of the participating institutions. This regional quality improvement database included 23 centers in the six New England states during the time interval of this study. Data are entered prospectively by trained nurses, clinical data ab-	Unclear	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Patients were excluded if their procedure took place on a Saturday or Sunday, if they were transferred from another institution, if the surgery was an emergency or urgent, or if they had a planned concomitant CABG or any history of an ipsilateral CEA.	Open (procedure codes not reported)	Length of stay

				stractors, or physicians. Between 2003 and 2011					
Gonzalez 2014	USA	Hospitals, number unclear	20690 patients	National sample form Medicare provider analysis and review files for 2005 and 2006	Unclear	Abdominal aortic aneurysm and ruptured (codes not reported)	Patients <65 + >99. The study included also diagnosis not meeting our inclusion criteria: aortic valve repair and coronary artery bypass	Open and endovascular (procedure codes not reported)	Mortality, complications and failure to rescue
Goodney 2003 (volume standards)	USA	Hospitals, number unclear	12573 patients	The national Medicare database (MEDPAR, 1994 to 1999)	Unclear	Abdominal aortic aneurysm (codes not reported)	Patients <65 and >99. Patients with rupture or thoracic abdominal aneurysm. The study included diagnoses not meeting our inclusion criteria: coronary artery bypass, aortic valve replacement, mitral valve replacement.	Open and endovascular (procedure codes not reported)	Mortality (including in-hospital death)
Goodney 2013	USA	Hospitals, numbers unclear	12573 (open) and 2732 patients (endo)	Medicare Physician/ Supplier file and the Medicare Denominator file from 1999 to 2007	Unclear	Thoracic aortic aneurysm (ICD-9 441.1 or 441.2)	Patients with thoracic abdominal aneurysms, thoracic aortic dissections, and “other” aortic pathology , and patients with ICD-9 procedural codes that may indicate the presence of “debranching” or other procedures to extend endovascular landing zones, such as 39.24	Open and endovascular (ICD-9 codes 38.44, 38.45, 39.73 and 39.79)	Mortality

							(aorto-renal bypass), 39.25 (aorta-iliac-femoral bypass).		
Gray 2011	USA	61 centers/77 surgeons	3388 patients	The CAPTURE 2 study was initiated in March 2006; the data in the current analysis include a subgroup of patients who had an attempted carotid artery stenting procedure between March 2006 and January 2009	Data linked to patient outcomes reporting in a study	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Patients >80 years, and symptomatic patients.	Endovascular (procedure codes not reported)	Mortality
Hannan 1998	USA, New York	161 hospitals/ 518 surgeons	28 207 patients	New York's Statewide Planning and Research (SPARCS) administrative database 1990 to 1995	Data in the system are abstracted from medical records by trained medical records personnel in each hospital, and the NYSDOH is responsible for verifying the accuracy of reported information	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 code not reported)		Open (ICD-9 code not reported)	Mortality
Hernandez-Boussard 2012	USA	Hospitals, number unclear	182843 patients	Nationwide Inpatient Sample database (NIS), from 2005 to 2008	As the NIS sampling frame changes over time, NIS Trends Supplement data were	Abdominal aortic aneu-	The study included also diagnosis not meeting our inclusion criteria: gastric	Open and endovascular (ICD-9 codes 38.44 and 39.71)	Mortality and complications

					used to address the sampling changes over the time period (Healthcare Cost and Utilization Project 2008).	rysm and ruptured (codes not reported)	bypass and coronary artery bypass		
Hill 2008	USA	Aprox. 555 hospitals	46901 patients	Nationwide Inpatient Sample (NIS). A database of hospital discharges, representative stratified sample of USA discharges. From 1998 to 2004.	Unclear	Abdominal aortic aneurysm (ICD-9 code 441.4)		Open and endovascular (ICD-9 codes 38.34, 38.44 and 39.71)	Mortality
Holt 2007	UK	Hospitals, numbers unclear	15515 elective procedures/ 6462 ruptured repairs/ 4845 urgent procedures	Hospital Episode Statistics (HES) from 2000 to 2005.	Compared with the hospital's Patient administration system (PAS) to double check data	Abdominal aortic aneurysm and ruptured (ICD 10 codes I173 or I174)		Open (OPCS-4 codes L184-L189, L194-L199, L222-L229, L258-L259, L481-L489, L652)	Mortality, complications, length of stay
Holt 2007d	UK (England)	Hospitals, numbers unclear	18248 patients of which 16 759 were elective and 1489 emergency	HES data were acquired for the years 2000 to 2005.	Unclear	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (OPCS4 codes 163.0, 163.1, 164, 165.2, 165.3, 165.8)	Patients with graft replacement of the carotid artery and bypasses of the carotid and pre-cerebral arteries	Open (OPCS4 codes L29.4. L29.5 and L29.9)	Mortality, complications

Holt 2009	UK (England)	134 Hospitals (trusts), 91 Hospitals (trusts) (endo)	5668 patients, 1645 patients (endo)	Hospital Episode Statistics (HES) for April 2005 to March 2007 (2 years)	Compared with the hospital's Patient administration system (PAS) to double check data	Abdominal aortic aneurysm (ICD-10 codes 71.3 or 71.4)		Open and endovascular (OPCS 4.3: L27.1 to 9, L28.1 to 9, L26.5, L26.6, L26.7)	Mortality, length of stay
Huber 2001	USA	Surgeons, for AAA and surgeons and hospitals for CEA, numbers unclear	Unclear, national sample	The Medicare files obtained from the Health Care Finance Administration (HCFA), 1996	Included both personal records and hospital data	Abdominal aortic aneurysm, arrowing of the common carotid artery or internal carotid artery (codes not reported)		Open (Current Procedural Terminology (CPT) codes 35301 thromboendarterectomy, carotid) and 35081, repair defect of artery, abdominal aorta, 35091 repair defect of artery, aorta, involving visceral vessels, and 35102 repair defect of artery, aorta, involving iliac vessels for elective AAA repair)	Mortality

Illonzo 2014	USA	Hospitals, number of hospitals unclear	295851 patients (open)/ 195928 patients (endo)	Medicare Inpatient Standard Analytical and denominator files for patients for the period 1995 to 2011.	Unclear	Abdominal aortic aneurysm (codes not reprted)	Patients undergoing thoracic, thoracic abdominal, or ruptured aneurysm repair were excluded	Open and endovascular (procedure codes not reported)	Mortality, complications
Indes 2011	USA	Hospitals and surgeons, numbers unclear	818 patients	Nationwide Inpatient Sample (NIS) 2003 to 2007	Unclear	Peripheral arterial disease (aortoiliac occlusive disease)	Patients with renovascular hypertension (ICD-9 codes 405.01, 405.11, and 405.91), renal artery atherosclerosis (ICD-9 code 440.1), renal artery thrombosis/ occlusion, (ICD-9 code 593.81), chronic vascular insufficiency of the intestine (mesenteric) (ICD-9 code 557.1), embolism and/or thrombosis of the upper extremity (ICD-9 code 444.21), and arterial embolism or thrombosis (femoral, peripheral, not otherwise specified, or popliteal) (ICD-9 code 444.22). Patients receiving endovascular and open surgery in the same hospitalization.	Endovascular (ICD-9 codes 39.50 and 39.90)	Mortality, complications, length of stay, costs

Jibawi 2006	UK (England)	223 hospital trusts	31078 patients	Hospital Episode Statistics (HES) in a five years period (1997-2002)	Admin database matched with patient records	Abdominal aortic aneurysm and ruptured abdominal aortic aneurysm (ICD-10 codes I 71.x)	Thoracic procedures	Open and endovascular (OPCS-4 codes L16.x - L.26.x)	Mortality
Kantonen 1997 (and 1999)	Finland	23 hospitals (surgeons, number unclear)	929 patients (elective)/ 610 patients (rupture)	The nationwide vascular registry, and Statistics Finland the Finnvasc registry from 1991 to 1995	For patients not found in Finnvasc registry copies of hospital record of the last visit was found.	Abdominal aortic aneurysm and ruptured abdominal aortic aneurysm (codes not reported)		Open (procedure codes not reported)	Mortality, complications
Kantonen 1998 (Ischemia)	Finland	25 hospitals, surgeons numbers unclear	1761 procedures	The Finnvasc registry	Unclear	Peripheral vascular disease (codes not reported. chronic leg ischemia)	Acute ischemia. Thrombectomies, operations for acute or chronic ischemia, repeated operations and operations with additional indications such as various aneurysms in combination with leg ischemia.	Open (procedure codes reported). All bypasses, patch-angioplasties and endarterectomies (femoropopliteal, femorocrural or femoropedal, aortoiliacal or artofemoral, femoror-femoral, and axillofemoral)	Mortality, complications

Kantonen 1998b (CEA)	Finland	23 hospitals/104 surgeons	1600 procedures	The Finnvasc registry, a national registry for all surgical and endovascular procedures. Sample from 1991 to 1995.	The total number of carotid operations recorded at the National Hospital Discharge Registry was provided by the National Research and Development Center for Welfare and Health (Stakes). These numbers were compared with the Finnvasc data. A random sample of 24 carotid operations were available from a previous Finnvasc registry reliability study, 7 in which primary Finnvasc data and data of forms refilled later by each centre were compared.	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)		Open (procedure codes not reported)	Mortality
Karp 1998	USA, Georgia	Hospitals, numbers unclear	1945 patients	Medicare beneficiaries in Georgia in 1993	Analysis included hospital records	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 code not reported)		Open (ICD-9 code 38.12)	Mortality and complications

Karthikesalingam 2014	UK/ USA	Hospitals, numbers unclear	11 799 patients (UK), 23838 patients (USA)	Hospital Episode Statistics (HES) from 2005 to 2010, Nationwide Inpatient Sample (NIS) from 2005 to 2010	Unclear	Ruptured or acute abdominal aortic aneurysm (OPCS-4 codes (UK) 1713 and 1718, ICD-9 codes 441.3 and 441.5)		Open and endovascular (OPCS-4 codes L194-199, L231, L236, L238-239, L254, L258, L259, L49, L271, L275, L276, L281, L285, L286, L289, ICD-9 38.44, 38.34, 39.25 and 39.71)	Mortality
Kucey 1998	Toronto, Canada	8 hospitals	1280 procedures	Canadian Institute for Health Information hospital discharge database for 1994 to 1996	The existence of each case was verified by searching each individual hospital database and by cross-referencing the actual inpatient chart with the Canadian Institute for Health Information database.	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Carotid artery surgeries for procedures other than primary atherosclerotic occlusive disease were excluded from the database. Complex reconstructions that involved carotid endarterectomy plus another procedure (eg, coronary artery bypass graft procedures) and redo surgeries also were excluded.	Open (Canadian classification of procedures code 50.12)	Mortality, complications
Khuri 1999	USA	AAA: 107 hospitals/ CEA: 93 hospitals	AAA: 3767 cases/ CEA: 10173)	Department of Veterans Affairs (VA) National Surgical Quality		Abdominal aortic aneurysm (CPT-code 4 35081) atherosclerosis/ narrowing		Open (CPT- 4 codes 35301 35081)	Mortality and complications (CEA)

				Improvement Program (NSQIP) database 1991 to 1999		of the common carotid artery or internal carotid artery (CPT-code 4 35301)			
Kumamaru 2015	USA	Surgeon, numbers unclear	454717 patients	Medicare data from 2001 to 2008	Unclear	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	<66 years. Patients with no identifiable performing surgeon were excluded	Open (ICD-9 code 38.12)	Mortality
Landon 2010	USA	Hospitals, numbers unclear	45 660 patients, this number includes patients receiving both open and endovascular procedures	Medicare program 2001–2004	Checked with physician claims	Abdominal aortic aneurysm (ICD-9 441.4)	Patients <65, diagnosis codes for AAA rupture (441.3), thoracic aneurysm (441.1, 441.2), thoracic abdominal aortic aneurysm (441.6, 441.7), aortic dissection (441.0*), repair of the thoracic aorta (38.35, 38.45, 39.73) or visceral/renal bypass (38.46, 39.24, 39.26).	Open and endovascular (ICD-9 codes 38.44, 39.25 and 39.71)	Mortality
Manheim 1998	USA, California	Hospitals, numbers unclear	35130 procedures (AAA), 7327 procedures (RAAA	California patient discharge data, contain all non-federal inpatient	Unclear	Abdominal aortic aneurysm, Ruptured or acute abdominal		Open (ICD- 9 codes 38.34, 38.44 and 38.64 (AAA), 39.25 and	Mortality

			),100963 procedures (LEB), and 106493 procedures (CEA)	hospital discharges between 1982 and 1994.		aortic aneurysm, peripheral artery disease in lower extremities, narrowing of the common carotid artery or internal carotid artery (codes not reported)		39.29 (LEB), and 38.12 (CEA)	
Massarweh 2011	USA, Washington	Hospitals, numbers unclear	7724 patients	Comprehensive Hospital Abstract Reporting System (CHARS) database, a population-based, administrative dataset comprising all nonfederal inpatient discharges in Washington State, January 1, 1994 and December 31, 2007	Unclear	Abdominal aortic aneurysm (codes not reported)	Acute, included also diagnoses and procedures not meeting our inclusion criteria: pancreatic and esophageal resection. Patients <18 years	Open and endovascular (procedure codes not reported)	Mortality, complications, readmissions
Matsen 2006	USA, Maryland	47 hospitals / 438 surgeons	23237 patients	The Maryland Health Services Cost Review Commission (HSCRC) database	Validated against John Hopkins database	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery	no age cut-off	Open (ICD-9 code 38.12)	Mortality, complications

				from 1994 to 2003.		(ICD-9 433.00 to 433.91)			
Mayo 1998	Maine, USA	10 hospitals/23 surgeons	341 patients	The Maine Carotid Endarterectomy Registry was established by the vascular surgery study group of the Maine Medical Assessment Foundation, a private, nonprofit, research and education organization. Ten of 17 hospitals contributed to the registry. Surgeon participants collected data from January 1 to December 31, 1995	To confirm completeness of the registry data, discharge data was obtained from Maine Health Information, a state-supported agency, for all carotid endarterectomies (International Classification of Diseases-9 code 3812) performed in Maine during calendar year 1995.To further verify the accuracy of the registry data, all charts of patients undergoing carotid endarterectomy at one hospital during calendar year 1995 were reviewed. This included registered and unregistered patients. Accuracy of postoperative events, including	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)		Open (ICD-9 code 38.12)	Complications

					stroke, transient ischemic attack (TIA), myocardial infarction, and death were evaluated.				
McPhee 2009	USA	Hospitals	24570 patients	Nationwide Inpatient Sample (NIS). A database of hospital discharges, representative stratified sample of USA discharges. Sample taken between 2001 and 2006	Unclear	Abdominal aortic aneurysm (ICD-9 code 441.4) and ruptured or acute abdominal aortic aneurysm (ICD-9 code 441.3)		Open and endovascular (ICD-9 38.44, 39.25, and 39.71)	Mortality
McPhee 2011	USA	Hospitals and surgeons, numbers unclear	5972 patients (open), 8121 procedures (endo)	Nationwide Inpatient Sample (NIS). A database of hospital discharges, representative stratified sample of USA discharges. Sample taken between 2003 and 2007		Abdominal aortic aneurysm (ICD-9 code 441.4)	Patients <40 years were excluded	Open and endovascular (ICD-9 codes 38.44, 39.25 and 39.71)	Mortality
Mell 2012	USA	Hospitals, numbers unclear	2616 patients	Data obtained from Medicare and Medicaid services through the Chronic Condition Data Warehouse, administrated by	Unclear	Abdominal aortic aneurysm (ICD-9 code 441.4 and 441.9)	Ruptured AAA, aortic dissections, thoracic aneurysms, thoraabdominal aneurysms or aneurysm diagnosis without treatment code. Patients <65 and >99 years of age	Open and endovascular (ICD-9 codes 38.34, 38.44, 38.64, 39.52, 39.71)	Mortality or reshospitalisation

				the Iowa Foundation for Medical Care. Includes a 5% sample of Medicare patients in the USA. Sample for 2005 and 2006					
Middleton 2002	Australia, New South Wales	46 hospitals/ 52 surgeons	666 patients	Sample based on review of medical records after consent by surgeons	Included medical records	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (codes not reported)	Patients were excluded if the operation was a "redo" or if the procedure was performed with the same anesthetic as cardiothoracic surgery	Open (codes not reported)	Mortality and complications
Miyata 2009	Japan	40 centers/ surgeons, numbers unclear	2875 procedures	Japan Adult Cardiovascular Surgery Database (JACVSD). The JACVSD was established in 2000 to report detailed surgical outcomes following cardiothoracic procedures. In 2009, the database captured clinical information from nearly half of the centers	The accuracy of the submitted data is verified through monthly visits to each hospital by administrative office members. After checking the data against clinical records and operative notes, administrators request that hospitals clarify any incomplete or unclear submissions. The validity of JACVSD data has further been	All thoracic aortic surgery procedures performed including those combined with CABG surgery, valve surgery or other major surgical interventions	No age restriction	Open and endovascular (procedure codes not reported)	Mortality

				conducting cardio-vascular surgery in Japan. Sample taken from 2003 and 2005	confirmed by independent comparisons of hospital adult cardiovascular surgery volume submitted to the JACVSD against that reported to the JATS (The Japanese Association for Thoracic Surgery) data registry. We excluded eight centers that entered fewer cases in JACVSD than in JATS.				
Modrall 2009	USA	>1000 hospitals	7413 patients	The Nationwide Inpatient Sample (NIS) from 2000 to 2005	Unclear	Peripheral vascular disease (ICD-9 440.1 and 447.3 renal artery occlusive disease)		Open (ICD-9 codes 39.24 and 39.26)	Mortality
Modrall 2011b	USA	6857 surgeons	22986 patients	The Nationwide Inpatient Sample (NIS) for the years 2000 to 2008	Unclear	Abdominal aortic aneurysm (ICD-9 codes 441.4 and 441.9)		Open (ICD-9 codes 38.34 and 38.44)	Mortality
Modrall 2014	USA	Surgeon, numbers unclear	11535 procedures (carotid), numbers for abdominal	The Nationwide Inpatient Sample (NIS) from the Healthcare Cost and Utilization	Unclear	Atherosclerosis/ narrowing of the common carotid artery		Endovascular (ICD-9 codes 00.63, 39.71 and 39.73)	Mortality, complications

			aortic aneurysms are unclear	Project for the years 2005 to 2009.		or internal carotid artery (ICD-9 433.00 to 433.1) and abdominal aortic aneurysms and thoracic aortic aneurysms (specific codes not reported)			
Morasch 2000	USA, Florida	Hospitals and surgeons, numbers unclear	45744 patients	Hospital UB92 discharge records for all Florida nonfederal hospitals obtained from the Florida Agency for Health Care Administration from 1992 to 1996	Unclear	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)		Open (ICD-9 code 38.12)	Mortality, complications
Nazarian 2008	USA, Maryland	47 hospitals/ 442 surgeons	22772 patients	Maryland hospital discharge database 1994 to 2003	Unclear	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 433.00 to 433.91)	Patients receiving CEA concurrently with another procedure, such as coronary artery bypass grafting	Open (ICD-9 code 38.12)	Mortality
O'Neill 2000	USA, Pennsylvania	532 surgeons	14 439 procedures	Pennsylvania Health Care Cost Containment	Unclear	Atherosclerosis/ narrowing of the common	Patients were excluded if undergoing other cardiac and peripheral	Open (ICD-9 code 38.12)	Mortality and complications

				Council (PHC4) for the period from 1994 to 1995. Physician data were obtained from the Physicians List of the American Medical Association		carotid artery or internal carotid artery (codes not reported)	vascular procedures, if surgeon details were missing, patients with a Medisgroups severity score of three or four (2.2% of all patients) as these patients had a greater presurgical risk of in-hospital mortality (i.e., greater than approximately 6%, and in cases were CEA was reported as secondary		
Pearce 1999	USA, Florida	Hospitals and surgeons, numbers differ by diagnosis and year	31 172 patients (LEAB), 45,744 patients (CEA), and 13415 patients (AAA)	The Florida Agency for Health Care Administration state admission data from 1992 to 1996	Unclear	Abdominal aortic aneurysm (ICD-9 code 441.4), and ruptured abdominal aortic aneurysm (ICD-9 code 441.3), peripheral artery disease (codes not reported. lower-extremity) and narrowing of the common carotid artery		Open (ICD-9 codes 38.34 and 38.44) for AAA, and LEB (39.9 and 39.29), for CEA (38.12)	Mortality and complications

						or internal carotid artery			
Perler 1998	USA, Maryland	48 hospitals	9981 cases	The Maryland Health Services Cost Review Commission (MHSCRC) database 1990 to 1995	Tested compared to Johns Hopkins Hospital records	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 433.00 with any fourth digit)	Patients receiving CEA concurrently with another procedure, such as coronary artery bypass grafting	Open (ICD-9 code 38.12)	Mortality, complications, length of stay, costs
Pronovost 1999	USA, Maryland	46 hospitals, surgeons, number unclear	2606 patients	Uniform Discharge Dataset managed by the Health Services Cost Review Commission (HSCRC) of Maryland. Sample taken from 1994 to 1996 + questionnaire sent to all unites about organizational characteristics such as staffing and care processes.	Unclear	Abdominal aortic aneurysm (code not reported), ruptured or acute abdominal aortic aneurysm (ICD- 9 code 441.3)	Patients <30 years with injury to blood vessels.	Open (ICD-9 38.44 and 39.25)	Mortality, hospital length of stay, days of intensive care
Reames 2014	USA	Hospitals, ranged from 2301 to 1888	National sample, ranged from 62327 to 46105	National Medicare claims data from 2000 through 2009	Unclear	Abdominal aorta aneurysm (code not reported), narrowing of	Patients < 65 years. A rupture of the aneurysm, presence of a thoracic abdominal aneurysm, or dissection. We also excluded	Open and endovascular (procedure codes not reported)	Mortality

						the common carotid artery or internal carotid artery (code not reported)	patients who underwent simultaneous coronary artery bypass grafting and valve surgery. Gastrointestinal (colectomy, esophagectomy, and pancreatectomy), 3 cardiac (aortic valve replacement, mitral valve replacement.		
Regenbogen 2012	USA	1939 hospitals	69141 patients	Medicaid claims data, 2005 to 2007. Cost data were collected from all payment data including inpatient, outpatient, carrier (i.e. physician), home health, skilled nursing facility, long stay hospital, hospice and durable medical equipment files)	Unclear	Abdominal aortic aneurysm (codes not reported)	Patients <65 years and >99 years, ruptured AAA, and living in hospice or nursing homes. Patients with thoracic abdominal aneurysms. Coronary artery bypass surgery and colectomy for cancer, ruptured AAA	Open and endovascular (procedure codes not reported)	Mortality and costs
Roddy 2000	USA, Massachusetts	20 centers	10211 procedures	Data on individual patients, including charges, were obtained from the Massachusetts Division of Health Care Finance and	Not necessary	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Combined CEA/coronary artery bypass grafting procedures (with ICD-9-CM procedure codes 35.2, 35.3, and 36.1)	Open (ICD-9 code 38.12)	Mortality, complications, length of stay, costs

				Policy, and hospital cost and charge data were provided by the Health Care Financing Administration 1995 to 1996					
Ruby 1996	USA, Connecticut	226 surgeons	3997 procedures	Connecticut Hospital Information Management Exchange data base from 1985 to 1991	Not done	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	No age cut-off	Open (ICD-9 code 38.12)	Mortality, complications, length of stay
Rutledge 1996	USA, North Carolina	Hospitals and surgeons	12658 patients, 1480 patients (rupture)	Data were obtained from four main data sets. The source of the patient information was the state hospital discharge database, which will be described in more detail. Data on hospitals in the state were obtained from the North Carolina American Hospital	Unclear	Abdominal aortic aneurysm (ICD-9 code 441.4) and ruptured abdominal aortic aneurysm (ICD-9 code 441.3)		Open and endovascular (procedure codes not reported)	Survival

				Association database. Data on county demographic information was obtained from the Area Resource File. Physician-specific information (age and board certification) was obtained from the North Carolina Board of Medical Examiner's database					
Schermerhorn 2008	USA	Total number of hospitals were for low volume category 685, medium 297 and high 265	1976 procedures (elective) and 573 procedures (acute)	The Nationwide In-patient Sample is a database from 1988 to 2003 maintained through the Healthcare Cost and Utilization Project (HCUP)	Unclear	Thoracic aortic aneurysm (ICD-9 codes 441.1 and 441.2)	<18 years of age, to isolate descending thoracic aneurysms, exclusion criteria included concomitant diagnosis of thoracic-abdominal aneurysm (441.6, 441.7),abdominal aortic aneurysm repair (38.44), cardioplegia (39.63), hypothermia (39.62), cardiac surgery (35.00-37.99), aorta to carotid or subclavian bypass (39.22),	Open (ICD-9 code 38.45)	Mortality, length of stay, complications

							and intrathoracic bypass (39.23).		
Sgroi 2015	USA	Surgeon, numbers unclear	20663 cases	The National Inpatient Sample for 2004 to 2011	Unclear	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 codes 433.10, 433.11, 433.30 and 433.31)		Endovascular (ICD-9 code 00.63)	Mortality, complications, length of stay, costs
Shishehbor 2014	USA	366 hospitals/ surgeons, numbers unclear	5240 patients	Data taken from a subset of patients participated in a multi-center post-marketing study (CHOICE (Carotid Stenting for High Surgical-Risk Patients; Evaluating Outcomes Through the Collection of Clinical Evidence) in the period 2006 to 2012.	Unclear, but possibly not relevant	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	There were no exclusion criteria for this study	Endovascular (Carotid artery stenting, procedure code not reported)	Mortality, complications and process measures
Staubach 2012	Germany	Hospitals, numbers unclear	5535 patients	The German CAS Registry of the Arbeitsgemeinschaft	Unclear	Atherosclerosis/ narrowing of the common carotid artery		Endovascular (Carotid artery	Mortality, complications

				Leitende Kardiologische Krankenhausarzte (ALKK) is an ongoing registry that was initiated in 1996 to document the current indications and outcomes of CAS and to improve its quality. Every patient treated by percutaneous intervention was prospectively enrolled in the registry. Sample includes patients treated from 1996 to 2009.		or internal carotid artery (specific code not reported)		stenting, procedure code not reported)	
Tu 2001	Canada, Ontario	130 surgeons	5878 patients	Physician billing codes for AAA surgery (R802, R816, R817) taken from the Ontario Health Insurance Plan (OHIP) physi-	Unclear	Abdominal aortic aneurysm (codes not reported)	Patients with ruptured aneurysms were excluded from the study	Open (R-codes 802, 816, 817)	Mortality

				cian claims data-base. 1992 to 1996					
Urbach 2004	Canada, Ontario	57 hospi-tals	6279 pa-tients	Unclear, "elec-tronic records"	Unclear	Abdominal aortic aneu-rysm (codes not reported)	Included also diagnoses and procedures not meet-ing our inclusion criteria: oesophagectomy, excision of a segment of the colon or rectum for colorectal can-cer, pancreaticoduodenec-tomy, major lung resection (lo-bectomy or pneumonec-tomy) for lung cancer	Open and endo-vascular (proce-dure codes not reported)	Mortality
Vogel 2009	USA, New Jer-sey	383 sur-geons	2837 proce-dures	The State Inpa-tient Databases for New Jersey from 2003 to 2007	Unclear	Peripheral vascular dis-ease (ICD-codes 440.2x atheroscler0-sis in native arteries of the extremities)	Patients <18 years, and pa-tients with acute admis-sions, and cases with asso-ciated renal, mesenteric, and cerebral disease diagnoses	Endovascular (ICD-9 codes 39.50 and 39.90)	Costs
Vogel 2009d	USA, New Jer-sey	Surgeon, numbers unclear	625 cases	State Inpatient Da-tabases for New Jersey, from 2005 to 2006	Unclear	Atheroscler0-sis/ narrowing of the common carotid artery or internal ca-rotid artery (specific code not reported)	No age restriction. Only elective admissions.	Endovascular (ICD-9 code 00.63)	Complica-tions, length of stay, costs

Vogel 2011	USA	Hospitals , range from 1335 to 1116, Hospitals , range from 1188 to 1291 (endo)	17210 procedures (open)/ 42155 procedures (endo)	The Medicare database from 2005 to 2007	Unclear	Abdominal aortic aneurysm (ICD-9 code 441.4)	Patients <65 years, and patients with ruptured AAA	Open and endovascular (ICD-9 codes 38.34, 38.44, 38.64 and 39.71)	Mortality, complications, length of stay, costs
Weiss 2014	USA, California	122 hospitals	1188 patients	California Office of Statewide Health Policy and Development discharge database from 1995 to 2010	Unclear	Thoracic abdominal aneurysm repair (ICD-9 codes 441.6 and 441.7)	<18 years of age, to isolate descending thoracic aneurysms, exclusion criteria included concomitant diagnosis of thoracic-abdominal aneurysm (441.6, 441.7),abdominal aortic aneurysm repair (38.44), cardioplegia (39.63), hypothermia (39.62), cardiac surgery (35.00-37.99), aorta to carotid or subclavian bypass (39.22), and intrathoracic bypass (39.23).	Open (ICD-9 codes 38.44 and 38.45)	Mortality, complications
Wen 1996	Canada, Ontario	All Ontario hospitals, numbers unclear	5492 patients/ 1203 patients (ruptured)	Hospital discharge abstracts from Ontario years 1988-92	Unclear	Abdominal aortic aneurysm (ICD-9 code 441.4), and ruptured abdominal	Ruptured AAA + patients were excluded if they underwent a secondary procedure involving any operations on the heart - for example coronary vessels,	Open (CC code 5034 or 5024 or 5125, for ruptured 5125)	Mortality, length of stay

						aortic aneurysm (ICD-9 code 441.3)	pericardium, valves, or septa (CC codes 47-49). Also excluded were patients with the following secondary diagnoses: dissecting aneurysm (ICD-9 code 4410) or thoracic aneurysm (ICD-9 codes 4411-4412); aneurysm of unspecified site, ruptured (ICD-9 code 4415); aortic aneurysm of unspecified site, without mention of rupture (ICD-9 code 4419); arterial embolism and thrombosis of abdominal (ICD-9 code 4440) or thoracic aorta (ICD-9 code 4441); congenital anomalies of aorta (ICD-9 code 7472) including coarctation (ICD-9 code 7471); or injury to abdominal aorta (ICD-9 code 9420).		
Wennberg 1998	USA	Hospitals, numbers unclear	113300 patients	The Health Care Financing Administration (HCFA) Medicare Provider Analysis and Re-	Unclear	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery	Patients were excluded if they underwent concurrent open heart procedure, had missing data on sex and race or where >65 years.	Open (ICD-9 code 38.12)	Mortality

				view file (MEDPAR) from 1992 to 1993.		(specific code not reported)			
Westvik 2006	USA, Connecticut	26 hospitals	14288 patients	A database consisting of patient discharge records from all acute care, non-federal Connecticut hospitals maintained by Chime, Inc. The Connecticut Hospital Association Chime Data Program has established and maintains a proprietary healthcare information system that incorporates statewide clinical, financial, and patient demographic data dating back to 1980. Sample taken from 1991 to 2002	Unclear	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 codes 433.x)		Open (ICD-9 code 38.12)	Mortality, complications

Appendix 4. Excluded studies

Study First author (reference no.)	Reason for exclusion of study
Harthun 2005	Focus on exploring confounder
Ebaugh 2001	Not volume- capacity
Maas 2013	Too few sites
Cho 2008	Too few sites
Peck 2001	Too few sites
Hollenbeak 2010	Not volume- specialty
Mandawat 2011	Not volume- comparison of procedures
Jarrett 2015	Possibly not surgical procedure

Appendix 5. Risk of bias

Study ID	Were the groups comparable?	Were the participants representative?	Was the exposed group drawn from the same sample as the non-exposed?	Was the study prospective?	Were the outcomes measured in the same way in the two groups?	Did the study include enough people?	Were all of the participants followed-up or was any loss to follow up adjusted for?	Was the follow-up long enough?	Were all relevant confounders accounted for or adjusted for?	Were the analysis of the results blinded?	Risk of bias
Allareddy 2007 + Allareddy 2010	Yes	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Low
Amundsen 1990	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Unclear	Unclear	High
Anderson 2014	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Arora 2015 (in lower-extremity)	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Birkmeyer 2002	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Birkmeyer 2003	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear

Boudourakis 2009	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Partly	Unclear	Unclear
Brooke 2008	Yes	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Low
Bush 2006	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Calvet 2014	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Cebul 1998	Partly	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Partly	Unclear	Unclear
Christian 2003	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Cowan 2002	Yes	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Low
Cowan 2003a	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Cowan 2003b	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Dardik 1998	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Dimick 2002b	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Dimick 2002a+ 2004	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear

Dimick 2003a	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Dimick 2003b (surgeon)	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Dimick 2008	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Dua 2014	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Unclear	Unclear	High
Dueck 2004 + Dueck 2004b(long)	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Eckstein 2007	Yes	Unclear	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Feasby 2002	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Partly	Unclear	Unclear
Feinglass 2009	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Finks 2011	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Gazoni 2010	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Unclear	Yes	High
Glance 2007	Unclear	Unclear	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear

Glaser 2014	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Gonzalez 2014	Yes	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Low
Goodney 2003	Yes	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Low
Goodney 2013	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Gray 2011	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Hannan 1998	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Hernandez -Boussard 2012	Yes	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Low
Hill 2008	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Holt 2007 (CEA)	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Holt 2007d (AAA)	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Partly	Unclear	Unclear
Holt 2009	Yes	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Low
Huber 2001	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Unclear	Unclear	High

Illonzo 2014	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Indes 2011	Yes	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Low
Jibawi 2006	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Unclear	Unclear	High
Kantonen 1997 + 1999	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Kantonen 1998 (Ischemia)	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Kantonen 1998b (CEA)	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Karp 1998	Yes	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Low
Karthikesalingam 2014	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Kucey 1998	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Khuri 1999	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Partly	Unclear	Unclear
Kumamaru 2015	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear

Landon 2010	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Manheim 1998	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Massarweh 2011	Yes	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Yes	Low
Matsen 2006	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Partly	Unclear	Unclear
Mayo 1998	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Unclear	Unclear	High
McPhee 2009	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
McPhee 2011	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Mell 2012	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Middleton 2002	Unclear	Unclear	Unclear	No	Yes	Yes	Not relevant	Yes	No	Unclear	High
Miyata 2009	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Unclear	Unclear	High
Modrall 2009	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Modrall 2011b (defining)	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear

Modrall 2014	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Morasch 2000	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Unclear	Unclear	High
Nazarian 2008	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Partly	Unclear	Unclear
O'Neill 2000	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Pearce 1999	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Partly	Unclear	Unclear
Perler 1998	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Unclear	Unclear	High
Pronovost 1999	Unclear	Yes	Yes	Partly	Yes	Yes	Not relevant	Yes	Yes	Yes	Low
Reames 2014	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Regenbogen 2012	Yes	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Low
Roddy 2000	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Ruby 1996	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Unclear	Unclear	High
Rutledge 1996	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Partly	Unclear	Unclear
Schermerhorn 2008	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Partly	Unclear	Unclear

Sgroi 2015	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Shishebor 2014	Unclear	Unclear	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	High
Staubach 2012	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Tu 2001	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Urbach 2004	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Vogel 2011	Partly	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Low
Vogel 2009a	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Unclear	Unclear	High
Vogel 2009d (carotid)	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Unclear	Unclear	High
Weiss 2014	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Wen 1996	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Wennberg 1998	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear
Westvik 2006	Unclear	Yes	Yes	No	Yes	Yes	Not relevant	Yes	Yes	Unclear	Unclear

Appendix 6. Results tables abdominal aortic aneurysms

The association of volume and quality for all surgery

Hospital volume: mortality in all patients for all surgery									
Study ID	Set-ting	Unit (sur-geon/ depart-ment/ hospital)	Patients (descrip-tion and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Gon-zalez 2014	USA	Hospi-tals, number unclear	20690 pa-tients	Abdominal aor-tic aneurysm and ruptured (codes not re-ported)	Open and endovascular (procedure codes not re-ported)	Divided into quintiles, high volume repre-sented the high-est quintile, and low the lowest quintile. Not further descri-bed.	Mortality (30-day morta-lity)	Compared with the highest-volume hospi-tals, the lowest-volume hospitals had increased rates of mortality (OR 1.80; 95% CI, 1.56 to 2.07)	Calculation of risk adjusted mortality rates (by patient age, sex, race, urgency and operation and comorbidi-ties), and logistic regres-sion
Gon-zalez 2014	USA	Hospi-tals, number unclear	20690 pa-tients	Abdominal aor-tic aneurysm and ruptured (codes not re-ported)	Open and endovascular (procedure codes not re-ported)	Divided into quintiles, high volume repre-sented the high-est quintile, and low the lowest quintile. Not further descri-bed.	Mortality (Failure to rescue)	Compared with the highest-volume hospi-tals, the lowest-volume hospitals had increased odds of failure to rescue (OR 1.38; 95%CI 1.16 to 1.64)	Calculation of risk adjusted mortality rates (by patient age, sex, race, urgency and operation and comorbidi-ties), and logistic regres-sion
Jibawi 2006	UK, Eng-land	223 hos-pital trusts	31078 pa-tients	Abdominal aor-tic aneurysm and ruptured	Open and endovascular (OPCS-4	Identified as part of the anal-ysis	Mortality (in-hospi-tal morta-lity)	Based on a bivariate correlation, there was an inverse correlation between volume and hospital mortality (-0.315, p<0.001).	Bivariate correlation (Pearson's), and logarith-mic transformation

				abdominal aortic aneurysm (ICD-10 codes I 71.x)	codes L16.x - L.26.x)			In the analysis using logarithmic transformation, the association was stronger (-0.447, p<0.001). Cut-off where no difference was seen between volume categories was estimated to be 14 procedures per year.	
Hernandez-Boussard 2012	USA	Hospitals, number unclear	182843 patients	Abdominal aortic aneurysm and ruptured (codes not reported)	Open and endovascular (ICD-9 codes 38.44 and 39.71)	Low <28, medium 28-61 and high >61	Mortality (in-hospital mortality)	The adj % mortality was higher in low than for high volume. % mortality by category was: low 2.66, medium 0.53 and high 0.23, p<0.0001	Rao-Scott chi-squared for categoricalal variables and Kruskal–Wallis Test for continuous variables. The Cochran-Armitage trend test was used to analyse outcomes by hospital volume. Risk adjusted rates adjusted for age, sex, age–sex interactions, DRG, and comorbidities. All models accounted for the clustered nature, admission within year specific hospital cluster, of the study sample.
Anderson 2014	USA	Hospitals, numbers unclear	159333 patients	Abdominal aortic aneurysm and ruptured (codes not reported)	Open and endovascular (procedure codes not reported)	>50 high	Mortality (in-hospital mortality)	Using adjusted logistic regressions, patients had decreased odds ratios of inpatient mortality over time when they received care at a high-volume hospital. Numbers not reported, only in figure for the following time periods 1998-1999, 2000-2001, 2002-2003, 2004-2005, 2006-2007, 2008-2009, 2010. The association was statistical significant for all periods with exception of in 2010.	Logistic regression and adjusting for age, race, sex, comorbidity, and teaching hospital status. Separate analyses were performed for each 2-year interval in the study period to observe changing odds ratios over time.

Hospital volume: mortality in elective patients for all surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Reames 2014	USA	Hospitals, ranged from 2301 to 1888	National sample, ranged from 62327 to 46105	Abdominal aortic aneurysm (code not reported)	Open and endovascular (codes not reported)	Hospital volume was defined as total volume of operations performed in Medicare beneficiaries during each 2-year period: low <18 procedures, high >70. The cut-off varied for each year.	Mortality (30- day mortality)	Odds of mortality was higher in low-volume hospitals for all years: Adj. OR (95% CI) year 1: 1.39 (1.19–1.62) Year 2: 1.59 (1.35–1.88) year 3: 1.28 (1.07–1.52) year 4: 1.48 (1.21–1.81) year 5: 1.48 (1.27–1.72).	Multivariable logistic regression during the 10-year study period, after adjusting for patient characteristics (age, sex, race (black or nonblack) and their interactions, urgency or emergency of the admission, the presence of coexisting conditions, and socioeconomic status), year of the procedure, and surgical approach.
Massarweh 2011	USA, Washington	Hospitals, numbers unlcear	7724 patients	Abdominal aortic aneurysm (codes not reported)	Open and endovascular (codes not reported)	>50 high	Mortality (30-day and 90-day)	Adjusted mortality, were generally similar for patients at high volume compared to low volume. Year 1, 30 day mortality: low volume 4.4%, high volume 4.9%, p-value= 0.58. Year 1, 90-day mortality: low-volume 5.2%, high volume 5.3%, p-value= 0.93. Year 2, 30 day mortality: low volume 3.7%, high volume 2.5%, p-value= 0.12. Year 2, 90-day mortality: low-volume 4.7%, high volume 3.1%, p-value= 0.07	Multilevel binomial generalized estimating equation regression models with an exchangeable correlation structure and robust standard errors were used to calculate risk-adjusted outcome rates. Adj for age, sex, type of insurance, length of stay, comorbidity, type of procedure, leapfrog era.

Birkmeyer 2002	USA	2819 hospitals	140577 patients	Abdominal aortic aneurysm (codes not reported)	Open and endovascular (codes not reported)	1: <17, 2: 17 to 30, 3: 31 to 49, 4: 50 to 79, 5:>79	Mortality (30-day mortality)	The mortality rate by category was: low 5.9%, medium 5.2%, high 5.3% and very high 4.4%. In the multivariate analysis, higher volume was associated with lower mortality rates. Compared to lowest volume quintile, the odds for operative mortality was by quintile; 2: OR 0.79 (95% CI 0.73 to 0.86), 3: OR 0.70 (95% CI 0.64 to 0.76), 4: OR 0.71 (95% CI 0.65 to 0.78), 5. OR 0.58 (95%CI 0.53 to 0.65).	Multiple logistic regression with adjustment for characteristics of the patients (age, gender, comorbidities, race, year of procedure, type of admission, and mean income)
Bush 2006	USA	123 hospitals	1904 patients of which 717 were endovascular and 1187 were open	Abdominal aortic aneurysm (ICD-9 codes 441.4)	Both (Open CPT codes 35081 and 35102 and EVAR CPT codes 34800, 34802, and 34804.	Low <10 procedures	Mortality (30-day mortality)	There was higher mortality in lower volume, low compared to high: OR 1.89, 95% CI 1.19 to 2.98, p< 0.006)	Multivariate logistic regression analysis, adj for procedure type, personal and system characteristics.
Dueck 2004	Canada, Ontario	Hospitals, number unclear	13701 patients	Abdominal aortic aneurysm (fee code R802, R816, and R817)	Open and endovascular (codes not reported)	Continuous variable analysed as annual volume per 10 cases	Mortality (30-day mortality)	An association was found in the univariate model (hazard ratio 1.01 (95% CI 1.00 to 1.01), but this effect diminished when explored in the multi-regression model suggesting that this relationship could be explained by other covariates- such as surgeon volume. Numbers for hospital volume in multivariate analysis not reported.	Univariate proportional hazards survival analysis was performed for each variable, a multivariate model was constructed. Adj for the following variables in the analysis; age, gender, income, hospital factors, year of operations.
Finks 2011	USA	Hospitals, range from 1860 to 2339	Patients, range from 56333 to 71170	Abdominal aortic aneurysm (codes not reported)	Open and endovascular (ICD-9 codes 38.34, 38.44, 38.64, 39.25 and 39.71)	Not defined, analysed as the proportion of the effect of hospital volume that could be attributed to volume	Mortality (30-day mortality)	Proportion of the difference in mortality explained by increased hospital volume over time was 11% Measures of uncertainty was not reported.	Stepwise logistic- regression model, adj for age, sex, race, admission type, comorbidities and socioeconomic status.

Goodney 2003	USA	Hospitals, number unclear	12573 patients	Abdominal aortic aneurysm (codes not reported)	Open and endovascular (codes not reported)	Hospitals were divided into five quintiles, the analysis includes a comparison of the lowest volume quintile (<17 procedures), and the highest volume (>79 procedures).	Mortality (30-day mortality)	The relative risk of mortality was lower in high versus low volume hospitals, with 0.51 (95% CI 0.49 to 0.53) at high volume hospitals compared to 0.54 (95% CI 0.52 to 0.56) in low volume hospitals.	The results are reported unadjusted because the authors had already stratified the samples. Adj for patient characteristics. Risks of in-hospital mortality was compared in high and low volume.
Regenbogen 2012	USA	1939 hospitals	69141 patients	Abdominal aortic aneurysm (codes not reported)	Open and endovascular (codes not reported)	1: <34. 2 : 35-60, 3: 61- 95, 4: 96-155, 5: >155	Mortality (30-day mortality)	The % mortality was higher in low volume, by quintiles, 1: 3.6%, 2: 3.1%, 3: 3.0%, 4: 2.9%, 5: 3.0%. The association between volume and mortality had a p-value of <0.0001.	Mantel-Haenszel chi-square tests for dichotomous outcomes variables
Urbach 2004	Canada, Ontario	57 hospitals	6279 patients	Abdominal aortic aneurysm (codes not reported)	Open and endovascular (codes not reported)	>42 high	Mortality (30-day mortality)	The Adj OR for the association between volume and mortality was 0.62 (95% CI 0.46 to 0.83). Higher volume was associated with lower mortality.	Binary logistic regression with risk-adjustment for age, sex, and comorbidity index.
Allareddy 2010	USA	1207 hospitals	35104 procedures	Abdominal aortic aneurysm (codes not reported)	Open and endovascular (ICD-9 codes 38.34, 38.44, 38.64, 39.71 and 39.25)	>50 high	Mortality (in-hospital mortality)	The rates of mortality in high was 2.63% and in low 3.47%. In the multivariable analysis, the OR for mortality lower in high volume (adj OR 0.83 (0.69 to 0.99).	Multivariable logistic regression models were used to examine the association between hospital volume and complications, adj for age, sex, admission type, type of procedure, year of procedure, hospital characteristics, and comorbidity
Hill 2008	USA	Aprox. 555 hospitals	46901 patients	Abdominal aortic aneurysm (ICD-9 code 441.4)	Open and endovascular (ICD-9 codes 38.34, 38.44 and 39.71)	<17 low, medium 18 to 49, >50 high	Mortality (in-hospital mortality)	High volume compared to low volume had a reduced risk of mortality of adjusted OR 0.6, 95% CI 0.5 to 0.7. Medium volume compared to low-volume was reduced, adjusted OR 0.7, 95% CI 0.6 to 0.8. Numbers for time trend is not reported, only in figure, this confirms the results from the multivariate analysis.	Multivariate Cox proportional hazards model

Bush 2006	USA	123 hospitals	1904 patients of which 717 were endovascular and 1187 were open	Abdominal aortic aneurysm (ICD-9 codes 441.4)	Both (Open CPT codes 35081 and 35102 and EVAR CPT codes 34800, 34802, and 34804.	Low <10 procedures	Mortality (one year mortality)	Patients at low volume sites were also at increased risk for 1-year mortality, however results for this outcome was not reported and the association had a p-value of 0.17.	Multivariate logistic regression analysis, adj for procedure type, personal and system characteristics.
Mell 2012	USA	Hospitals, numbers unclear	2616 patients	Abdominal aortic aneurysm (ICD-9 code 441.4 and 441.9)	Open and endovascular (ICD-9 Codes 38.34, 38.44, 38.64, 39.52 and 39.71)	1: <17, 2: 17 to 30, 3: 31 to 49, 4: 50 to 79, 5:>79	Mortality and rehospitalisation (30-day mortality or reshospitalisation)	Volume did not independently predict mortality or rehospitalisation. Compared to the highest volume quintile, the Odds per quintile was, 1: OR 1.09 (95% CI 0.77 to 1.56), 2: 1.17 (95% CI 0.80 to 1.71), 3: OR 1.36 (95% CI 0.954 to 1.94), 4: 1.36 (95% CI 0.953 to 1.95).	Variables were compared with x2, Fisher exact test, t-test, analysis of variance, or Wilcoxon rank-sum test when indicated. Multivariable hierarchical mixed-effects regression models controlling for age, gender, area of residence, race, comorbidities, procedure type (open or endo), surgeon type were then used to determine independent correlates for treatment and outcome variables and to adjust for clustering at the hospital level.

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

Hospital volume: mortality in patients undergoing acute/ ruptured admissions for all surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Dueck 2004	Canada, Ontario	Hospitals, number unclear	2601 patients	Ruptured or acute abdominal aortic aneurysm (fee code E627)	Open and endovascular (procedure codes not reported)	Continuous variable analysed as annual volume per 5 cases	Mortality (30-day mortality)	An association was found in the univariate model (hazard ratio 0.93 (95% CI 0.91 to 0.97), but this effect diminished in the multi-regression model suggesting that this relationship could be explained by other covariates- such as surgeon volume. Numbers for hospital volume in multivariate analysis not reported.	Univariate proportional hazards survival analysis was performed for each variable, a multivariate model was constructed. Adj for the following variables in the analysis; age, gender, income, hospital factors, year of operations.
Karthikesalingam 2014	UK	Hospitals, numbers unlcear	11 799 patients	Ruptured or acute abdominal aortic aneurysm	Open and endovascular (OPCS-4 codes L194-199, L231, L236, L238-239, L254, L258, L259, L49, L271, L275, L276, L281, L285, L286, L289)	Unclear	Mortality (in hospital mortality)	Numbers not reported, only p-value for the association of hospital volume with in-hospital mortality: <0.0001	Binary logistic regression with risk-adjustment for age, sex, social deprivation, and comorbidity index.
Karthikesalingam 2014	USA	Hospitals, numbers unlcear	23838 patients	Ruptured or acute abdominal aortic aneurysm	Open and endovascular (ICD-9 38.44, 38.34, 39.25 and 39.71)	Unclear	Mortality (in hospital mortality)	Numbers not reported, only p-value for the association of hospital volume with in-hospital mortality <0.0001	Binary logistic regression with risk-adjustment for age, sex, social deprivation, and

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

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

Hospital volume: complications in all patients for all surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Hernandez-Boussard 2012	USA	Hospitals, number unclear	182843 patients	Abdominal aortic aneurysm and ruptured (codes not reported)	Open and endovascular surgery (ICD-9 codes 38.44 and 39.71)	Low <28, medium 28-61 and high >61	Complications	Patients with one or more complications were 8.84% in the low-volume group, 7.78% in the medium-volume group, and 7.23% in the high-volume group. The volume-complications relationship had a p-value of 0.001. The relationship was stronger for blood-stream infections (all numbers are rates per 1000) (low 11.38, medium 9.75 and high 9.63, p<0.0006), post-operative pulmonary embolism and deep vein thrombosis (low 3.5, medium 2.85 and high 1.65, p<0.0001), sepsis (low 14.64, medium 13.62 and high 12.48, p<0.001), wound dehiscence (low 5.09, medium 3.13 and high 3.14, p<0.0001)and accidental punctures or lacerations (low 3.54, medium 3.96 and high 3.66, p=0.0233), and with little or no association for pressure ulcers (low 12.18, medium 8.56 and high 12.26, p=0.31), failure to rescue (low 118.46, medium 121.61 and high 120.86, p<0.11) and respiratory failure (low 45.47, medium 22.67 and high 40.06, p=0.06).	Rao-Scott chi-squared for categoricalal variables and Kruskal–Wallis Test for continuous variables. The Cochran-Armitage trend test was used to analyse outcomes by hospital volume. Risk adjusted rates adjusted for age, sex, age–sex interactions, DRG, and comorbidities. All models accounted for the clustered nature, admission within year specific hospital cluster, of the study sample.
Gonzalez 2014	USA	Hospitals, number unclear	20690 patients	Abdominal aortic aneurysm and ruptured (codes not reported)	Open and endovascular (procedure codes not reported)	Divided into quintiles, high volume represented the highest quintile, and low the lowest quintile. Not further described.	Complications	Compared with the highest-volume hospitals, the lowest-volume hospitals had a small increase in major postoperative complications (OR 1.18; 95% CI 1.09 to 1.27)	Calculation of risk adjusted mortality rates (by patient age, sex, race, urgency and operation and comorbidities), and logistic regression

Hospital volume: complications in elective patients for all surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Allareddy 2010 (and Allareddy 2007)	USA	1207 hospitals	35104 procedures	Abdominal aortic aneurysm (codes not reported)	Open and endovascular (ICD-9 codes 38.34, 38.44, 38.64, 39.71 and 39.25)	>50 high	Complications (cardiac, nervous system, respiratory, digestive, urinary, latrogenic induced complications, hemorrhage/ hematoma/ seroma complicating a procedure, septicemia and other complications)	The risk of any complications was lower in high volume compared to low volume. The adj OR for any complications was 0.89 (95% CI 0.81 to 0.98). Cardiac adj OR 0.87 (95% CI 0.75 to 1.01), nervous system 1.31 (95% CI 0.93 to 1.84), respiratory 0.73 (95% CI 0.61 to 0.88), digestive 0.85 (95% CI 0.71 to 1.01), urinary 1.07 (95% CI 0.89 to 1.28), latrogenic induced complications 1.03 (95% CI 0.87 to 1.21), hemorrhage/ hematoma/ seroma complicating a procedure 0.91 (95% CI 0.77 to 1.07), septicemia 0.91 (95% CI 0.73 to 1.13), and other complications 0.76 (95% CI 0.61 to 0.99)	Multivariable logistic regression models were used to examine the association between hospital volume and complications, adj for age, sex, admission type, type of procedure, year of procedure, hospital characteristics, and comorbidity
Bush 2006	USA	123 hospitals	1904 patients of which 717 were endovascular and 1187 were open	Abdominal aortic aneurysm (ICD-9 codes 441.4)	Both (Open CPT codes 35081 and 35102 and EVAR CPT codes 34800, 34802, and 34804.	Low <10 procedures	Complications (30-day complications)	The association was reported as not statistical significant (p=0.17)	Multivariate logistic regression analysis, adj for procedure type, personal and system characteristics.
Massarweh 2011	USA, Washington	Hospitals,	7724 patients	Abdominal aortic aneurysm	Open and endovascular (procedure	>50 high	Complications (occurrence of a postoperative complication	Adjusted complication rates were generally similar for patients who underwent AAA	Multilevel binomial generalized estimating equation

		num-bers un-lcear		(codes not reported)	codes not re-ported)		within 30 days of the index oper-ation)	repair at high volume compared to low volume. Year 1, 30 day complica-tions: low volume 29.3%, high vol-ume 26.2%, p-value= 0.93. Year 2, 30-day complications: low-volume 26.2%, high volume 20.0%, p-value= 0.03. The only statewide difference in outcomes was a lower rate of complications (28.8% vs 25.1%, p 0.001) in the post-LF era	regression models with an exchangeable corre-lation structure and robust standard errors were used to calculate risk-adjusted outcome rates. Adj for age, sex, type of insurance, length of stay, comorbidity, type of procedure, leapfrog era.
Regen-bogen 2012	USA	1939 hospi-tals	69141 pa-tients	Abdominal aortic an-eurysm (codes not reported)	Open and endovascular (procedure codes not re-ported)	1: <34. 2 : 35-60, 3: 61- 95, 4: 96-155, 5: >155	Complications (pulmo-nary failure; pneumonia; myocardial infarction; deep venous thrombosis/pulmonary embolism; acute renal failure; postoperative hemor-rhage; surgical site in-fection; and gastroin-testinal bleeding)	The % complications was higher in low volume, by quintiles, 1: 18.5%, 2: 16%, 3: 15.9%, 4: 15%, 5: 15.5%. The association between volume and complications ad a p-value of <0.0001.	Multiple logistic regres-sion, age, gender, race, admission type, length of stay

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

Hospital volume: costs in elective patients for all surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Regenbogen 2012	USA	1939 hospitals	69141 patients	Abdominal aortic aneurysm (codes not reported)	Open and endovascular (procedure codes not reported)	1: <34. 2 : 35-60, 3: 61- 95, 4: 96-155, 5: >155	Costs (home health, USD per patient)	Total payments in USD by quintiles, 1: 402, 2: 325, 3: 346, 4: 297, 5: 318. USD associated with home health for low was 84 (20.59%) higher compared with high	Multiple logistic regression, adj for age, gender, race, admission type, length of stay
Regenbogen 2012	USA	1939 hospitals	69141 patients	Abdominal aortic aneurysm (codes not reported)	Open and endovascular (procedure codes not reported)	1: <34. 2 : 35-60, 3: 61- 95, 4: 96-155, 5: >155	Costs (outpatient care, USD per patient)	Total payments in USD by quintiles, 1: 150, 2: 169, 3: 182, 4: 205, 5: 177. USD associated with outpatient care for low was 27 (18%) lower compared with high	Multiple logistic regression, adj for age, gender, race, admission type, length of stay
Regenbogen 2012	USA	1939 hospitals	69141 patients	Abdominal aortic aneurysm (codes not reported)	Open and endovascular (procedure codes not reported)	1: <34. 2 : 35-60, 3: 61- 95, 4: 96-155, 5: >155	Costs (physician services, USD per patient)	Total payments in USD by quintiles, 1: 4059, 2: 3769, 3: 3754, 4: 3523, 5: 3446. USD associated with physician services for low was 613 (15.1%) higher compared with high	Multiple logistic regression, adj for age, gender, race, admission type, length of stay
Regenbogen 2012	USA	1939 hospitals	69141 patients	Abdominal aortic aneurysm (codes not reported)	Open and endovascular (procedure codes not reported)	1: <34. 2 : 35-60, 3: 61- 95, 4: 96-155, 5: >155	Costs (post-discharge ancillary care, USD per patient)	Total payments in USD by quintiles, 1: 2366, 2: 1943, 3: 1880, 4: 1687, 5: 1667. USD associated with ancillary care for low was 699 (29.5%) higher compared with high	Multiple logistic regression, adj for age, gender, race, admission type, length of stay
Regenbogen 2012	USA	1939 hospitals	69141 patients	Abdominal aortic aneurysm (codes not reported)	Open and endovascular (procedure codes not reported)	1: <34. 2 : 35-60, 3: 61- 95, 4: 96-155, 5: >155	Costs (readmissions, USD per patient)	Total payments in USD by quintiles, 1: 1617, 2: 1370, 3: 1425, 4: 1413, 5: 1448. USD associated with readmissions for low was 169 (10.5%) higher compared with high	Multiple logistic regression, adj for age, gender, race, admission type, length of stay
Regenbogen 2012	USA	1939 hospitals	69141 patients	Abdominal aortic aneurysm (codes not reported)	Open and endovascular (procedure codes not reported)	1: <34. 2 : 35-60, 3: 61- 95, 4: 96-155, 5: >155	Costs (skilled nursing, USD per patient)	Total payments in USD by quintiles, 1: 686, 2: 584, 3: 507, 4: 504, 5: 472. USD associated with skilled nursing for low was 214 (31.2%) higher compared with high	Multiple logistic regression, adj for age, gender, race, admission type, length of stay

The association of volume and quality for open surgery

Hospital volume: mortality in all patients for open surgery									
Study ID	Set-ting	Unit (sur-geon/ depart-ment/ hospi-tal)	Patients (descrip-tion and N)	Condition (diagnosis)	Procedure	Volume cut-off	Out-come	Results	Description of analysis
Dimick 2008	USA	2301 hospi-tals	54203 pa-tients	Abdominal aor-tic aneurysm (ICD-9 code 441.4) and rup-tured (ICD-9 code 441.3)	Open sur-gery (ICD-9 code 38.44)	Low <24, medium 25 to 49, high 50 to 88, very high 89 to 405.	Morta-lity (30-day morta-lity)	Mortality rate by volume was, low 7.8%, medium 6.6%, high 6.2% and very high 5.2%. Higher volume predicted lower mortality in the multivariate model (OR 1.52; 95% CI, 1.33 to 1.73). Because high-volume hospitals perform more endovascular repairs, an analysis of vol-ume and mortality adjusting for the type of repair was conducted. After this ad-justment, the low-volume hospitals still had a 50% higher mortality rate com-pared with the highest-volume hospitals (OR 1.52; 95% CI, 1.35-1.72).	Multiple logistic regression analysis adjusting for age, sex, race, admission acuity (elective, urgent, or emer-gency), median income, and coexisting diseases. Ac-counted for the non-independence of patients within hospitals by calculating robust variance estimates designed to deal with clustering of this nature. The proportion of the hospi-tal volume effect attributable to endovascular repair was estimated by running a lo-gistic regression model with and without the variable for type of repair.
Dimick 2002a (and 2004)	USA, Ma-ry-land	52 hos-pitals	2987 pa-tients	Abdominal aor-tic aneurysm (code not re-ported), rup-tured or acute	Open (ICD-9 codes 38.44 and 39.25)	Low <20, medium 20 to 36, and high >36.	Morta-lity (in-hospi-tal morta-lity)	In the multivariate analysis, the adj odds for mortality was lower for high volume for those over 65 years (OR 0.57, 95% CI 0.37 to 0.86; p<0.008), but not for those under 65 years (OR 1.1; 95% CI 0.4 to 4.3)	Univariate predictions and multiple-logistic regression for in-hospital death and complications adj for age, sex, race, comorbidities, and severity of disease. For

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

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

Hospital volume: mortality in elective patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Illonzo 2014	USA	Hospitals, number of hospitals unclear	295851 patients	Abdominal aortic aneurysm (codes not reported)	Open (procedure codes not reported)	Low <3, medium 4 to 7, high 8 to 257	Mortality (30 day mortality after complications associated with procedure)	High volume hospitals had a higher success rate of rescue compared to low volume hospitals (p<0.001). Trend in failure to rescue 2.73% for high volume vs 5.66% for low volume. In the multivariate regression, the OR for failure to rescue in medium volume compared to low was 0.68 (95% CI 0.64 to 0.73), in high OR 0.30 (95%CI 0.28 to 0.32) (data from the multivariate analysis included for both open and endovascular).	Multivariate logistic regression analysis adj for age, gender, race, comorbidities, hospital annual volume, and year of the surgery.
Amundsen 1990	Norway	26 surgical units	279 patients	Abdominal aortic aneurysm (code not reported)	Open (procedure codes not reported)	Volume categories were 1: <9, 2: 10 to 29, 3: 30 to 39, 4: >40	Mortality (30-day mortality)	Hospital mortality for elective surgery: 1-9 surgeries: 8/58 (13.8%), 10-29 surgeries: 6/82 (7.3%), 30-39 surgeries 4/67 (6%), >40 surgeries 1/45 (2.2%). The odds of mortality was OR 2.7 (p=0.04).	Cross tabulation and chi-square. A model consisting of the significant variables (log likelihood ratio tests, p<0.05) predicts the probability of dying. The odds ratio- the ratio between the odds for dying in two groups of patients as given by

									the levels of a prognostic variable, indicate the strength of that variable and can be found by exponentian of its regression coefficient.
Kantonen 1997 (and 1999)	Finland	23 hospitals	929 patients	Abdominal aortic aneurysm (codes not reported)	Open (procedure codes not reported)	>15 high	Mortality (30-day mortality)	There was no association according to the authors between volume and mortality. Numbers not reported, only plotted in figure.	Correlation between volume and mortality was tested using linear regression analysis.
Khuri 1999	USA	107 hospitals	3767 cases	Abdominal aortic aneurysm (CPT-code 4 35081)	Open (CPT- 4 code 35081)	Quartiles, 1: 0 to 3, 2: 4 to 6, 3: 7 to 10, and 4: 11 to 32	Mortality (30-day mortality)	Lower volume was not found to be a strong predictor of mortality (in logistic regression -0.02844 (SE 0.02), p=0.10)	A mixed effects hierarchical logistic regression analysis adj for patient risk factors.
Landon 2010	USA	Hospitals, numbers unlcear	78257 cases	Abdominal aortic aneurysm (ICD-9 code 441.4)	Open (ICD-9 codes 38.44 or 39.25)	1: <9, 2: 10 to 17, 3: 18 to 29, 4: 30 to 49, 5: >50.	Mortality (30-day mortality)	Mortality decreases with higher volume, with an absolute difference of >3 percentage points between the highest- and lowest volume hospitals	All models were adjusted for baseline clinical and demographic characteristics. Observed mortality in each quintile was compared with predicted adjusted mortality computed under the counterfactual assumption that all procedures occurred at a hospital in the lowest-volume quintile.
Brooke 2008	USA (California)	140 hospitals of 337 hospitals included	6406 cases	Abdominal aortic aneurysm (codes not reported)	Open (ICD-9 codes 38.34, 38.36, 38.44, 38.64, 39.25, 39.52)	>50 high	Mortality (in-hospital mortality)	The average rates of mortality at time-point 1 (2000-2003): high volume 69 (3.96%)/ low volume 74	Rate of rate ratio for two periods (relative risk) was calculated. The effect of Leapfrog standards on hospital

								(3.85%) Time-point 2 (2003-2005): high volume 55 (4.39%)/ low volume 75 (5.05%). In the adj regression model, the effect of volume on mortality was uncertain. The RR 0.80 (95% CI 0.44 to 1.45)	LOS was analysed using a linear regression model and fit using a random intercept for each hospital and a log-normal distribution. Adj for age, sex, comorbidities, type of admissions
Dardik 1998	USA, Maryland	47 hospitals	3293 patients	Abdominal aortic aneurysm (codes not reported)	Open (ICD-9 codes 38.34, 38.44, 38.64, 38.84, 39.54)	Low <50, medium 50 to 99, and high >100	Mortality (in-hospital mortality)	There association is uncertain. Low 54 % (6.3), medium 46% (3.6), high 46.9% (3.0), p=0.53. The association of hospital volume with mortality was not evaluated in the multivariate analysis.	Categoricalal variables were analysed by Pearson's test or Fisher's Exact Test. Continuous variables were analysed by analysis of variance for parametric variables and the Mann-Whitney U test or Kruskal-Wallis test for nonparametric variables. Multiple logistic regression was used for multivariate analysis and controlled for age, sex, race, hypertension, diabetes, comorbidities, and health beaviours.
Dimick 2002b	USA	507 in 1996 and 536 1997 hospitals	7980 patients	Abdominal aortic aneurysm (code not reported)	Open (ICD-9 code 38.44)	>30 high	Mortality (in-hospital mortality)	The mortality rate in high was 3.1% and 4.7% in low. In the multiple regression analysis, having surgery at a low volume hospital predicted increased in-hospital	Multiple logistic regression of the in hospital death rate was used to test its association with hospital volume after adjusting for age, sex, comorbidities, admission type and

								death (OR 1.71; 95% CI, 1.37–2.14)	race. LOS was not normally distributed and was skewed to the left, so multiple linear regression of log-transformed LOS was used for the multivariate analysis. The Shapiro-Wilk test was used to ensure normality of the log-transformed data.
Dimick 2003	USA	536 hospitals	3912 patients	Abdominal aortic aneurysm (code not reported)	Open (ICD-9 codes 38.44 and 39.25)	>35 high	Mortality (in-hospital mortality)	Patients undergoing surgery at an high volume hospital had 30% reduction in risk for death (95% CI, 2% to 51%; p<0.05)	Univariate analysis and multiple regression with hospital clustering, adj for age, race, gender, nature of admission, comorbidity, and hospital specialty.
Dua 2014	USA	Hospitals, numbers unlcear	Unclear	Abdominal aortic aneurysm (ICD-9 code 441.4 and 441.9)	Open (ICD-9 codes 38.34, 38.44, 38.64 and 39.52)	No-cut off, this is explored as part of the analysis, threshold set at <5	Mortality (in-hospital mortality)	Hospitals with mortality higher than 40% complete fewer than five procedures. These hospitals have a mortality of up to 100% (OR 2.5 to 10.6) when compared to the mean 6 two standard deviations of all hospitals or the middle 95% of all hospitals; 0.20 to 0.84; p <0 .001.	Statistical analysis was completed using analysis of variance for continuous variables (number of cases) and x2 for categorical variables (i.e., hospital covariates, inpatient mortality). The Mann-Whitney U test was used for LOS and median total costs. Mann-Kendall trend analysis was completed to determine if trends outside the 95% CI were statistically significant; s val-

									ues and P values are reported in conjunction with odds ratios (ORs).
Eckstein 2007	Germany	131 hospitals	10163 patients	Abdominal aortic aneurysm (codes not reported)	Open (procedure codes not reported)	1: <9, 2: 10 to 19. 3: 20 to 29, 4: 30 to 39, 5: 40 to 49 and 6: >50	Mortality (in-hospital mortality)	The mortality rate was 5.2% for low-volume hospitals and 2.6% for high volume hospitals. In the stepwise regression analysis, OR for annual volume as predictor of mortality was 1.003 (95% CI 1 to 1.006; p=0.075). Hospitals with >50 procedures had lower mortality rate than the other thresholds, with the largest difference for hospitals with 1-9 procedures (OR 1.90, 95% CI 1.12 to 3.22)	Stepwise regression of thresholds. To identify a relationship between annual volume and preoperative and/or intraoperative parameters and further outcome parameters we analysed the different volume groups descriptively. Statistics were performed by use of the chi-sqare-test and Odds-Ratios (OR) with a confidence interval (CI) of 95%. Conspicuous parameters in the descriptive analysis of volume groups were subjected to a tatistical trend analysis (Cochran Armitage Trend Test).
Holt 2007	UK	Hospitals, numbers unlcear	15515 procedures	Abdominal aortic aneurysm (ICD 10 codes I171.4)	Open (OPCS-4 codes L194-L199, L222-L229, L258-L259, L491-L499, L652)	1: <7.2, 2: 7.3 to 12.6, 3: 12.7 to 19.4, 4: 19.5 to 32, 5:>32	Mortality (in-hospital mortality)	Death rate by quintile was, 1: 8.5%, 2: 7.6%, 3: 7.2%, 4: 7.7%, 5: 5.9%. In the multivariate analysis, increasing annual hospital volume was associated with a reduction in the mortality rate for elective (OR 0.92, 95% CI 0.88 to 0.96, p<0.001)	Odds ratios, with the lowest volume-quintile in each group set at an odds ratio of 1.0, and the odds of the other four quintiles calculated against this fixed value. Multiple regression. Maximum likelihood estimates were generated tested by X2 analysis. Volume was

									quantified in terms of proportional odds ratios with 95% Wald confidence limits. Adj for age, sex.
Holt 2009	UK, England	134 Hospitals (trusts)	5668 patients	Abdominal aortic aneurysm (ICD-10 codes I173 or I174)	Open (procedure codes not reported)	Unclear, divided into five quintiles.	Mortality (in-hospital mortality)	In the multivariate analysis, higher volume was associated with a lower rate of mortality: OR 0.99; 95% CI 0.989 to 0.999, p=0.0216	The effect of volume on outcome was evaluated using both crude data and after risk-adjustment. The samples were the same for both crude and adjusted analyses. Multiple logistic regression model, controlled for gender, comorbidities and age.
Manheim 1998	USA, California	Hospitals, numbers unlcear	Unclear	Abdominal aortic aneurysm (codes not reported)	Open (ICD-9 codes 38.34, 38.44 and 38.64)	Low <20, moderate 20 to 49, and high 50 to 99	Mortality (in-hospital mortality)	The OR for dying in medium volume hospitals was 0.78 (p<0.001), OR in high was 0.84 (p<0.001) compared to low volume	Multiple logistic regression adj for age, gender, year of surgery, admission type and comorbidities
McPhee 2011	USA	Hospitals, numbers unclear	Unclear	Abdominal aortic aneurysm (ICD-9 code 441.4)	Open (ICD-9 38.44 and 39.25)	Low <7, medium 7 to 30, and high >30	Mortality (in-hospital mortality)	The high-volume institutions had lower in-hospital mortality rate (3.3%) than the medium-(4.9%) and low-volume (5.9%) institutions; p<0.01. In the multivariate analysis, low volume compared to high volume and medium volume compared to high volume was associated with increased mortality,	Multivariable logistic regression models, adj for patient level factors such as age, gender, comorbidity and hospital level characteristics.

								but these associations were uncertain (OR 1.6 (95% CI 0.98 to 2.7) and OR 1.6 (95% CI 1.0 to 2.4).	
Vogel 2011	USA	Hospitals , range from 1335 to 1116	17210 procedures	Abdominal aortic aneurysm (ICD-9 code 441.4)	Open (ICD-9 codes 38.34,38.44 and 38.64)	Top ten % volume was categorized as high-volume, all remaining hospitals placed in the low-group	Mortality (in-hospital mortality)	Patients in low-volume hospitals were more likely to die after surgery; OR 1.22, 95% CI 1.04 to 1.44.	Multivariable analysis with forward step-wise regressions, adj for age, sex, race, comorbidities and hospital procedure.
Wen 1996	Canada, Ontario	All Ontario hospitals, numbers unclear	5492 patients	Abdominal aortic aneurysm (ICD-9 code 441.4)	Open (CC code 5034 or 5024 or 5125)	1: <10, 2: 10 to 20, 3: 21 to 40, and 4: >40	Mortality (in-hospital mortality)	The % mortality rate per quintile; 1: 4.6, 2: 4.0, 3: 3.8, 4: 3.5 (p=0.59). In the linear regression analysis, each 10 case per year increase in hospital volume was related to a 6% reduction in adj. odds of death OR 0.94, 95% CI 0.88 to 0.99).	Stepwise multiple logistic regression analysis was used to examine the volume-mortality relationship, and stepwise multiple linear regression was used to examine the volume-postoperative LHS relationship at the individual patient level. Adj for bed size and teaching status of the admitting hospital, patient's sex and age, comorbidity index, and whether the patient had been transferred from another hospital.
Rutledge 1996	USA, North Carolina	Hospitals, numbers unlcear	12658 patients	Abdominal aortic aneurysm (ICD-9 code 441.4)	Open (codes not reported)	Unclear	Mortality (in-hospital survival)	Hospital experience with elective AAAs was analysed, and although there	Very little described, no apparent adjustments. Logistic regression.

								was a trend toward improved survival in hospitals with a greater case load of AAAs, this did not achieve statistical significance (p = 0.59). Numbers not reported.	
Pearce 1999	USA, Florida	Hospitals, range over time 156 to 165	13415 patients	Abdominal aortic aneurysm (ICD-9 code 441.4)	Open (ICD-9 38.34 and 38.44)	Unclear	Mortality and complications (hospital mortality, myocardial infarction or cerebrovascular accident)	The relative reduction in risk for doubling of hospital volume was (Coefficient Relative risk) 0.88, p=0.0003	Multiple logistic regression, adj for age, sex, emergency admission status, hospital characteristics, year of discharge.

Surgeon volume: mortality in elective patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Huber 2001	USA	Surgeons, number unclear	Unclear	Abdominal aortic aneurysm (codes not reported)	Open (Current Procedural Terminology (CPT) codes 35081, repair defect of artery, abdominal aorta, 35091 repair defect of artery, aorta, involving visceral vessels, and 35102 repair defect of artery, aorta, involving iliac vessels for elective AAA repair)	1: <3, 2: 4 to 6, 3: 7 to 10, and 5: >11	Mortality (30-day mortality)	The % mortality rate was lower for high volume compared to low-volume. The mortality rate was 7.5 for low and 4.0 for those with more than 11 AAA repairs, respectively.	Analysis poorly described, results reported as %. Mortality rates were adjusted for race, sex, and age, but not for comorbidities
Kantonen 1997 (and 1999)	Finland	Surgeons, number unclear	929 patients	Abdominal aortic aneurysm (codes not reported)	Open (procedure codes not reported)	Unclear	Mortality (30-day mortality)	There was an association, judged to be strong by the authors, between surgeons' total vascular case load and aneurysm case load on mortality. No numbers reported, only p-values (p<0.01).	Correlation between volume and mortality was tested using linear regression analysis.
Dimick 2003	USA	897 surgeons	3912 patients	Abdominal aortic aneurysm (codes not reported)	Open (ICD-9 codes 38.44 and 39.25)	>10 high	Mortality (in-hospital mortality)	Surgery by a high volume surgeon was associated with 40% reduction in mortality (95% CI, 12% to 60%; p<0.01).	Univariate analysis and multiple regression with hospital clustering, adj for age, race, gender, nature of admission, comorbidity, and hospital specialty.
McPhee 2011	USA	Surgeons,	Unclear	Abdominal aortic aneurysm (ICD-	Open surgery (ICD-9 codes 38.44 and 39.25)	Low <2, medium 3	Mortality (in-hospital mortality)	Overall, low- (7.5%) and medium-volume (4.3%) surgeons had higher mortality rates than higher-volume surgeons (3.0%);	Multivariable logistic regression models, adj for patient level factors

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

Hospital volume: mortality in patients undergoing acute/ ruptured admissions for open surgery									
Study ID	Setting	Unit (sur-geon/ depart-ment/ hospi-tal)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Out-come	Results	Description of analysis
Amund-sen 1990	Norway	26 sur-gical units	155 patients	Ruptured or acute ab-dominal aortic aneu-rysm (code not re-ported)	Open (proce-dure codes not reported)	Volume categories were 1: <9, 2: 10 to 29, 3: 30 to 39, 4: >40	Morta-lity (30-day morta-lity)	Hospital mortality for acute surgery by category: 1: 36/50 (72%), 2: 14/22 (63.6%), 3: 7/13 (53.8%), 4: 8/15 (53.3%). The chance of dying was almost twice as high (OR 1.9) in low volume compared to units with >10 surgeries, although there was high uncertainty associated with this outcome p=0.14)	Cross tabulation and chi-square. A model consisting of the signifi-cant variables (log likelihood ra-tio tests, p<0.05) predicts the probability of dying. The odds ra-tio- the ratio between the odds for dying in two groups of pa-tients as given by the levels of a prognostic variable, indicate the strength of that variable and can be found by exponentian of its re-gression coefficient.
Kanto-nen 1997 (and 1999)	Finland	26 hos-pitals	610 patients	Ruptured or acute ab-dominal aortic aneu-rysm (code not re-ported)	Open (proce-dure codes not reported)	>10 high	Morta-lity (30-day morta-lity)	There was no association according to the authors. Numbers not reported, only plotted in figure.	Correlation between volume and mortality was tested using linear regression analysis.
Dardik 1998	USA, Maryland	45 hos-pitals	527 patients	Ruptured or acute ab-dominal aortic aneu-rysm (ICD-9 code 441.02 and 441.3)	Open (ICD-9 co-des 38.34, 38.44, 38.64, 38.84 and 39.54)	Low <10, medium 10 to 19, and high >20	Morta-lity (in hospi-tal morta-lity)	There association is uncer-tain. Low 45.6% (4.1), me-dium 49.2% (3.6), high 47.1% (3.6), p=0.8. The as-sociation of hospital vol-ume with mortality was not evaluated in the multi-variate analysis.	Categoricalal variables were ana-lysed by Pearson's test or Fisher's Exact Test. Continuous variables were analysed by analysis of vari-ance for parametric variables and the Mann-Whitney U test or Kruskal-Wallis test for

									nonparametric variables. Multiple logistic regression was used for multivariate analysis and controlled for age, sex, race, hypertension, diabetes, comorbidities, and health beaviours.
Dua 2014	USA	Hospitals, numbers unclear	Unclear	Ruptured or acute abdominal aortic aneurysm (ICD-9 code 441.3)	Open (ICD-9 codes 38.34,38.44, 38.64 and 39.52)	No-cut off, this is explored as part of the analysis, threshold set at <10	Mortality (in hospital mortality)	Hospitals have a 95% CI of 0% to 100% for mortality, indicative of the high mortality risk associated with rupture. Most hospitals complete one to 10 OARs and one to eight EVARs for ruptured AAA. Hospitals that complete >10 surgeries have a mortality between 20% and 40%.	Statistical analysis was completed using analysis of variance for continuous variables (number of cases) and x2 for categorical variables (ie, hospital covariates, inpatient mortality). The Mann-Whitney U test was used for LOS and median total costs. Mann-Kendall trend analysis was completed to determine if trends outside the 95% CI were statistically significant; s values and P values are reported in conjunction with odds ratios (ORs).
Holt 2007	UK	Hospitals, numbers unclear	6462 patients	Abdominal aortic aneurysm (ICD 10 codes I171.3)	Open (OPCS-4 codes L184-L189, L194-L199, L222-L229, L258-L259, L481-L489, L652)	1: <7.2, 2: 7.3 to 12.6, 3: 12.7 to 19.4, 4: 19.5 to 32, 5:>32	Mortality (in hospital mortality)	Death rate by quintile was, 1: 4.1%, 2: 42.9%, 3: 43.7%, 4: 39.0%, 5: 42.4%. In the multivariate analysis, increasing annual hospital volume had a weak or no association with mortality rate for ruptured (OR 0.98, 95% CI 0.95 to 1.02, p=0.302)	Odds ratios, with the lowest volume-quintile in each group set at an odds ratio of 1.0, and the odds of the other four quintiles calculated against this fixed value. Multiple regression. Maximum likelihood estimates were generated tested by X2 analysis. Volume was quantified in terms of proportional odds ratios with 95% Wald confidence limits. Adj for age, sex.
Holt 2007	UK	26 hospitals	4845 patients	Abdominal aortic aneurysm (ICD 10 codes I171.3)	Open (OPCS-4 codes L184-L189, L194-L199, L222-L229, L258-	1: <2. 2: 2.1-4.2, 3: 4.3- 6.6, 4: 6.7-12.2, 5:>12.2	Mortality (in hospital mortality)	Death rate by quintile was, 1: 27%, 2: 24.1%, 3: 21.8%, 4: 21.2%, 5: 23.6%. In the multivariate analysis, increasing annual hospital	Odds ratios, with the lowest volume-quintile in each group set at an odds ratio of 1.0, and the odds of the other four quintiles calculated against this fixed value. Multiple regression. Maximum

					L259, L481-L489, L652)			was associated with a reduction in the mortality rate for urgent (OR 0.94, 95% CI 0.90 to 0.99, p<0.017)	likelihood estimates were generated tested by X2 analysis. Volume was quantified in terms of proportional odds ratios with 95% Wald confidence limits. Adj for age, sex.
McPhee 2009	USA	Hospitals, numbers unclear	Unclear	Ruptured or acute abdominal aortic aneurysm (ICD-9 code 441.3)	Open (ICD-9 codes 38.44 and 39.25)	Low <13, medium 13 to 29, high >29	Mortality (in hospital mortality)	In the multivariate analysis, low compared to high volume was associated with higher mortality (OR 1.24; 95% CI 1.01 to 1.52). The difference in mortality between moderate and high volume categories were uncertain (OR 1.09; 95% CI 0.91 to 1.32)	Multivariable logistic regression models, controlled for age, sex, comorbidities, insurance type, year of procedure, hospital characteristics
Wen 1996	Canada, Ontario	All Ontario hospitals, numbers unclear	1203 patients	Ruptured or acute abdominal aortic aneurysm (ICD-9 code 441.3)	Open (CC code 5125)	1: <2, 2: 2 to 4, 3: 4 to 8, 4: >8	Mortality (in hospital mortality)	% mortality rate per quintile; 1: 44.7, 2: 40.6, 3: 38.6, 4: 39.0 (p= 0.82). There was little or no association between hospital volume and mortality in ruptured cases. Adj OR from the linear regression analysis was 0.97 (95% Ci 0.91 to 1.03)	Stepwise multiple logistic regression analysis was used to examine the volume-mortality relationship, and stepwise multiple linear regression was used to examine the volume-postoperative LHS relationship at the individual patient level. Adj for bed size and teaching status of the admitting hospital, patient's sex and age, comorbidity index, and whether the patient had been transferred from another hospital.
Cowan 2003	USA	Hospitals	Unclear	Ruptured or acute abdominal aortic aneurysm (ICD-9 441.3, 441.5)	Open (ICD-9 codes 38.44 and 38.45)	Low 1 to 4 procedures, medium 5 to 15 and high 16 to 191	Mortality (in-hospital mortality)	No statistical significant relationship between hospital volume and mortality in the univariate analysis (p=0.375). Numbers not reported.	Student's t-test and logistical multivariate regressions.

Dimick 2002b	USA	507 in 1996 and 536 1997 hospitals	5907 patients	Ruptured or acute abdominal aortic aneurysm (ICD-9 code 441.3)	Open (ICD-9 code 38.44)	Unclear	Mortality (in-hospital mortality)	The mortality rate in high was 42.4% and 49.6% in low. In the multiple regression analysis, having surgery at a low volume hospital predicted increased in-hospital death (OR 1.43; 95% CI, 1.15–1.78)	Multiple logistic regression of the in hospital death rate was used to test its association with hospital volume after adjusting for age, sex, comorbidities, admission type and race. LOS was not normally distributed and was skewed to the left, so multiple linear regression of log-transformed LOS was used for the multivariate analysis. The Shapiro-Wilk test was used to ensure normality of the log-transformed data.
Manheim 1998	USA, California	Hospitals, numbers unclear	Unclear	Ruptured or acute abdominal aortic aneurysm (code not reported)	Open (ICD-9 codes 38.34, 38.44 and 38.64)	Low <20, moderate 20 to 49, and high 50 to 99	Mortality (in-hospital mortality)	The OR for dying in medium volume hospitals was 0.74 (p<0.001), OR in high was 0.49 (p<0.001) compared to low volume	Multiple logistic regression, adj for age, gender, year of surgery, admission type and comorbidities
Rutledge 1996	USA, North Carolina	Hospitals, numbers unclear	1480 patients	Ruptured or acute abdominal aortic aneurysm (ICD-9 code 441.3)	Open (codes not reported)	Unclear	Mortality (in-hospital survival)	Although there appears to be a trend to improved survival with increased hospital caseload, this did not reach statistical significance (p = 0.23).	Logistic regression was used to assess the association between hospital AAA caseload and patient survival after RAAA.

Surgeon volume: mortality in patients undergoing acute open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Kantonen 1997 (and 1999)	Finland	Surgeons, number unclear	610 patients	Ruptured or acute abdominal aortic aneurysm (codes not reported)	Open (procedure codes not reported)	Unclear	Mortality (30-day mortality)	There was no association according to the authors. Numbers not reported, only plotted in figure.	Correlation between volume and mortality was tested using linear regression analysis.
Dardik 1998	USA, Maryland	226 surgeons	527 procedures	Ruptured or acute abdominal aortic aneurysm (ICD-9 codes 441.02 and 441.3)	Open (ICD-9 codes 38.34, 38.44, 38.64, 38.84 and 39.54)	Low 1-4, medium 5 to 9, and high >10	Mortality (in hospital mortality)	There was a lower rate of in-hospital mortality associated with high-volume surgeons. Low 50.8% (2.8), medium 47.1% (4.6), high 36.3% (5.1), p<0.05. In the multivariate analysis, high volume surgeons had a lower mortality rate compared with low and medium volume: OR 0.54 (95% CI 0.33 to 0.88), p<0.014	Categoricalal variables were analysed by Pearson's test or Fisher's Exact Test. Continuous variables were analysed by analysis of variance for parametric variables and the Mann-Whitney U test or Kruskal-Wallis test for nonparametric variables. Multiple logistic regression was used for multivariate analysis and controlled for age, sex, race, hypertension, diabetes, comorbidities, and health behaviours.
Modrall 2011	USA	6857 surgeons	22986 patients	Abdominal aortic aneurysm (ICD-9 code 441.4 and 441.9)	Open (ICD-9 codes 38.34 and 38.44)	Divided into diciles, lowest had <1 procedures, highest had >12.	Mortality (in-hospital mortality)	Increasing volume per surgeon was not a significant predictor of in-hospital mortality in the multivariate analysis (data not shown), whereas increasing composite surgeon volume (all vascular) remained a significant predictor of lower in-hospital mortality OR 0.994; 95% CI 0.992 to 0.996; p<0.0001.	Multiple logistic regression, adj for age, gender, race, elective repair, comorbidity, source of payment, and hospital characteristics

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

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

Hospital volume: complications in elective patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Il-lonzo 2014	USA, Medicare files	Hospitals, number of hospitals unclear	295851 patients	Abdominal aortic aneurysm (codes not reported)	Open repair (procedure codes not reported)	Low <3, medium 4 to 7, high 8 to 257	Complications (cardiac arrest, vascular device implant and graft complications, amputation and wound complications)	Hospitals of high volume had fewer complications after open repair than low-volume did: pulmonary embolism (0.51% vs 0.62%; p<0.02), sepsis (2.11% vs 3.36%; p<.001), septic shock (0.13% vs 0.44%; p<0.001), perioperative stroke (0.05% vs 0.11%; p< 0.001), acute dialysis (0.43% vs 0.68%; p<0 .001), arterial reintervention (1.08% vs 1.68%; p<0.001), and prolonged ventilation (3.73% vs 5.63%; p<0.001).	Multivariate logistic regression analysis adj for age, gender, race, comorbidities, hospital annual volume, and year of the surgery.
Holt 2007	UK	Hospitals, number of hospitals unclear	15515 procedures	Abdominal aortic aneurysm (ICD 10 codes I171.4)	Open (OPCS-4 codes L194-L199, L222-L229, L258-L259, L491-L499, L652)	1: <7.2, 2: 7.3 to 12.6, 3: 12.7 to 19.4, 4: 19.5 to 32, 5:>32	Complications (renal, respiratory, system infection, shock, local infection, local complications (graft failure and hemorrhage, hematoma, seroma), thrombotic or embolic, cardiac, disseminated intravascular coagulation, ischemic stroke and transfusion)	Complication rate by quintile was, 1: 23%, 2: 24%, 3: 23%, 4: 23%, 5: 22%. In the multivariate analysis, increasing annual hospital volume had a weak or no association with complication rate for elective (p=ns). Numbers from multivariate analysis not reported.	Odds ratios, with the lowest volume-quintile in each group set at an odds ratio of 1.0, and the odds of the other four quintiles calculated against this fixed value. Multiple regression. Maximum likelihood estimates were generated tested by X2 analysis. Volume was quantified in terms of proportional odds ratios with 95% Wald confidence limits. Adj for age, sex.
Eck-stein 2007	Germany	131 hospitals	10163 patients	Abdominal aortic aneurysm	Open (procedure codes not reported)	1: <9, 2: 10 to 19. 3: 20 to 29, 4: 30 to 39, 5: 40	Complications (secondary bleeding, intes-	General and specific complications occurred equally across volume groups according to the authors. Association with volume	Stepwise regression of thresholds. To identify a relationship between annual volume and preoperative and/or intraoperative

				(codes not reported)		to 49 and 6: >50	tinal ischemia, peripheral arterial thrombosis/ embolism)	not tested in the multivariate analysis.	parameters and further outcome parameters we analysed the different volume groups descriptively. Statistics were performed by us of the chi-sqare-test and Odds-Ratios (OR) with a confidence interval (CI) of 95%. Conspicuous parameters in the descriptive analysis of volume groups were subjected to a statistical trend analysis (Cochran Armitage Trend Test).
Vogel 2011	USA	Hospitals , range from 1335 to 1116	17210 procedures	Abdominal aortic aneurysm (ICD-9 code 441.4)	Open (ICD-9 codes 38.34, 38.44 and 38.64)	Top ten % volume was categorized as high-volume, all remaining hospitals placed in the low-group	Complications (pneumonia, urinary tract infection, sepsis and surgical site infection)	Mean frequency of any complications were: high volume mean 810 (12.1%) and 1346 for (12.8%) low-volume. For pneumonia, high volume 374 (5.59%) complications and 712 (6.77%) for low-volume. For sepsis high volume had 134 (2%) and low-volume had 285 (2.71%) for UTI high volume had 255 (3.81%) and low-volume had 343 (3.26%). For SSI high volume had 146 (2.18%) and low-volume had 185 (1.76%). In the logistic regression analysis, patients in low volume were more likely to develop pneumonia (OR 1.23; 95% CI 1.08 to 1.40) or sepsis (OR 1.36; 95% CI 1.11 to 1.68).	Multivariable analysis with forward step-wise regressions, adj for age, sex, race, comorbidities and hospital procedure.

Hospital volume: complications in patients undergoing acute/ ruptured admissions for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Holt 2007	UK	Hospitals, numbers unclear	6462 patients	Ruptured or acute abdominal aortic aneurysm (ICD-10 code 71.3)	Open (OPCS-4 codes L184-L189, L194-L199, L222-L229, L258-L259, L481-L489, L652)	1: <2.8, 2: 2.9-5.6, 3: 5.7-9.2, 4: 9.3-13.2, 5:>13.2	Complications (renal, respiratory, system infection, shock, local infection, local complications (graft failure and hemorrhage, hematoma, seroma), thrombotic or embolic, cardiac, dessiminated intravascular coagulation, ischemic stroke and transfusion)	Complication rate by quintile was, 1: 39%, 2: 40%, 3: 39%, 4: 44%, 5: 37%. In the multivariate analysis, increasing annual hospital volume had a weak or no association with complication rate for ruptured (p=ns).	Odds ratios, with the lowest volume-quintile in each group set at an odds ratio of 1.0, and the odds of the other four quintiles calculated against this fixed value. Multiple regression. Maximum likelihood estimates were generated tested by X2 analysis. Volume was quantified in terms of proportional odds ratios with 95% Wald confidence limits. Adj for age, sex.
Holt 2007	UK	26 hospitals	4845 patients	Urgent abdominal aortic aneurysm (ICD-10 code 71.3)	Open (OPCS-4 codes L184-L189, L194-L199, L222-L229, L258-L259, L481-L489, L652)	1: <7.2, 2: 7.3 to 12.6, 3: 12.7 to 19.4, 4: 19.5 to 32, 5:>32	Complications (renal, respiratory, system infection, shock, local infection, local complications (graft failure and hemorrhage, hematoma, seroma), thrombotic or embolic, cardiac, dessiminated intravascular coagulation, ischemic stroke and transfusion)	Complication rate by quintile was, 1: 35%, 2: 38%, 3: 32%, 4: 36%, 5: 35%. In the multivariate analysis, increasing annual hospital volume had a weak or no association with complication rate for urgent (p=ns).	Odds ratios, with the lowest volume-quintile in each group set at an odds ratio of 1.0, and the odds of the other four quintiles calculated against this fixed value. Multiple regression. Maximum likelihood estimates were generated tested by X2 analysis. Volume was quantified in terms of proportional odds ratios with 95% Wald confidence limits. Adj for age, sex.
Kantonen 1997 (and 1999)	Finland	26 hospitals	610 patients	Ruptured or acute abdominal aortic aneurysm	Open (codes not reported)	>10 high	Complications (shock)	There was no association according to the authors. Numbers not reported.	Correlation between volume and mortality was tested using linear regression analysis.

				(codes not reported)					

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

Hospital volume: length of stay in elective patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Brooke 2008	USA (California)	140 hospitals of 337 hospitals included	6406 cases	Abdominal aortic aneurysm (codes not reported)	Open (ICD-9 codes 38.34, 38.36, 38.44, 38.64, 39.25 and 39.52)	>50 high	Length of hospital stay (hospital days)	The average rates of length of stay at time-point 1 (2000-2003): high volume 6.92 days (SD 1.2)/ low volume 7.09 days (SD 1.7) Time-point 2 (2003-2005): high volume 6.94 days (SD 1.0)/ low volume 7.48 days (SD 3.0). In the adj regression model, the effect of volume on length of stay was not statistically significant. Figures not reported.	Rate of rate ratio for two periods (relative risk) was calculated. The effect of Leapfrog standards on hospital LOS was analysed using a linear regression model and fit using a random intercept for each hospital and a log-normal distribution. Adj for age, sex, comorbidities, type of admissions. Probably complete LOS data.
Dimick 2002b	USA	507 in 1996 and 536 1997 hospitals	7980 patients	Abdominal aortic aneurysm (code not reported)	Open (ICD-9 code 38.44)	>30 high	Length of hospital stay (hospital days)	In the univariate analysis, high volume had a median 1 day shorter stay than low (7 days [IQR 6-10] versus 8 days [IQR 6 to 10], p<0.02. Little or no association between volume and length of stay was found in the multivariate analysis, figures not reported.	Multiple logistic regression of the in hospital death rate was used to test its association with hospital volume after adjusting for age, sex, comorbidities, admission type and race. LOS was not normally distributed and was skewed to the left, so multiple linear regression of log-transformed LOS was used for the multivariate analysis. The Shapiro-Wilk test was used to ensure normality of the log-transformed data. Probably complete LOS data.
Eckstein 2007	Germany	131 hospitals	10163 patients	Abdominal aortic aneurysm (codes not reported)	Open (procedure codes not reported)	1: <9, 2: 10 to 19. 3: 20 to 29, 4: 30 to 39, 5: 40 to 49 and 6: >50	Length of hospital stay (hospital days)	Higher median hospital stay in low versus high volume hospitals (p<0.001). Range from 19 (low-volume) to 15 (in high volume). Association with volume not tested in the multivariate analysis.	Stepwise regression of thresholds. To identify a relationship between annual volume and preoperative and/or intraoperative parameters and further outcome parameters we analysed the differ-

									ent volume groups descriptively. Statistics were performed by use of the chi-sqare-test and Odds-Ratios (OR) with a confidence interval (CI) of 95%. Conspicuous parameters in the descriptive analysis of volume groups were subjected to a statistical trend analysis (Cochran Armitage Trend Test). Complete LOS data.
Holt 2007	UK	Hospitals	15515 elective procedures	Abdominal aortic aneurysm (ICD 10 code 71.4)	Open (OPCS-4 codes L194-L199, L222-L229, L258-L259, L491-L499, L652)	1: <7.2, 2: 7.3 to 12.6, 3: 12.7 to 19.4, 4: 19.5 to 32, 5:>32	Length of hospital stay (hospital days)	Length of stay days by quintile was, 1: 16.19, 2: 14.55, 3: 14.51, 4: 15.49, 5: 17-02. In the multivariate analysis, the duration of stay was longer at lower volume hospitals (p<0.001)	Odds ratios, with the lowest volume-quintile in each group set at an odds ratio of 1.0, and the odds of the other four quintiles calculated against this fixed value. This allowed the calculation of the number of excess deaths per 1000 procedures. Multiple regression. Maximum likelihood estimates were generated tested by X2 analysis. Volume as an independent variable was quantified in terms of proportional odds ratios with 95% Wald confidence limits. Adj for age, sex. Complete data for LOS.
Vogel 2011	USA	Hospitals , range from 1335 to 1116	17210 procedures	Abdominal aortic aneurysm (ICD-9 code 441.4)	Open (ICD-9 codes 38.34, 38.44 and 38.64)	Top ten % volume was categorized as high-volume, all remaining hospitals placed in the low-group	Length of stay (hospital days)	Hospital days were lower in high-volume hospitals. Mean hospital days in high volume 8.94 (SD 7.59) and low-volume 9.28 (SD 8.01), p<0.004.	Multivariable analysis with forward stepwise reressions, adj for age, sex, race, comorbidities and hospital procedure. Complete data for LOS.
Wen 1996	Canada, Ontario	All Ontario hospitals, numbers unclear	5492 patients	Abdominal aortic aneurysm (ICD-9 code 441.4)	Open (CC code 5034 or 5024 or 5125)	1: <10, 2: 10 to 20, 3: 21 to 40, and 4: >40	Length of stay (hospital days)	Mean days per quintile; 1: 11.5, 2: 11.2, 3: 11.0, 4: 11.1 (p<0.06). 10 case per year increase in hospital volume was related to a 0.29 day reduction in postoperative length of stay in unruptured	Stepwise multiple logistic regression analysis was used to examine the volume-mortality relationship, and stepwise multiple linear regression was used to examine the volume-postoperative LHS relationship at the individual patient level. Adj for bed size and teaching status

								cases, adj OR in the linear regression was: 0.29 (95% CI 0.22 to 0.35).	of the admitting hospital, patient's sex and age, comorbidity index, and whether the patient had been transferred from another hospital.
Eckstein 2007	Germany	131 hospitals	10163 patients	Abdominal aortic aneurysm (codes not reported)	Open (procedure codes not reported)	1: <9, 2: 10 to 19. 3: 20 to 29, 4: 30 to 39, 5: 40 to 49 and 6: >50	Length of stay (intensive care days)	Higher median inpatient intensive days in low versus high volume hospitals (p<0.001). Range from 4 (low-volume) to 2 (in high volume) days of stay. Association with volume not tested in the multivariate analysis.	Stepwise regression of thresholds. To identify a relationship between annual volume and preoperative and/or intraoperative parameters and further outcome parameters we analysed the different volume groups descriptively. Statistics were performed by use of the chi-sqare-test and Odds-Ratios (OR) with a confidence interval (CI) of 95%. Conspicuous parameters in the descriptive analysis of volume groups were subjected to a statistical trend analysis (Cochran Armitage Trend Test).
Vogel 2011	USA	Hospitals , range from 1335 to 1116	17210 procedures	Abdominal aortic aneurysm (ICD-9 code 441.4)	Open (ICD-9 codes 38.34, 38.44 and 38.64)	Top ten % volume was categorized as high-volume, all remaining hospitals placed in the low-group	Length of stay (intensive unit days)	Intensive unit days were lower in high-volume hospitals. Mean hospital days in high volume days 4.41 (SD 6.66) and low-volume 4.64 (SD 6.69), p<0.3.	Multivariable analysis with forward stepwise regressions, adj for age, sex, race, comorbidities and hospital procedure. Complete data for LOS.

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

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

Surgeon volume: length of stay in patients undergoing acute open surgery									
Study ID	Set-ting	Unit (sur-geon/ de-part-ment/ hospital)	Patients (descrip-tion and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Dar-dik 1998	USA, Ma-ry-land	226 sur-geons	527 procedures	Ruptured or acute ab-dominal aortic aneurysm (ICD-9 codes 441.02 and 441.3)	Open (ICD-9 co-des 38.34, 38.44, 38.64, 38.84 and 39.54)	Low 1-4, medium 5 to 9, and high >10	Length of stay (hospital days)	There was little or no association between volume and hospital length of stay (days). Low 11.7 (0.8), medium 11.6 (1.0), high 12.4 (1.8), p=0.46. The association of volume with length of stay was not evaluated in the multivariate anal-ysis.	Categoricalal variables were analysed by Pearson's test or Fisher's Exact Test. Continuous variables were analysed by analysis of variance for parametric variables and the Mann-Whitney U test or Kruskal-Wallis test for nonparametric variables. Multiple logistic regression was used for multivariate analysis and controlled for age, sex, race, hyperten-sion, diabetes, comorbidities, and health behaviours. Probably complete LOS data.

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

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

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

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

The association of volume and quality endovascular surgery

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

Hospital volume: mortality in elective patients for endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Illonzo 2014	USA	Hospitals, number of hospitals unclear	195928 patients	Abdominal aortic aneurysm (codes not reported)	Endovascular (codes not reported)	Low <4, medium 5 to 17, high 18 to 177	Mortality (30 day mortality after complications associated with procedure)	High volume hospitals had a higher success rate of rescue compared to low volume hospitals (p<0.001). Trend in failure to rescue 0.7% for high volume vs 1.69% for low volume.	Multivariate logistic regression analysis adj for age, gender, race, comorbidities, hospital annual volume, and year of the surgery.
Landon 2010	USA	Hospitals, numbers unlcear	29390 cases	Abdominal aortic aneurysm (ICD-9 code 441.4)	Endovascular (ICD-9 code 39.71)	1: <9, 2: 10 to 17, 3: 18 to 29, 4: 30 to 49, 5: >50.	Mortality (30-day mortality)	Mortality by quintile, after adjustment, showed a substantial decrease by higher volume between the first and second quintile (2.5% versus 1.6%), with continued minor decreases over quintiles 3 to 5.	All models were adjusted for baseline clinical and demographic characteristics. Observed mortality in each quintile was compared with predicted adjusted mortality computed under the counterfactual assumption that all procedures occurred at a hospital in the lowest-volume quintile.
McPhee 2011	USA	Hospitals	8121 procedures	Abdominal aortic aneurysm (ICD-9 code 441.4)	Endovascular (ICD-9 code 39.71)	Low <15, medium 16 to 70, and high >70	Mortality (In-hospital mortality)	The association between hospital volume and mortality for endovascular procedures was uncertain, although low volume hospitals had a higher mortality (OR, 2.3; 95% CI, 0.96-5.3).	Multivariable logistic regression models, adj for patient level factors such as age, gender, comorbidity and hospital level characteristics.
Dua 2014	USA	Hospitals, N unclear	Unclear	Abdominal aortic aneurysm (ICD-9 code 441.4 and 441.9)	Endovascular (ICD-9 code 39.71)	No-cut off, this is explored as part of the analysis, threshold set at <8	Mortality (In-hospital mortality)	Hospitals with mortality higher than 13% complete fewer than eight procedures. These hospitals also have a mortality of up to 100% (OR 7.7 to 33.2) when compared to the mean 6	Statistical analysis was completed using analysis of variance for continuous variables (number of cases) and x2 for categorical variables (i.e., hospital covariates, inpatient mortality). The Mann-Whitney U test was used for LOS

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

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

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

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

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

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

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

Appendix 7. Results tables thoracic and abdominal aortic aneurysms

The association of volume and quality all surgery

Hospital volume: mortality for all patients for all surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Miyata 2009	Japan	40 centers	2875 procedures	All thoracic aortic surgery procedures performed including those combined with CABG surgery, valve surgery or other major surgical interventions	All (procedure codes not reported)	High >40 procedures, medium 21 to 40, and low 5 to 20.	Mortality (30-day mortality)	The rates of 30-day mortality by volume category was in low 1: 9.6%, medium 6.1%, high 4.4%, p=0.002. The Odds for 30-day mortality was lower in high volume centers: OR 0.988 - 0.999, p=0.03	The impact of hospital volume on unadjusted outcomes was tested using a hierarchical mixed-effects logistic regression model. Risk adj. mortality rates were calculated by dividing the observed mortality rate by the expected mortality rate at the same hospital and multiplying by the overall thoracic aortic mortality rate of the JACVSD.
Miyata 2009	Japan	40 centers	2875 procedures	All thoracic aortic surgery procedures performed including those combined with CABG surgery, valve surgery or other major	All (procedure codes not reported)	High >40 procedures, medium 21 to 40, and low 5 to 20.	Operative mortality (overall mortality extending the 30-day mortality)	The rates of operative mortality by volume category was in low 1: 10.8%, medium 7.7%, high 5.8%, p=0.002. The Odds for operative mortality was lower in high volume centers: OR 0.989—0.999, p=0. 02	The impact of hospital volume on unadjusted outcomes was tested using a hierarchical mixed-effects logistic regression model. Risk adj. mortality rates were calculated by dividing the observed mortality rate by the expected mortality rate at the same hospital and multiplying by the overall thoracic aortic mortality rate of the JACVSD.

				surgical inter-ventions					

Surgeon volume: mortality for all patients for all surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Miyata 2009	Japan	Surgeons, numbers unclear	2875 procedures	All thoracic aortic surgery procedures performed including those combined with CABG surgery, valve surgery or other major surgical interventions	All (procedure codes not reported	High >15, low <15	Mortality (30-day mortality)	There was little or no association between volume and 30-day mortality: OR 0.997- 0.01, p=0.3	The impact of hospital volume on unadjusted outcomes was tested using a hierarchical mixed-effects logistic regression model. 30-day mortality is presented by volume interaction. Risk adj. mortality rates were calculated by dividing the observed mortality rate by the expected mortality rate at the same hospital and multiplying by the overall thoracic aortic mortality rate of the JACVSD.
Miyata 2009	Japan	Surgeons, numbers unclear	2875 procedures	All thoracic aortic surgery procedures performed including those combined with CABG surgery, valve surgery or other major surgical interventions	Unclear, possibly both	High >15, low <15	Operative mortality (overall mortality extending the 30-day mortality)	There was little or no association between volume and 30-day mortality: OR 0.996—1.008, p=0.5	The impact of hospital volume on unadjusted outcomes was tested using a hierarchical mixed-effects logistic regression model. 30-day mortality is presented by volume interaction. Risk adj. mortality rates were calculated by dividing the observed mortality rate by the expected mortality rate at the same hospital and multiplying by the overall thoracic aortic mortality rate of the JACVSD.

Hospital volume: mortality for patients undergoing elective admissions for all surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Gazoni 2010	USA, Virginia	17 hospitals	731 procedures	Thoracic abdominal aortic aneurysms, ascending aneurysms, arch aneurysm, descending aneurysms	All (procedure codes not reported)	Low <40, high >80	Mortality (30-day mortality)	The number of people who died in the high volume hospitals was 19/515 (3.7%), and 18/216 in the low volume (8.3%), p=0.01. The multivariate analysis found that high volume hospitals predicts lower mortality: OR 0.41, 95%CI 0.18 to 0.92, p=0.03	Logistical, multivariate regressions were constructed to model the effects of volume on selected risk factors and outcomes as well as the total estimated cost of hospital stay.

Hospital volume: complications for elective patients for all surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Gazoni 2010	USA, Virginia	17 hospitals	731 procedures	Thoracic abdominal aortic aneurysms, ascending aneurysms, arch aneurysm, descending aneurysms	All (procedure codes not reported)	Low <40, high >80	Complications (permanent stroke, pneumonia, prolonged ventilator course, renal failure and reoperation for bleeding)	There were fewer complications in the high volume hospitals, such as renal failure (cases in high volume was 23/515 (4.5%), and 18/216 (8.3%) in low, p=0.05), prolonged ventilator (cases in high volume 86/515 (16.7%), and 55/216 (25.5%) in low volume, p<0.01), and in permanent stroke (cases in high volume was 25/515 (4.8%), and 39/216 (1.4%) in low volume, p<0.01): There were also fewer cases of reoperation of bleeding (cases in high volume 28/515 (5.4%), and 17/216 (7.9%) in low volume, p=0.23) and pneumonia (cases in high were 34/515 (6.6%), and 9/216 (4.2%) in low volume, p=0.23), but these results were more uncertain.	Logistical, multivariate regressions were constructed to model the effects of volume on selected risk factors and outcomes as well as the total estimated cost of hospital stay.

Hospital volume: length of stay for elective patients for all surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Gazoni 2010	USA, Virginia	17 hospitals	731 procedures, number of patients unclear	Thoracic abdominal aortic aneurysms, ascending aneurysms, arch aneurysm, descending aneurysms	All (procedure codes not reported)	Low <40, high >80	Length of stay (hospital days)	The number of hospital days was 8.5 (SD 10.1) in high, and 11.6 (SD 17) in the low volume, p-value <0.01. Results from the multivariate analysis found that high volume hospitals predicts decreased length of stay: OR 0.96, 95% CI 0.94 to 0.98; p=0.001	Logistical, multivariate regressions were constructed to model the effects of volume on selected risk factors and outcomes as well as the total estimated cost of hospital stay. Probably complete data for LOS

Costs for patients undergoing elective admissions for all surgery										
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis	Study ID
Gazoni 2010	USA, Virginia	17 hospitals	731 procedures	Thoracic abdominal aortic aneurysms, ascending aneurysms, arch aneurysm, descending aneurysms	All (procedure codes not reported)	Elective	Low <40, high >80	Costs	Mean overall cost was lower in high volume centers (USD 42,736 (SD USD 38,405) compared to low-volume centers (USD 51,296 (SD USD 41,375) (p<0.04). The difference in cost was accentuated in cases with an associated mortality (high volume USD 59,907 (SD USD 47,493) compared to low-volume USD 99,452 (USD 79,639; p <0.02). In cases with no complications, the difference in cost was more uncertain (high volume USD 31,769 (SD USD 11,048) compared to low volume USD 34,533 (SD USD 6,051; p< 0.12).	Logistical, multivariate regressions were constructed to model the effects of volume on selected risk factors and outcomes as well as the total estimated cost of hospital stay.

The association of volume and quality for open surgery

Hospital volume: mortality for all patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Goodney 2013	USA	Hospitals, numbers unclear	12573 patients	Thoracic aortic aneurysm (ICD-9 441.1 or 441.2)	Open surgical repair (38.44 and 38.45)	Cut off unclear	Mortality (30-day mortality)	There was higher mortality in low volume hospitals: 13.5% in very low volume hospitals, 7.3% in very high-volume hospitals; p< 0.001. In the multivariable analysis, the OR by volume category compared to very low, was: low 0.8 (95% CI 0.6 to 0.9; p<0.001), medium 0.8 (95% CI 0.7 to 0.9; p0.007), high 0.5 (95% CI 0.4 to 0.6; p<0.001), and very high 0.5 (95% 0.4 to 0.6; p<0.001)	The outcome of perioperative death was a binary categorical variable and was analysed using X2 tests. Survival curves were estimated using Kaplan-Meier analysis, and life-table analysis was used to establish rates of 5-year survival with surrounding 95% Cis .Log-rank tests were used to determine significant differences in survival between groups. Multivariable analyses to adjust for differences inpatient age, race, gender, socioeconomic status.
Weiss 2014	USA, California	122 hospitals	1188 patients	Thoracic abdominal aneurysm repair (ICD-9 441.6 and 441.7)	Open surgical repair (38.44 and 38.45)	High >9	Mortality (in-hospital mortality)	Mortality in high-volume was 20.4% (67/479 deaths), and 25.2% (217/709 deaths) in low-volume. P<0.08. Adj analysis for mortality found an OR of 0.37 (95% CI 0.12 to 1.12, p> =0.08) when the threshold was defined as any year in which the hospital reached the 9-case threshold. When the threshold was set as any hospital that had previously reached the threshold of 9 cases the OR was 0.40 (95% CI 0.17 to 0.96, p<0.04)	Multivariate logistic regression estimated the OR of each outcome comparing patients by volume. Adj for age, sex and comorbidities/ rupture

Schermerhorn 2008	USA	Hospitals of which 685 were low volume, 602 were medium and 1262 were high	2549 patients	Thoracic aortic aneurysm (ICD-9 441.1 or 441.2)	Open surgical repair (38.45)	Low <1, medium 2 to 3, and high 3 to 25	Mortality (in-hospital mortality)	There was less mortality in high versus low volume, % mortality by volume category was: 21.7 in low, 20.4 in medium, and 15.5 in high, p<0.01. The adj multivariate analysis found that volume predicted mortality, OR 1.3, 95% CI 1.1 to 1.6, p<0.05.	Mortality over time was analysed by the X2 test of trend as well as logistic regression. Predictors of mortality were analysed by univariate and multivariate logistic regression. Adj for age, comorbidities, severity of disease.

Hospital volume: mortality for elective patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Christian 2003	USA	99 hospitals	9869 patients	Thoracic abdominal aortic aneurysms and abdominal aortic aneurysms (441.00, 441.02, 441.03-441.7, 441.9)	Open (ICD-9 codes 38.34, 38.44, 38.64)	1: <15, 2: 15-29, 3: 30- 44, 4:>45/	Mortality (in-hospital mortality)	There was higher mortality in lower volume 1st compared to 4th: OR 1.67, 95% CI 1.32 to 2.11, p<0.0001), 2nd quartile compared to 4th: OR 1.17, 95% CI 0.96 to 1.42, p=0.11, 3rd compared to 4tht: OR 1.15, 95% CI 0.93 to 1.41, p=0.17	Multivariate logistic regression analysis adj for age, gender, emergency status, whether the patient was transferred in from another acute-care institution, insurance status, race and comorbidities
Cowan 2003a	USA	308 hospitals	1542 patients	Thoracic abdominal aortic aneurysms and abdominal aortic aneurysms (ICD-9 441.0, 441.2, 441.4, 441.7, 441.9)	Open surgical repair (ICD-9 38.44, 38.45)	Low 1 to 3, medium 2 to 9 and high 5 to 31	Mortality (in-hospital mortality)	Low volume was associated with a higher mortality. The mortality was 27.3% in low, 23.8% in medium and 15% in high volume hospitals, p-value <0.001 based on Pearson 2 test. The OR for low and medium volume hospitals compared to high were respectively: OR 2.2; 95% CI 1.6-3.1; p<0.001 and OR 1.7; 95% CI 1.2-2.4; p<0 .004)	Univariate comparisons, analysis of variance, Kruskal-Wallis test, and simple linear regression. Stepwise binary logistic regression (inclusion threshold, of in-hospital mortality adj. age, gender, race, comorbidity.
Schermerhorn 2008	USA	Total number of hospitals were for low volume category 685, medium 297 and high 265	1976 procedures	Thoracic aortic aneurysm (ICD-9 441.2)	Open surgical repair (38.45)	Low <1, medium 2 to 3, and high 3 to 25	Mortality (in-hospital mortality)	There was less mortality in high versus low volume, % mortality by volume category was: 13.2 in low, 12 in medium, and 8.4 in high, p<0.01. Elective surgeries were not entered in the multivariate analysis.	Mortality over time was analysed by the X2 test of trend as well as logistic regression. Predictors of mortality were analysed by univariate and multivariate logistic regression. Adj for age, comorbidities, severity of disease.

Surgeon volume: mortality for elective patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Cowan 2003a	USA	Surgeons, numbers unclear	1542 patients	Thoracic abdominal aortic aneurysms and abdominal aortic aneurysms (ICD-9 441.0, 441.2, 441.4, 441.7, 441.9)	Open surgical repair (ICD-9 38.44, 38.45)	Low 1 to 2, high 3 to 18	Mortality (in-hospital mortality)	Low volume was associated with a higher mortality. The mortality was 25.6% in low, and 11% in high volume surgeons, p-value <0.001 based on Pearson 2 test. In the binary logistic regression model the odds of mortality by low volume surgeon was OR 2.6 (95% CI 1.7 to 4,1; p<0001)	Univariate comparisons, analysis of variance, Kruskal-Wallis test, and simple linear regression. Stepwise binary logistic regression (inclusion threshold, of in-hospital mortality adj. age, gender, race, comorbidity.

Hospital volume: mortality for patients with rupture for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Cowan 2003b	USA	Hospitals	Unclear	Thoracic abdominal aortic aneurysms (ICD-9 441.1, 441.6)	Open surgical repair (ICD-9 38.44, 38.45)	Low 1 to 3, medium 2 to 6 and high 6 to 31	Mortality (in-hospital mortality)	No significant relationship between hospital total TAAA surgical volume (either low, medium, or high) and mortality after surgery to treat ruptured TAAA could be demonstrated with univariate analysis (p=0.398).	Univariate comparisons performed with the 2 test, analysis of variance, Kruskal-Wallis test, and simple linear regression, where appropriate. Stepwise binary logistic regression of in-hospital mortality adjusting for potentially confounding patient case-mix variables and postoperative complications.
Schermerhorn 2008	USA	Hospitals of which 685 were low volume, 602 were medium and 1262 were high	573 procedures	Thoracic aortic aneurysm (ICD-9 441.1)	Open surgical repair (38.45)	Low <1, medium 2 to 3, and high 3 to 25	Mortality (in-hospital mortality)	There was little or no difference between volume categories in mortality, the % mortality by volume category was: 46.5 in low, 45.6 in medium and 44.2 in high, p=0.89. Acute surgeries not entered in the multivariate analysis.	Mortality over time was analysed by the X2 test of trend as well as logistic regression. Adj for age, comorbidities, severity of disease.

Hospital volume: complications for all patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Weiss 2014	USA, California	122 hospitals	1188 patients	Thoracic abdominal aneurysm repair (ICD-9 441.6 and 441.7)	Open surgical repair (38.44 and 38.45)	High >9	Complications (including postoperative myocardial infarction, stroke, paraplegia, renal failure, prolonged intubation adult respiratory distress syndrome, wound or graft infection, sepsis and blood transfusion)	Overall there was little or no difference between volume categories. The adj analysis found associations between volume and infection and sepsis for one of the volume thresholds. The rate of all complications in high-volume was 54% (177), and 53.8% (463) in low-volume, p=0.9. Adj analysis found an OR of 0.94 (95% CI 0.55 to 1.61, p=0.83) when the threshold was defined as any year in which the hospital reached the 9-case threshold. When the threshold was set as any hospital that had previously reached the threshold of 9 cases the OR was 1.17 (95% CI 0.74 to 1.86, p=0.51).	Multivariate logistic regression estimated the OR of each outcome comparing patients by volume. Adj for age, sex and comorbidities/ rupture
Schermerhorn 2008	USA	Hospitals of which 685 were low volume, 602 were medium and 1262 were high	2549 patients	Thoracic aortic aneurysm (ICD-9 441.1 or 441.2)	Open surgical repair (38.45)	Low <1, medium 2 to 3, and high 3 to 25	Complications (including stroke, non-stroke neurologic, cardiac and respiratory complications, and acute renal failure.	There was little or no difference between volume categories for complications. % all complications was 44.4 in low, 41 in medium and 44.5 in high, p=0.33. % stroke was 2.3 in low, 2.5 in medium and 3.2 in high, p=0.5. % neuro non-stroke was 2.2 in low, 1.3 in medium and 1.3 in high, p=0.26. % respiratory was 12.4 in low, 13.3 in medium and 13.9 in high, p=0.66. % acute renal failure was 10.8 in low, 11.3 in medium and 9.8 in high, =0.58. Variable not explored in multivariate analysis.	Mortality over time was analysed by the X2 test of trend as well as logistic regression. Predictors of mortality were analysed by univariate and multivariate logistic regression. Adj for age, comorbidities, severity of disease.

Hospital volume: complications for elective patients for open surgery									
Study ID	Set-ting	Unit (sur-geon/ depart-ment/ hospital)	Patients (descrip-tion and N)	Condition (diagno-sis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Cowan 2003a	USA	308 hos-pitals	1542 pa-tients	Thoracic ab-dominal aortic an-eurysms and ab-dominal aortic an-eurysms (ICD-9 441.0, 441.2, 441.4, 441.7, 441.9)	Open surgi-cal repair (ICD-9 38.44, 38.45)	Low 1 to 3, me-dium 2 to 9 and high 5 to 31	Complications (cardiac, pul-monary, uri-nary and hem-orrhagic com-plications, renal failure and oli-guria)	On average, high volume hospitals had a somewhat higher rate of postoperative complications com-pared with lower volume centers. % any complica-tion in low 51.5%, medium 56.8% and high 57.9%, p<0.08. Cardiac by category: low 12.8%, medium 13.9% and high 17.8%, p<0.60. Pulmonary compli-cations: low 17.4%, medium 16, 9%, high 22.7%, (p<0.033). Urinary tract: low 7.7, medium 10.5, high 11.7%, p<.08). Hemorrhage: low 14.8%, medium 11.8%, and high 10.3%, p<0.07. Acute renal failure: low 12.3, medium 17.8 and high 13%, p<0.3	Univariate com-parisons, analysis of variance, Krus-kal-Wallis test, and simple linear regression. Step-wise binary logistic re-gression (inclu-sion threshold, of in-hospital mor-tality adj. age, gender, race, comorbidity.

Hospital volume: length of stay for all patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Schermerhorn 2008	USA	Hospitals of which 685 were low volume, 602 were medium and 1262 were high	2549 patients	Thoracic aortic aneurysm (ICD-9 441.1 or 441.2)	Open surgical repair (38.45)	Low <1, medium 2 to 3, and high 3 to 25	Length of stay (hospital days)	Higher volume was associated with longer hospital stay. Median days and range was 15 (1 to 176) in low, 17 (1 to 98) in medium, and 19 (1 to 330) in high, p<0.01. Variable not explored in multivariate analysis.	Mortality over time was analysed by the X2 test of trend as well as logistic regression. Predictors of mortality were analysed by univariate and multivariate logistic regression. Adj for age, comorbidities, severity of disease. Unclear how referral were addressed, but longer median stay in high volume.

Hospital volume: length of stay for elective patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Cowan 2003a	USA	308 hospitals	1542 patients	Thoracic abdominal aortic aneurysms and abdominal aortic aneurysms (ICD-9 441.0, 441.2, 441.4, 441.7, 441.9)	Open surgical repair (ICD-9 38.44, 38.45)	Low 1 to 3, medium 2 to 9 and high 5 to 31	Length of stay (hospital days)	The length of stay was somewhat higher in the higher volume groups. The median length of stay of surviving patients per volume category was for low 11 days (interquartile range 8-18), for medium 13 days (interquartile range 8-21), and for high 12 days (interquartile range 9-20), p-value 0.004.	Univariate comparisons, analysis of variance, Kruskal-Wallis test, and simple linear regression. Stepwise binary logistic regression (inclusion threshold, of in-hospital mortality adj. age, gender, race, comorbidity. Adj for nature of admission, and all LOS is calculated post surgery.

Surgeon volume: length of stay for elective patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Cowan 2003a	USA	Surgeons, numbers unclear	1542 patients	Thoracic abdominal aortic aneurysms and abdominal aortic aneurysms (ICD-9 441.0, 441.2, 441.4, 441.7, 441.9)	Open surgical repair (ICD-9 38.44, 38.45)	Low 1 to 2, high 3 to 18	Length of stay (hospital days)	Not reported, possibly because surgeon volume was not a statistically significant predictor	Univariate comparisons, analysis of variance, Kruskal-Wallis test, and simple linear regression. Stepwise binary logistic regression (inclusion threshold, of in-hospital mortality adj. age, gender, race, comorbidity.

The association of volume and quality for endovascular surgery

Hospital volume: mortality for all patients for endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Goodney 2013	USA	Hospitals, numbers unclear	2732 patients	Thoracic aortic aneurysm (ICD-9 441.1 or 441.2)	Endovascular (39.73 and 39.79)	Cut off unclear	Mortality (30-day mortality)	Mortality across volume strata for endovascular procedures (9.0% in very low-volume hospitals, 7.3% in very high-volume hospitals; p=0.328). In the multivariable analysis, the OR by volume category compared to very low, was: low 1.1 (95% CI 0.7 to 1.6; p=0.78), medium 1.0 (95% CI 0.7 to 1.5; p=0.98), high 0.7 (95% CI 0.5 to 1.1; p=0.15), and very high 0.8 (95% CI 0.5 to 1.2; p=0.21)	The outcome of perioperative death was a binary categorical variable and was analysed using X2 tests. Survival curves were estimated using Kaplan-Meier analysis, and life-table analysis was used to establish rates of 5-year survival with surrounding 95% CIs. Log-rank tests were used to determine significant differences in survival between groups. Multivariable analyses to adjust for differences inpatient age, race, gender, socioeconomic status. To

Surgeon volume: mortality for elective patients for endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Modrall 2014	USA	Surgeon, numbers unclear	Unclear	Thoracic abdominal aortic aneurysms and abdominal aortic aneurysms (specific codes not reported)	Endovascular (ICD-9 codes 39.71 and 39.73)	Low <5, medium 5 to 16, and high >16	Mortality (in-hospital stroke or death)	The incidence of stroke/death decreased as clinicians' annual volume increased (p<0.0023 in Cochran-Armitage trend test). After adjusting for patient and hospital characteristics, volume predicted stroke and death OR 0.85; 95%CI 0.75 to 0.97; p<0.020	Categorical data analysed using X2 and Cochrane-Armitage trend test, and multiple regression analysis adj for demographics, symptomatic patients, comorbidities and hospital characteristics

Appendix 8. Results tables carotid artery disease

The association of volume and quality for open surgery

Hospital volume: mortality for all patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Birkmeyer 2002	USA	2990 hospitals	479289 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9)	Open (Carotid endarterectomy procedure codes not reported)	1: <40, 2: 40 to 69, 3: 70 to 109, 4: 110 to 164, 5:>164	Mortality (30-day mortality)	The mortality rate by category was: low 1.9%, medium 1.8%, high 1.7% and very high 1.7%. In the multivariate analysis, compared to lowest volume quintile, the odds by quintile was 2: OR 0.95 (95% CI 0.88 to 1.02), 3: OR 0.91 (95% CI 0.84 to 0.99), 4: OR 0.88 (95%CI 0.81 to 0.95), 5: OR 0.88 (95%CI 0.80 to 0.96).	
Wennberg 1998	USA	Hospitals, numbers unclear	113300 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	Low 1 to 6, medium 7 to 21, and high >21	Mortality (30-day mortality)	The 30-day mortality rate increased by lower volume in the adjusted analysis. Rate in high volume was 1.7% (95% CI 1.6% to 1.8%), medium volume 1.9% (95% CI 1.7% to 2.1) and low 2.5% (95% 2.0% to 2.9%), p<0.001.	Chi-square tests were used to assess mortality rates and trends across categories of predictors. Logistic regression adj for age, gender, race, comorbidities, admission type

Huber 2001	USA	Hospitals, unclear how many	Unclear, national sample	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery	Open (Current Procedural Terminology (CPT) codes 35301 thromboendarterectomy, carotid)	Unclear	Mortality (30-day mortality)	The 30-day mortality rate was lower in high volume compared to low volume. High volume had a rate of 1.7% and low 2.5%.	Analysis poorly described, results reported as % . Mortality rates were adjusted for race, sex, and age, but not for comorbidities.
Finks 2011 (same authors as Birkmeyer 2002, but this sample continues from the Birkmeyer 2002)	USA	Hospitals, range from 2341 to 2635	Patients, range from 178070 to 232388	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9)	Open (Carotid endarterectomy ICD-9 code 38.12)	unclear	Mortality (30-day mortality including in-hospital mortality)	Proportion of the difference in mortality explained by increased hospital volume over time was 0%. Measures of uncertainty was not reported.	Chi-square tests to determine the significance of trends and logistic-regression models with robust standard errors, adjusted for clustering at the hospital level. Logistic-regression models adj for patient characteristics, including age, sex, race, admission acuity (elective, urgent, or emergency), coexisting conditions, and a composite measure of socioeconomic status according to ZIP Code
Middleton 2002	USA, New South Wales	46 hospitals	666 patients	Atherosclerosis/ narrowing of the common	Open (codes not reported)	>10 high (per six months)	Mortality (30-day mortality)	There was higher odds of death in high volume compared to low volume (OR 4.96, 05%	Poisson regression without adjustment for personal factors

				carotid artery or internal carotid artery (codes not reported)				CI 1.00 to 23.57) (n= 666). Analysis problematic because of few deaths.	
Khuri 1999	USA	93 hospitals	10173 cases	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (CPT-code 4 35301)	Open (CPT- 4 code 35301)	Quartiles, 1: 0 to 10, 2: 11 to 18, 3: 19 to 28, and 4: 29 to 73	Mortality (30-day mortality)	Lower volume was not found to be a predictor of mortality (in logistic regression 0.00357 (SE 0.01), p=0.72)	A mixed effects hierarchical logistic regression analysis adj for patient risk factors.
Reames 2014	USA	Hospitals, ranged from 2569 to 2275	National sample, ranged from 148468 to 103038	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9)	Open and endovascular (procedure codes not reported)	Low <32 procedures, high >100. The cut-off varied for each year.	30- day mortality (including in-hospital)	Adj. OR (95% CI) year 1: 1.32 (1.12–1.56) year 2: 1.31 (1.11–1.52) year 3: 1.38 (1.14–1.69) year 4: 1.17 (.965–1.43) year 5: 1.28 (1.08–1.53). The Odds of mortality was higher in low-volume hospitals for all years except year 4.	Multivariable logistic regression to examine the relationship between hospital volume and operative mortality during the 10-year study period, after adjusting for patient characteristics (age, sex, race (black or nonblack) and their interactions, urgency or emergency of the admission, the presence of coexisting conditions, and socioeconomic status), year of the procedure, and surgical approach.

Hannan 1998	USA, new York	Hospitals	28 207 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 code not reported)	Open (ICD-9 code not reported)	High >100	Mortality (in-hospital mortality)	There were lower odds of death in high volume (OR 0.94, 95% CI 0.74 to 1.19) than in low volume (OR 1.28, 95% CI 1.13 to 1.45). All compared to statewide mean mortality rate.	Stepwise regression model adj for personal factors including age, gender, race, admission status (elective, nonelective), and relevant diagnoses.
Roddy 2000	USA, Massachusetts	20 centers	10211 procedures	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	Data is presented for four categories: two categories of high volume where one is an academic institution (volume not reported) and the other is a non-academic institution ≥50. The two remaining categories consisted of medium 24-49 and low volume 12-23 non-academic institutions.	Mortality (in-hospital mortality)	Overall % mortality for all three years per category was academic high 0.38% (11 deaths) non-academic high 0.48% (22 deaths), non-academic medium 0.83% (14 deaths) a nonacademic low 0.91% (4 deaths).	Analysis of variance to compare the means of all the cost and LOS data, and a $\chi 2$ test was used in comparison of incidence. Subgroup analysis was achieved with Bonferroni adjusted P values from pairwise comparisons of means (≤.05).

Westvik 2006	USA, Connecticut	26 hospitals	14288 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 codes 433.x)	Open (Carotid endarterectomy ICD-9 code 38.12)	Low <10, medium 10 to 49, or high > 50	Mortality (In-hospital mortality)	Rates of in-hospital mortality in high was 0.3%, medium was 0.7%, and low was 0.9%. P-value from the Chi-square test was 0.0008. Results for in-hospital mortality alone was not reported for the multivariate analysis.	Pearson's 2 analyzed categorical variables or Fisher's Exact Test. Continuous variables were analyzed by the Mann-Whitney t-test or Kruskal-Wallis test. Multivariable logistic regression, adj race, gender, comorbidities, severity of disease.
Nazarian 2008	USA, Maryland	47 hospitals	22772 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 433.00 to 433.91)	Open (Carotid endarterectomy ICD-9 code 38.12)	Low volume <130, high >130	Mortality (in-hospital mortality)	High volume hospitals had an odds ratio of death of 0.945 per additional procedure, or 0.055 decrease in the odds of death (p< 0.013), whereas low volume hospitals had an odds ratio of 0.998 (p< 0.563).	Crude odds ratios of death were first determined by logistic regression for annual surgeon volume and annual hospital volume. Heterogeneity by calendar year was explored by performing the analysis within each year. Nonlinear relationships between death and average annual surgeon and hospital volume were explored by examining logit-transformed lowess smoothing functions. Adj for age, race, gender and comorbidities
Perler 1998	USA, Maryland	48 hospitals	9981 cases	Atherosclerosis/ narrowing of the common carotid ar-	Open (Carotid endarterectomy ICD-9 code 38.12)	Low <10, medium 11 to 49 and high >50	Mortality (in-hospital mortality)	The mortality rate was 1.9% in low, 1.1% in moderate, and 0.8% in high-volume hospitals (p = 0.079).	Statistical analysis was performed on discrete variables with X2 analysis, and all other data were analyzed with the

				tery or internal carotid artery (ICD-9 433.00 with any fourth digit)					Kruskal-Wallis or Mann-Whitney tests. Post-hoc comparisons were performed with Fisher's protected least significant difference, Bonferroni, and Scheffé's post hoc tests, using analysis of variance as an approximation of the Kruskal-Wallis test because of the large sample size.
Cowan 2002	USA	Hospitals, numbers unclear	35821 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	Low <100	Mortality (in-hospital mortality)	Low volume hospitals was a risk factor for mortality in the univariate analysis (OR 1.5, p=0.003). But in the multivariate analysis, low volume hospitals did not have a statistically significant effect (numbers not reported)	Differences between continuous variables were tested using ANOVA. Mantel-Haenszel odds ratios (OR) were calculated to determine patient, surgeon, and hospital variables that predicted mortality. The multivariate model of mortality was adj for age, comorbidities, race, gender, nature of admission. Pearson's chi-square was used to determine differences in the rate of postoperative stroke and prolonged length of stay.

Manheim 1998	USA, California	Hospitals, numbers unclear	Unclear, 106493 procedures	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9)	Open (Carotid endarterectomy ICD-9 code 38.12)	Low <20, moderate 20 to 49, and high 50 to 99, and very high >100	Mortality (In-hospital mortality)	The OR for dying in medium volume hospitals was 0.80 (p<0.002), OR in high was 0.68 (p<0.001), and very high OR 0.66 (p<0.001) compared to low volume	Multiple logistic regression, adj for age, gender, year of surgery, admission type and comorbidities
Matsen 2006	USA, Maryland	47 hospitals	23237 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 433.00 to 433.91)	Open (Carotid endarterectomy ICD-9 code 38.12)	Low <20, moderate 21 to 100, and high >100	Mortality (not further specified)	On logistic regression, the effect of hospital volume was not statistically significant. Numbers not reported.	Logistic regression, otherwise not described. Adj for age, gender, race and symptoms

Surgeon volume: mortality for all patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Birkmeyer 2003	USA	Surgeons 8818	Patients 136049	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9)	Open (procedure codes not reported)	Low <18, medium 18 to 40, and high >40	Mortality (30-day mortality)	In the multivariate analysis, lower volume was associated with higher mortality rates. Adj OR 1.70 (95% CI 1.51 to 1.91). Surgeon volume effect present with and without adjustment for hospital volume, in the adjusted analysis, hospital volume accounted for 0% of the effect.	Multiple logistic regression with adjustment for characteristics of the patients (age, gender, comorbidities and race)
Huber 2001	USA	Surgeons, number unclear	Unclear, national sample	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery	Open (Current Procedural Terminology (CPT) codes 35301 thromboendarterectomy, carotid)	1. <3, 2: 4 to 7, 3: 8 to 12, 4: 13 to 24, 5: 25 to 42, 6: >43	Mortality (30-day mortality)	The % mortality rate was lower for high volume compared to low-volume. The mortality rate ranged from 2.8% among those surgeons who performed fewer than four procedures (low-volume surgeons) to 1.4% for those who performed more than 42 procedures (high-volume surgeons).	Analysis poorly described, results reported as %. Mortality rates were adjusted for race, sex, and age, but not for comorbidities
Kumamaru 2015	USA	Surgeon, numbers unclear	454717 patients	Atherosclerosis/ narrowing of the common	Open (Carotid	Surgeon case-volume was 0 to 9, 10	Mortality (30-day mortality)	The 30-day mortality of low volume surgeons was consistently higher compared with those performed	To assess the change in post-CEA 30-day mortality over time, the relative risk of 30-day mortality in the

				carotid artery or internal carotid artery (specific code not reported)	endarterectomy ICD-9 code 38.12)	to 19, 20 to 39 and ≥40.		by higher volume surgeons (1.79% versus 1.19% in 2001–2002, and 1.42% versus 1.04% in 2007–2008). The logistic regression analysis showed that the increased relative risk of 30-day mortality for low volume surgeons remained statistically significantly higher compared with higher past-year case-volume surgeons. Numbers not reported.	later time blocks relative to the 2001 to 2002 block, using logistic regression, adjusting for all patient- and surgeon-level measured covariates and
Middleton 2002	USA, New South Wales	52 surgeons	666 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (codes not reported)	Open (codes not reported)	Low <6, medium 6 to 15 and high >15 (per six months)	Mortality (30-day mortality)	There was a higher incidence among patients treated by higher volume surgeons: OR 4.96, 95% CI 1.00 to 23.57. Analysis problematic because of few deaths.	Poisson regression without adjustment for personal factors
Cowan 2002	USA	2330 surgeons	35821 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	Surgeons were categorized as low-volume surgeons (< 10 procedures, medium-volume surgeons (10 to 29), or high-volume	Mortality (in-hospital mortality)	For elective, the % mortality was 0.78 for low, 0.54 for medium and 0.32 for high, p<0.001. For emergent the % mortality was 1.68 for low, 0.89 for medium and 0.82 for high, p<0.003. For all patients in the multivariate analysis, low volume surgeons had	Differences between continuous variables were tested using ANOVA. Mantel-Haenszel odds ratios (OR) were calculated to determine patient, surgeon, and hospital variables that predicted mortality. The multivariate model of mortality was adj for

						surgeons (>30 CEAs per year)		higher Odds of mortality: OR 1.9, 95% CI 1.4 to 2.5, p<0.001.	age, comorbidities, race, gender, nature of admission. Pearson's chi-square was used to determine differences in the rate of postoperative stroke and prolonged length of stay.
Nazarian 2008	USA, Maryland	442 surgeons	22772 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 433.00 to 433.91)	Open (Carotid endarterectomy ICD-9 code 38.12)	Low <3, medium 4-15, high >15	Mortality (in-hospital mortality)	Higher volume surgeons had lower estimated odds of death, particularly those performing four to 15 CEAs per year. Logistic regression of odds ratio of death per additional procedure per year for low volume was 0.802 (95% CI 0.505 to 1.275) p<0.351, for medium volume 0.935 (95% CI 0.887 to 0.986) p<0.013, for high volume 0.997 (95% CI .0.987 to 1.006) p<0.485.	Crude odds ratios of death were first determined by logistic regression for annual surgeon volume and annual hospital volume. Heterogeneity by calendar year was explored by performing the analysis within each year. Nonlinear relationships between death and average annual surgeon and hospital volume were explored by examining logit-transformed lowess smoothing functions. Adj for age, race, gender and comorbidities
Boudourakis 2009	USA	16,230 surgeons	Range 6301 to 4354	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific	Open (Carotid endarterectomy ICD-9 codes not reported)	High >50, low <5	Mortality (not further specified)	The % mortality in year 1 for high was 0.5% and low 1.0%, p<0.05. In year 2 the % mortality in high was 0.2% and in low 0.4%, p=NS. There was little or no association between surgeon volume	Bivariate analyses and hierarchical generalized linear models. These analyses subsequently guided the selection of variables for adjustment in the multivariable regression models for mortality

				code not reported)				and mortality in the multivariate analysis. Adj OR for year 1: 1.2 (95% CI 0.5 to 3.2) and for year 2: 2.3 (0.6 to 8.1)	and logistic linear regression for length of stay. Adj for patient characteristics (age, gender, race, insurance, comorbidities and income.
Matsen 2006	USA, Maryland	438 surgeons	23237 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 433.00 to 433.91)	Open (Carotid endarterectomy ICD-9 code 38.12)	Low <15, moderate 15 to 74 and high >75	Mortality (not further specified)	On logistic regression, surgeon volume was associated with somewhat lower risk OR 0.99, p<0 .05.	Logistic regression, otherwise not described. Adj for age, gender, race and symptoms
Hannan 1998	USA, new York	Surgeon	28 207 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 code not reported)	Open (ICD-9 code not reported)	High <5 versus >5 for low	Mortality (in-hospital mortality)	There were lower odds of death in high volume (OR 1.89, 95% CI 1.43 to 2.46) than in low volume (OR 1.11, 95% CI 0.99 to 1.25). All compared to statewide mean mortality rate.	Stepwise regression model adj for personal factors including age, gender, race, admission status (elective, non elective), and relevant diagnoses.
O'Neill 2000	USA, Pennsylvania	532 surgeons	14 439 procedures	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery	Open (ICD-9 code 38.12)	1: 1 to 2, 2: 3 to 24, 3: 25 to 49 and 4: 50 to 99, and 5: >100	Mortality (in-hospital)	The association was uncertain, not statistical significant- numbers not reported.	Multivariate logistic regression adjusting for patient factors including age, gender, source of admission, and comorbidities.

				(codes not reported)					

Hospital volume: mortality for elective patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Christian 2003	USA	102 hospitals	17015 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (codes not reported)	Open (ICD-9 codes 38.12, 38.32, 38.42	1: <50, 2: 50-99, 3:100-149, 4: >150	(Mortality) in-hospital mortality	There was higher mortality in lower volume, but with large uncertainties 1st compared to 4th OR 1.53 , 95% CI .860 to 2.72, p=0.15), 2nd quartile compared to 4th: OR 1.62, 95% CI 0.97 to 2.68, p=0.06, 3rd compared to 4tht: OR 1.06, 95% CI 0.53 to .09, p=0.87	Multivariate logistic regression analysis adj for age, gender, emergency status, whether the patient was transferred in from another acute-care institution, insurance status, race and comorbidities
Holt 2007	UK (England)	Hospitals, numbers unclear	16 759 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (OPCS4 codes 163.0, 163.1, 164, 165.2, 165.3, 165.8)	Open (Carotid endarterectomy OPCS4 codes L29.4. L29.5 and L29.9)	1: 1 to 9.4, 2: 9.5 to 17.2, 3: 17.3 to 34.6, 4: 34.7 to 52.2, 5: 52.3 to 95.6	Mortality (in-hospital mortality)	The in-hospital death rate was 1.5% in the lowest-volume quintile to 0.95% in the highest-volume quintile, p=0.047. In the multiple regression analysis, increasing annual volumes was associated with reduced mortality rates OR 0.898 (95% CI 0.808 to 0.999; p= 0.047).	Analysis was through evaluation of temporal trends in the data over the five-year period, with adjustment for age and gender. For the mortality rate and complication rate, multiple logistic regressions were performed. Adjusted for age and gender. For the length of stay, multiple linear regressions were performed adj for age, gender and year of procedure and the dependent variable log length of stay.

Hospital volume: mortality for patients undergoing emergency admissions for open surgery										
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis	Study ID
Holt 2007	UK (England)	Hospitals, numbers unclear	1489 procedures	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (OPCS4 codes 163.0, 163.1, 164, 165.2, 165.3, 165.8)	Open (Carotid endarterectomy OPCS4 codes L29.4. L29.5 and L29.9)	Emergency	1: 1, 2: 1.1 to 2, 3: 2.1 to 4, 4: 4.1 to 6.4, 5: 6.5 to 15	Mortality (in-hospital mortality)	The in-hospital death rate was 3.16% in the lowest-volume quintile to 3.29% highest-volume quintile. In the multiple regression analysis, there was little or no association between hospital volume and mortality: OR 0.975, 95% CI 0.798 to 1.191, p= 0.8.	Analysis was through evaluation of temporal trends in the data over the five-year period, with adjustment for age and gender. For the mortality rate and complication rate, multiple logistic regressions were performed. Adjusted for age and gender. For the length of stay, multiple linear regressions were performed adj for age, gender and year of procedure and the dependent variable log length of stay.

Hospital volume: mortality and complications for all patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Cebul 1998	USA, Ohio	115 hospitals	678 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 code not reported)	Open (ICD-9 code 38.12)	< 62 procedures	Mortality and complications (30-day mortality and stroke)	There was lower risk in higher volume compare to lower volume OR 0.29, 95% CI 0.12 to 0.69, p<0.006)	Multivariate logistic regression analysis, adj personal characteristics
Kantonen 1998	Finland	23 hospitals	1600 procedures	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (procedure codes not reported)	Unclear	Mortality and complications (30-day mortality and stroke)	No association was found between the hospital volume and adverse events after carotid surgery. Results only presented in plot, numbers not reported.	The risk factor analysis was performed by means of logistic multiple regression analysis. These risk factors included indication for carotid surgery, age and comorbidities.

Karp 1998	USA, Georgia	Hospitals, unclear	1945 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 code not reported)	Open (ICD-9 code 38.12)	Quartiles, 1: 1 to 10, 2: 11 to 25, 3: 26 to 50, and 4: 51 to 250.	Complications and mortality (30-day survival free of hospitalization associated stroke or MI)	There was higher risk in low volume compared to higher volume. OR by quartile compared to highest volume category: 1: 2.6 (95% CI 0.9 to 6.4), 2: 1.7 (0.7 to 3.6), 3: 1.3 (0.6 to 2.7).	Multiple logistic regression adj for potential risk factors included comorbidities, as well as demographic and anatomic characteristics of patients, such as age and degree of stenosis.

Kucey 1998	Toronto, Canada	8 hospitals	1280 procedures	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy Canadian classification of procedures code 50.12)	Low <6, medium 6 and 12, high >12	Mortality and complications (30-day mortality or stroke)	The rate of stroke/ mortality from the univariate analysis was for low 18.4%, medium 8% (p< 0.0456 compared to low) and high 5.4% (p< 0.0019 compared to low). The multivariate analysis found that low surgeon volume were associated with higher rates of mortality and stroke OR 3.98 (95% CI, 1.65, 9.58, p<0.002). Medium-volume had an OR of 1.53 (95% CI 0.90 to 2.60, p<0.12)	Univariate analysis was conducted to assess the association between various patient risk factors and the 30- day stroke or death rate. Multivariate logistic regression analysis and stepwise regression analysis, adj for age, gender, surgeon type, severity, comorbidities, side of surgery and admission type
Middleton 2002	USA, New South Wales	46 hospitals	666 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (codes not reported)	Open (codes not reported)	>10 high (per six months)	Complications (30-day fatal and non –fatal stroke)	No association was found, numbers not reported. Analysis problematic because of few deaths.	Poisson regression without adjustment for personal factors

Middleton 2002	USA, New South Wales	46 hospitals	666 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (codes not reported)	Open (codes not reported)	>10 high (per six months)	Complications (30-day stroke and mortality)	No association was found, numbers not reported. Analysis problematic because of few deaths.	Poisson regression without adjustment for personal factors
Westvik 2006	USA, Connecticut	26 hospitals	14288 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 codes 433.x)	Open (Carotid endarterectomy ICD-9 code 38.12)	Low <10, medium 10 to 49, or high > 50	Mortality and complications (All complications, in-hospital mortality, stroke and cardiac)	Results from multivariate analysis found that low and medium volume had a higher risk compared with high volume, but that this association was not statistically significant. Low volume had an adj OR of 0.17 (95% CI 0.02 to 1.90; p=0.150) and medium had 0.15 (95% CI 0.01 to 1.68; p=0.124) compared with high, on a combined risk if death, stroke and cardiac complications.	Categorical variables were analyzed by Pearson's 2 or Fisher's Exact Test. Continuous variables were analyzed by the Mann-Whitney t-test or Kruskal-Wallis test. Multivariable logistic regression, adj race, gender, comorbidities, severity of disease.

Feasby 2002	Canada	Hospitals, numbers unclear	14268 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy Canadian classification of procedures 50.12)	Low <150, high >150	Mortality and complications (in-hospital mortality or stroke)	Low-volume hospitals had higher rates of stroke and deaths. For hospitals throughout the four years the % mortality/ stroke was 3.9% for high and 5.2% for low, p<0.006. Numbers from the multivariate analysis was not reported. The effect of hospital volume was not statistically significant.	X2 analysis and unpaired t-tests to explore associations between outcomes and patient characteristics (age, gender, admission type, comorbidities) and physician variables. Logistic regression to identify predictors for the multivariate analysis, and then multivariate analysis to explore predictors of mortality and stroke. Adj for age, gender, admission type and comorbidities
Morasch 2000	USA, Florida	Hospitals, numbers unclear	45744 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	High> 100	Mortality and complications (mortality, stroke or myocardial infarction)	Compared to high volume, low volume had higher rates of complications per year, ranging from 5.6 to 9.6 over five years, p<0.001.	X2 tests for annual trends. Not further described

Pearce 1999	USA, Florida	Hospitals, range over time 156 to 165	45744 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9)	Open (Carotid endarterectomy ICD-9 code 38.12)	Unclear	Mortality and complications (in hospital death, myocardial infarction or cerebrovascular accident)	The relative reduction in risk for doubling of hospital volume was (Coefficient Relative risk) 0.93, p=0.012	Multiple logistic regression, adj for age, sex, emergency admission status, hospital characteristics, year of discharge.

Surgeon volume: mortality and complications for all patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Ruby 1996	USA, Connecticut	226 surgeons	3997 procedures	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	Four categories <1, 2 to 5, 6 to 10 and >10.	Mortality and complications (stroke and mortality)	Chi-square analysis of linear trends found that surgeons with <1 procedures were 2.5 times more likely (p<0.02) to have a serious complication than those performing >10. The complication rate for surgeon volume category was: category <1 10.1%, category 2-5 procedures had a rate of 6.2%, category of 6-10 procedures had a rate of 4.6% and the category with >10 procedures had a rate of 4.3%	Data were analysed using chi-square tests for linear trends and Odds ratios. Age, sex and hospital characteristics did not predict outcomes
Kantonen 1998	Finland	104 surgeons	1600 procedures	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (procedure codes not reported)	Unclear	Mortality and complications (30-day mortality and stroke)	An inverse association between the surgeon's carotid case load and the combined mortality and morbidity rate was found, as there was a trend towards better results after 10 carotid operations per year (p<0.005). This association was also found when surgeon's caseload was added to the multivariate analysis. Results only presented in plot, numbers not reported.	The risk factor analysis was performed by means of logistic multiple regression analysis. These risk factors included indication for carotid surgery, age and comorbidities.

Feasby 2002	Canada	367 surgeons	14268 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy Canadian classification of procedures 50.12)	1: 1-14, 2: 15-29, 3: 30-59, 4: >60	Mortality and complications (in-hospital mortality or stroke)	Low-volume surgeons had higher rates of stroke and deaths. For surgeons throughout the four years there was a % mortality/ stroke per group of: 1: 7.8%, 2: 4.8%, 3: 4.7%, and 4: 3.8%. Numbers from the multivariate analysis were not reported, but the effect of surgeon volume was "statistically significant".	X2 analysis and unpaired t-tests to explore associations between outcomes and patient characteristics (age, gender, admission type, comorbidities) and physician variables. Logistic regression to identify predictors for the multivariate analysis, and then multivariate analysis to explore predictors of mortality and stroke. Adj for age, gender, admission type and comorbidities
Pearce 1999	USA, Florida	Surgeons, range over time 647 to 829	Unclear, 45744 procedures	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9)	Open (Carotid endarterectomy ICD-9 code 38.12)	Unclear	Mortality and complications (in hospital death, myocardial infarction or cerebrovascular accident)	A doubling of surgeon volume was associated with 4% reduction in risk (Coefficient Relative risk ratio 0.96, p=0.006)	Multiple logistic regression, adj for age, sex, emergency admission status, hospital characteristics, year of discharge.
Morasch 2000	USA, Florida	Surgeons, numbers unclear	45744 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	High >30	Mortality and complications (mortality, stroke or myocardial infarction)	Compared to high volume, low volume had higher rates of complications per year, ranging from 5.7 to 9.8 over five years, p<0.001.	X2 tests for annual trends. Not further described

Hospital volume: complications for all patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Khuri 1999	USA	93 hospitals	10173 cases	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (CPT-code 4 35301)	Open (CPT-4 code 35301)	Quartiles, 1: 0 to 10, 2: 11 to 18, 3: 19 to 28, and 4: 29 to 73	Complications (30-day stroke)	Lower volume was not found to be a strong predictor of mortality (in logistic regression -0.00338 (SE 0.006), p=0.60)	A mixed effects hierarchical logistic regression analysis adj for patient risk factors.
Mayo 1998	USA, Maine	10 hospitals	341 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	Low 2-28, high 29 to 101	Complications (stroke)	Patients treated in low-volume hospitals had a stroke rate of 3.3% compared with a rate of 2.3% among high-volume hospitals. This difference was not statistically significant.	"Standard statistical procedures" were used to perform chi-square tests to assess the statistical significance of differences in proportions across volume and symptom categories.
Roddy 2000	USA, Massachusetts	20 centers	10211 procedures	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	Data is presented for four categories: two categories of high volume where one is an academic institution (volume not reported) and the other is a non-academic institution ≥50. The two remaining cate-	Complications (Stroke)	Overall % stroke for all three years per category was: Academic high 0.52% (15 strokes) non-academic high 1.41% (65 strokes), non-academic medium 1.71% (29 strokes) a non-academic low 0.23% (1 stroke). volume centers.	Analysis of variance to compare the means of all the cost and LOS data, and a $\chi 2$ test was used in comparison of incidence. Subgroup analysis was achieved with Bonferroni adjusted P values from pairwise comparisons of means (≤.05).

						gories consisted of medium 24-49 and low volume 12-23 non-academic institutions.			
Westvik 2006	USA, Connecticut	26 hospitals	14288 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 codes 433.x)	Open (Carotid endarterectomy ICD-9 code 38.12)	Low <10, medium 10 to 49, or high > 50	Complications (Cardiac complications and stroke)	Rates of cardiac complications in high was 2.3%, medium was 2.3%, and high was 4.7%, p<0.018. Results from multivariate analysis found that low and medium volume had a higher risk compared with high volume. The adj OR for in high compared to low was 0.49 (95% CI 0.20 to 1.24; p=0.134) and compared to medium 0.35 (95% CI 0.17 to 0.71; p=0.003) . Rates of stroke in high was 1.0%, medium was 1.6%, and high was 2.1%. P-value from the Chi-square test was 0.006. Results for stroke alone was not reported for the multivariate analysis.	Categorical variables were analyzed by Pearson's 2 or Fisher's Exact Test. Continuous variables were analyzed by the Mann-Whitney t-test or Kruskal-Wallis test. Multivariable logistic regression, adj race, gender, comorbidities, severity of disease.
Matsen 2006	USA, Maryland	47 hospitals	23237 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 433.00 to 433.91)	Open (Carotid endarterectomy ICD-9 code 38.12)	Low <20, moderate 21 to 100, and high >100	Complications (stroke)	During the 10-year study period, low-volume hospitals had higher rates of stroke in low volume hospitals (1.39%), those with moderate volume had (0.77%), and high-volume hospitals had 0.60% (p<0 .008). This association remained significant only for asymptomatic pa-	Logistic regression, otherwise not described. Adj for age, gender, race and symptoms

								tients p<0.030). On logistic regression, this apparent association between hospital volume and stroke rate disappeared when controlled for other covariates.	
Perler 1998	USA, Maryland	48 hospitals	9981 cases	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 433.00 with any fourth digit)	Open (Carotid endarterectomy ICD-9 code 38.12)	Low <10, medium 11 to 49 and high >50	Complications (neurologic complications)	The neurologic complication rate was higher (6.1%; p<0.001) in low-volume when compared with moderate (1.3%) and high-volume (1.8%) hospitals.	Statistical analysis was performed on discrete variables with X2 analysis, and all other data were analyzed with the Kruskal-Wallis or Mann-Whitney tests. Post-hoc comparisons were performed with Fisher's protected least significant difference, Bonferroni, and Scheffé's post hoc tests, using analysis of variance as an approximation of the Kruskal-Wallis test as a result of the large sample size.

Surgeon volume: complications for all patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Mayo 1998	USA, Maine	23 surgeons	341 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	Low <11, high 12 to 41	Complications (stroke)	Low-volume surgeons had a stroke rate of 1.7%. The stroke rate among patients of high-volume surgeons was 2.4%. This difference was not statistically significant.	"Standard statistical procedures" were used to perform chi-square tests to assess the statistical significance of differences in proportions across volume and symptom categories.
Matsen 2006	USA, Maryland	438 surgeons	23237 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 433.00 to 433.91)	Open (Carotid endarterectomy ICD-9 code 38.12)	Low <15, moderate 15 to 74 and high >75	Complications (stroke)	For all patients, low-volume surgeons had higher rates of stroke (1.01%) compared with moderate (0.68%) or high-volume surgeons (0.37%) (p<0.006). When stratified by symptomatic and asymptomatic status, this association only persisted for asymptomatic patients (p<0.006). On logistic regression, this apparent association between surgeon volume and stroke rate disappeared when controlled for race.	Logistic regression, otherwise not described. Adj for age, gender, race and symptoms

O'Neill 2000	USA, Pennsylvania	532 surgeons	14 439 procedures	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (codes not reported)	Open (ICD-9 code 38.12)	1: 1 to 2, 2: 3 to 24, 3: 25 to 49 and 4: 50 to 99, and 5: >100	Complications (morbidity- not further specified)	The lowest volume category predicted bad outcome with a regression mortality of 4.758 (SE 1.904), p<0.013	Multivariate logistic regression adjusting for patient factors including age, gender, source of admission, and comorbidities.

Surgeon volume: complications for elective patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Cowan 2002	USA	2330 surgeons	26149 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	Surgeons were categorized as low-volume surgeons (< 10 procedures, medium-volume surgeons (10 to 29), or high-volume surgeons (>30 CEAs per year)	Complications (postoperative stroke)	% postoperative stroke was 1.78 for low, 1.60 for medium and 1.02 for high, p<0.001. Not evaluated in multivariate analysis.	Mantel-Haenszel odds ratios (OR) were calculated to determine patient, surgeon, and hospital variables that predicted mortality. The multivariate model of mortality was adj for age, comorbidities, race, gender, nature of admission. Pearson's chi-square was used to determine differences in the rate of postoperative stroke and prolonged length of stay.

Surgeon volume: complications for patients undergoing emergency admissions for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Cowan 2002	USA	2330 surgeons	9672 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	Surgeons were categorized as low-volume surgeons (< 10 procedures, medium-volume surgeons (10 to 29), or high-volume surgeons (>30 CEAs per year)	Complications (postoperative stroke)	% postoperative stroke was 2.50 for low, 1.70 for medium and 1.51 for high, p<0.014. Not evaluated in multivariate analysis.	Mantel-Haenszel odds ratios (OR) were calculated to determine patient, surgeon, and hospital variables that predicted mortality. The multivariate model of mortality was adj for age, comorbidities, race, gender, nature of admission. Pearson's chi-square was used to determine differences in the rate of postoperative stroke and prolonged length of stay.

Hospital volume: complications for elective patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Holt 2007	UK (England)	Hospitals, numbers unclear	16 759 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (OPCS4 codes 163.0, 163.1, 164, 165.2, 165.3, 165.8)	Open (Carotid endarterectomy OPCS4 codes L29.4. L29.5 and L29.9)	1: 1 to 9.4, 2: 9.5 to 17.2, 3: 17.3 to 34.6, 4: 34.7 to 52.2, 5: 52.3 to 95.6	Complications (including renal, cardiac, respiratory, infection, shock, other complications (graft failure and hemorrhage, hematoma, seroma), thrombotic/embolic, Disseminated Intravascular Coagulation and transfusion	The complication rate was 6.26% in the lowest-volume quintile to 5.94% highest-volume quintile. In the multiple regression analysis, there was little or no association between the complication rate and volume for (p= 0.275). Numbers not reported.	Analysis was through evaluation of temporal trends in the data over the five-year period, with adjustment for age and gender. For the mortality rate and complication rate, multiple logistic regressions were performed. Adjusted for age and gender. For the length of stay, multiple linear regressions were performed adj for age, gender and year of procedure and the dependent variable log length of stay.

Hospital volume: complications for patients undergoing emergency admissions for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Holt 2007	UK (England)	Hospitals, numbers unclear	1489 procedures	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (OPCS4 codes 163.0, 163.1, 164, 165.2, 165.3, 165.8)	Open (Carotid endarterectomy OPCS4 codes L29.4. L29.5 and L29.9)	1: 1, 2: 1.1 to 2, 3: 2.1 to 4, 4: 4.1 to 6.4, 5: 6.5 to 15	Complications (including renal, cardiac, respiratory, infection, shock, other complications (graft failure and hemorrhage, hematoma, seroma), thrombotic/embolic, disseminated Intravascular coagulation and transfusion	The complication rate was 27.6% in the lowest-volume quintile to 24.7% highest-volume quintile. In the multiple regression analysis, there was little or no association between the complication rate and volume for (p=0.181). Numbers not reported.	Analysis was through evaluation of temporal trends in the data over the five-year period, with adjustment for age and gender. For the mortality rate and complication rate, multiple logistic regressions were performed. Adjusted for age and gender. For the length of stay, multiple linear regressions were performed adj for age, gender and year of procedure and the dependent variable log length of stay.

Hospital volume: length of stay for all patients for open surgery									
Study ID	Set-ting	Unit (sur-geon/ depart-ment/ hospital)	Patients (descrip-tion and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analy-sis
Perler 1998	USA, Mary-land	48 hos-pitals	9981 ca-ses	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 433.00 with any fourth digit)	Open (Ca-rotid endarterec-tomy ICD-9 code 38.12)	Low <10, medium 11 to 49 and high >50	Length of stay	Higher volume was associ-ated with shorter length of stay: high 4.22 days (SEM 0.06), medium 5.14 days (SEM 0.08) (p<0.0001 com-pared to high volume), low days 6.25 (SEM 0.50) (p<0.0045 compared to high volume)	Statistical analysis was performed on discrete variables with X2 analysis, and all other data were analyzed with the Kruskal-Wallis or Mann-Whitney tests. Post-hoc com-parisons were per-formed with Fisher's protected least sig-nificant difference, Bonferroni, and Scheffé's post hoc tests, using analysis of variance as an approximation of the Kruskal-Wallis test as a result of the large sample size. Transfers are addressed.

Roddy 2000	USA, Massachusetts	20 centers	10211 procedures	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	Data is presented for four categories: two categories of high volume where one is an academic institution (volume not reported) and the other is a non-academic institution ≥50. The two remaining categories consisted of medium 24-49 and low volume 12-23 non-academic institutions.	Length of stay (days in hospital and intensive care unit)	The association was uncertain. The intensive care length of stay with 1.25 in high volume, 1.38 in medium and 1.13 in low. Length of stay in hospital days were in high volume 3.74, in medium 4.25 and in low 3.89.	Analysis of variance to compare the means of all the cost and LOS data, and a $\chi 2$ test was used in comparison of incidence. Subgroup analysis was achieved with Bonferroni adjusted P values from pairwise comparisons of means (≤.05). Transfers addressed.

Surgeon volume: length of stay for all patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Boudourakis 2009	USA	16,230 surgeons	Range 6301 to 4354	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 codes not reported)	High >50, low <5	Length of stay	The mean day in year 1 for high was 2.7 and low 4.5, p<0.001. In year 2 the mean day in high was 2.3 and in low 3.9, p<0.001. Surgeon volume was associated with increased length of stay for low-volume hospitals: year one Coefficient 1.4 (95% CI 1.0 to 1.8) and year 2 Coefficient 0.9 (95% CI 0.5 to1.3)	Bivariate analyses and hierarchical generalized linear models. These analyses subsequently guided the selection of variables for adjustment in the multivariable regression models for mortality and logistic linear regression for length of stay. Adj for patient characteristics (age, gender, race, insurance, comorbidities and income. Unclear how referrals were managed.

Ruby 1996	USA, Connecticut	226 surgeons	3997 procedures	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	Four categories <1, 2 to 5, 6 to 10 and >10.	Length of stay (number more than seven days)	Patients of surgeons who performed 1 procedures were 3.54 (p<0.0001) times more likely to have prolonged stay than patients of surgeons with >10 procedures. The prolonged stay rate for surgeon volume category was: category <1 30.2%, category 2-5 procedures had a rate of 18.6%, category of 6-10 procedures had a rate of 16.8% and the category with >10 procedures had a rate of 10.9%	Data were analysed using chi-square tests for linear trends and Odds ratios. Age, sex and hospital characteristics did not predict outcomes. Only acute care hospitals, thus refferals not a problem.

Surgeon volume: length of stay for elective patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Cowan 2002	USA	2330 surgeons	26149 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	Surgeons were categorized as low-volume surgeons (< 10 procedures, medium-volume surgeons (10 to 29), or high-volume surgeons (>30 CEAs per year)	Length of stay (number more than four days)	The % prolonged length of stay was 16.8 for low, 11.8 for medium and 8.6 for high, p<0.001. Not evaluated in multivariate analysis.	Haenszel odds ratios (OR) were calculated to determine patient, surgeon, and hospital variables that predicted mortality. The multivariate model of mortality was adj for age, comorbidities, race, gender, nature of admission. Pearson's chi-square was used to determine differences in the rate of postoperative stroke and prolonged length of stay.

Glaser 2014	USA, New Jersey	Surgeons, numbers unclear	8860 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (procedure codes not reported)	1: <15, 2: 16-29, 3: 30-49, 4: >50	Length of stay	Of the total cohort of patients who had a length of stay >1 day, 47% were operated on by surgeons whose annualized volume was in the lowest quartile (<15 cases per year; p <0 .01). Conversely, 15.7% of all of the patients who had a length of stay of <1 day were operated upon by surgeons whose annualized volume was in the highest quartile (>50 cases per year; p< 0.01). The multivariate analysis found that low-volume surgeons was a statistically significant predictor of length of stay >1 day. Adj OR 3.1 (95% CI 1.9 to 5.0; p<0.01)	Univariate analysis to determine factors that were associated with a postoperative length of stay >1 day. Factors significant in multivariate analysis, hierarchical, also known as mixed-effects, were used to perform multivariable logistic regression analysis to determine factors that were independently predictive of a post-operative length of stay >1 day. Adj for age, gender, complications, comorbidities and system characteristics. Referrals are addressed.

Surgeon volume: length of stay for patients undergoing emergency admissions for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Cowan 2002	USA	2330 surgeons	9672 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	Surgeons were categorized as low-volume surgeons (< 10 procedures, medium-volume surgeons (10 to 29), or high-volume surgeons (>30 CEAs per year)	Length of stay (number more than four days)	The % prolonged hospitalisations was 56.8 for low, 48.8 for medium and 41.4 for high, p<0.001. Not evaluated in multivariate analysis.	Haenszel odds ratios (OR) were calculated to determine patient, surgeon, and hospital variables that predicted mortality. The multivariate model of mortality was adj for age, comorbidities, race, gender, nature of admission. Pearson's chi-square was used to determine differences in the rate of postoperative stroke and prolonged length of stay.

Hospital volume: costs for all patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Perler 1998	USA, Maryland	48 hospitals	9981 cases	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 433.00 with any fourth digit)	Open (Carotid endarterectomy ICD-9 code 38.12)	Low <10, medium 11 to 49 and high >50	Costs (Hospital charges)	Mean hospital charges were lower in high-volume institutions when compared with low-volume and moderate-volume hospitals. High USD 6294 (SEM 66), medium USD 7797 (SEM 97) ($p<0.0001$ versus high volume), and low USD 7824 (SEM 401) ($p<0.0004$ compared to high volume)	Statistical analysis was performed on discrete variables with X2 analysis, and all other data were analyzed with the Kruskal-Wallis or Mann-Whitney tests. Post-hoc comparisons were performed with Fisher's protected least significant difference, Bonferroni, and Scheffé's post hoc tests, using analysis of variance as an approximation of the Kruskal-Wallis test as a result

									of the large sample size.
Roddy 2000	USA, Massachusetts	20 centers	10211 procedures	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 code 38.12)	Data is presented for four categories: two categories of high volume where one is an academic institution (volume not reported) and the other is a non-academic institution ≥50. The two remaining categories consisted of medium 24-49 and low volume 12-23 non-academic institutions.	Costs (Total costs with direct medical expense)	Overall costs per category was for academic high volume USD 7882 and non-academic high volume USD6475, for non-academic medium and low USD7218 and USD6239	Analysis of variance to compare the means of all the cost and LOS data, and a χ2 test was used in comparison of incidence. Subgroup analysis was achieved with Bonferroni adjusted P values from pairwise comparisons of means (≤.05).

Hospital volume: length of stay for elective patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Glaser 2014	USA, New Jersey	Hospitals, numbers unclear	8860 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Open (Carotid endarterectomy ICD-9 codes not reported)	1: <80, 2: 8-119, 3: 120-240 and 4: >240.	Length of stay	Patients with a length of stay >1 day were more common (34% vs 14%) at centers in the lowest quartile of annual volume (<80 cases per year; P < .01).The multivariate analysis found that low-volume centers were not a statistically significant predictor. Numbers were not reported.	Univariate analysis to determine factors that were associated with a postoperative length of stay >1 day. Factors significant in multivariate analysis, hierarchical, also known as mixed-effects, were used to perform multivariable logistic regression analysis to determine factors that were independently predictive of a postoperative length of stay >1 day. Adj for age, gender, complications, comorbidities and system characteristics.

The association of volume and quality for endovascular surgery

Hospital volume: mortality for all patients for endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Shishehbor 2014	USA	366 hospitals	5240 high risk patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Endovascular (Carotid artery stenting, procedure code not reported)	Low <30, medium 30-100, high >100	Mortality (30-day mortality, stroke and myocardial infarction)	The adj OR from the hierarchical multivariable linear regression analysis was 1.01 (95% CI 0.60–1.69; p< 0.98)	Hierarchical multivariable linear regression analysis, adj for age, gender, severity of disease, comorbidities and other risk factors
Staubach 2012	Germany	Hospitals, numbers unclear	5535 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Endovascular (Carotid artery stenting, procedure code not reported)	1 to 49, 50 to 99, 100 to 199, >200	Mortality (in-hospital mortality or cerebral ischemic event)/ in-hospital mortality or stroke)	In the logistic regression analysis, higher volume was found to have lower odds of in-hospital mortality or cerebral ischemic event. Second quartile compared with 1st: OR 0.80 (95% CI 0.57–1.12, 3rd quartile compared with 1st OR 0.91 (95% CI 0.67 to 1.24), and 4th quartile compared with 1st 0.62 (95% CI 0.46 to 0.88); p< 0.05. In the logistic regression analysis, the association is uncertain for in-hospital mortality or stroke. Second quartile compared with 1st: OR 0.89 (95% CI 0.53–1.42, 3rd quartile compared with 1st OR 1.07 (95% CI 0.70 to 1.65), and 4th quartile compared with 1st 0.77 (95% CI 0.48 to 1.25); p< 0.54)	To demonstrate trends across the four groups, two-sided Cochran–Armitage test or onckheere–Terpstra test was used. Logistic regression models adj for age, gender, comorbidities, severity and other risk factors

Hospital volume: mortality for elective patients for endovascular surgery									
Study ID	Set-ting	Unit (sur-geon/ depart-ment/ hospital)	Patients (descrip-tion and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Gray 2011	USA	61 cen-ters/ hospitals	3388 pa-tients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Endovascular (Carotid artery stenting, pro-cedure code not reported)	Cohort di-vided into two groups based on the ac-ceptable 30-day mortality rate <3% and >3%.	Mortality (30-day mortality and stroke)	An inverse relationship be-tween mortality/ stroke and patient volume was found in the linear regression: (y) 4.43, 0.74*log(x), where y represents mortality/ stroke rates and x represents vol-ume in number of patients/site, with p value for slope 0.0001, and r2=0.53	For variables involving the differences be-tween the 2 groups, asymptotic 95% confi-dence intervals were calculated. Linear re-gression modeling was conducted to ana-lyze the relationship between the outcome event rate and potentially predictive varia-bles from the clinical sites. Log transfor-mation was performed on the number of subjects per site and per operator as well as on the 30-day death and stroke rates in the linear regression analyses. Unclear of adj for age, gender and comorbidities, but there does not seem to be big differences across volume categories. High has so-mewhat higher baselines risk.

Surgeon volume: mortality for patients with severe and moderate symptoms undergoing endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Calvet 2013	International study, including France, Germany and UK (England)	Surgeon, numbers unclear	1679 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Endovascular (Carotid artery stenting codes not reported)	L ow <3.2, medium 3.2 to 5.6. and high >5.6	Mortality (30-day mortality or stroke)	The 30-day risk of stroke or death was higher in patients treated by operators with low (10.1%; RR 1.99, 95% CI 1.27 to 3.10 and medium volumes (8.4%; adjusted RR 1.66, 95% CI 1.04 to 2.64 compared with patients treated by high in-trial volume operators (5.1%). The adj analysis concluded that the relative effects were even stronger in patients treated by low volume operators with adjusted RR 2.30, 95% CI 1.36 to 3.87 and medium volumes: adjusted RR 1.93, 95% CI 1.14 to 3.27 compared with patients treated by high-volume operators.	The nonparametric Mann–Whitney U test was used to compare those ratios. We performed a multivariate analysis adjusting the crude effect estimates for the following potential predictors of 30-day risk of stroke or death after stroke: age, sex, comorbidity and severity and source trial. To account for the inherent clustering within data (the same operator performs multiple procedures over time), models using the framework of multilevel modeling with random intercepts were included for individual operators.

Surgeon volume: mortality and complications for all patients undergoing endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Sgroi 2015	USA	Surgeon, numbers unclear	20663 cases	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 codes 433.10, 433.11, 433.30 and 433.31)	Endovascular (Carotid artery stenting ICD-9 code 00.63)	Estimation based on a 10-unit volume difference among centers.	Mortality (in-hospital mortality)	There was little or no difference in adj risk in-hospital mortality 1.01 (95% CI 0.96-1.05)	Continuous variables were reported as an average 6 standard deviation, and categorical variables were reported as counts and proportions. Multivariate analyses with logistic regression adj. for age, gender, ethnicity, history of stroke, and Charlson Comorbidity Index score as well as for the hospital's location (urban vs rural) and type (teaching vs non-teaching).
Shishehbor 2014	USA	Surgeons, numbers unclear	5240 high risk patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Endovascular (Carotid artery stenting, procedure code not reported)	Low <30, medium 30-100, high >100	Mortality and complications (30-day mortality, stroke and myocardial infarction)	The adj OR from the hierarchical multivariable linear regression analysis was 1.39 (95% CI 0.55–3.50; p< 0.48	Hierarchical multivariable linear regression analysis, adj for age, gender, severity of disease, comorbidities and other risk factors

Surgeon volume: mortality and complications for elective patients for endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Gray 2011	USA	77 surgeons	3388 patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Endovascular (Carotid artery stenting codes not reported)	Cohort divided into two groups based on the acceptable 30-day mortality rate <3% and >3%.	Mortality (30-day mortality and stroke)	An inverse relationship between mortality/ stroke and patient volume was found in the linear regression: log(y) 4.71- 0.85*log(x), where y represents mortality/ stroke rates and x represents volume in number of patients/operator, with p value for slope 0.0001, and r2=0.81	For variables involving the differences between the 2 groups, asymptotic 95% confidence intervals were calculated. Linear regression modeling was conducted to analyze the relationship between the outcome event rate and potentially predictive variables from the clinical sites. Log transformation was performed on the number of subjects per site and per operator as well as on the 30-day death and stroke rates in the linear regression analyses. Unclear of adj for age, gender and comorbidities, but there does not seem to be big differences across volume categories. High has somewhat higher baselines risk.
Modrall 2014	USA	Surgeon, numbers unclear	11535 procedures	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 433.00 to 433.1)	Endovascular (Carotid artery stenting ICD-9 code 00.63)	Low <5, medium 5 to 15, and high >15	Mortality and complications (in-hospital stroke or death)	The stroke/death rate decreased significantly as the number of procedures performed annually increased. The stroke/death rate for clinicians in the high volume tertile (2.27%) was nearly half of that observed in the low-volume tertile (4.43%) (p<0 .0001 in the Cochran-Armitage trend test). After adjusting for patient and hospital characteristics, volume	Categorical data analysed using X2 and Cochrane-Armitage trend test, and multiple regression analysis adj for demographics, symptomatic patients, comorbidities and hospital characteristics

								predicted stroke and death OR, 0.84; 95% CI 0.74 to 0.94; p<0.0003	

Surgeon volume: complications for all patients for endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Sgroi 2015	USA	Surgeon, numbers unclear	20663 cases	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 codes 433.10, 433.11, 433.30 and 433.31)	Endovascular (Carotid artery stenting ICD-9 code 00.63)	Estimation based on a 10-unit volume difference among centers.	Complications (myocardial infarction and stroke)	The risk of stroke was lower in high volume (OR 0.97, 95% CI 0.94 to 0.99; p<0.021), but the association as uncertain for myocardial infarction (OR 0.99, 95% CI 0.96 to 1.02)	Continuous variables were reported as an average 6 standard deviation, and categorical variables were reported as counts and proportions. Multivariate analyses with logistic regression adj. for age, gender, ethnicity, history of stroke, and Charlson Comorbidity Index score as well as for the hospital's location (urban vs rural) and type (teaching vs non-teaching).
Vogel 2009d	USA, New Jersey	Surgeon, numbers unclear	625 cases	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Endovascular (Carotid artery stenting ICD-9 code 00.63)	High >20, medium 10 to 19, and low <10	Complications (Stroke)	There was little or no difference in stroke rate. Surgeons who performed 20 to 35 procedures had a stroke rate of 1.92% compared with the 3.80% (p<0.641) stroke rate for those who performed fewer than five procedures.	Chi-square analysis with calculating odds ratio (OR) and 95% confidence interval (95% CI) for categorical variables, t test and analysis of variance (ANOVA) for continuous variables, and test for difference between two independent proportions when results were presented as percentage.

Surgeon volume: length of stay for all patients undergoing endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Sgroi 2015	USA	Surgeon, numbers unclear	20663 cases	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 codes 433.10, 433.11, 433.30 and 433.31)	Endovascular (Carotid artery stenting ICD-9 code 00.63)	Estimation based on a 10-unit volume difference among centers.	Length of stay (days)	The length of stay was associated with shorter stay in high volume (mean days difference -0.05, 95% CI -0.06 to -0.04, p<0.001)	Continuous variables were reported as an average 6 standard deviation, and categorical variables were reported as counts and proportions. Multivariate analyses with logistic regression were then performed to estimate the risk of in-hospital mortality and postoperative stroke and MI as associated with the provider performing the procedure and volume of cases, adjusting in each case for the patient's age, gender, ethnicity, history of stroke, and Charlson Comorbidity Index score as well as for the hospital's location (urban vs rural) and type (teaching vs nonteaching). Unclear if the sample was adj for referrals or if it was possible to make direct links between the individual patient and outcomes.
Vogel 2009d	USA, New Jersey	Surgeon, numbers unclear	625 cases	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Endovascular (Carotid artery stenting ICD-9 code 00.63)	High >20, medium 10 to 19, and low <10	Length of stay (Hospital days)	High-volume (mean 1.7 days (SD 1.4 days)) and medium-volume (mean 1.7 days (SD 1.2 days)), had lower length of stay than low-volume (mean 2.4 days (SD 4.1 days; p<0	Chi-square analysis with calculating odds ratio (OR) and 95% confidence interval (95% CI) for categorical variables, t test and analysis of variance (ANOVA) for continuous variables, and test for difference between two independent proportions when results were presented as percentage. Adj for patient demographics

								.0182 and p<0.0422, respectively))	(age, gender, and race), admission type, principal and secondary diagnoses, principal and secondary procedures, discharge status, physician (surgeon) identifier, number of days from admission to procedure, hospital length of stay (LOS), hospital charges and costs.

Surgeon volume: costs for all patients undergoing endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Vogel 2009d	USA, New Jersey	Surgeon, numbers unclear	625 cases	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Endovascular (Carotid artery stenting ICD-9 code 00.63)	High >20, medium 10 to 19, and low <10	Costs (Hospital resource utilization/ medical supplies)	The total hospital costs per volume category showed mixed results. High-volume specialists had higher total costs of USD 13193 (SD 9095) compared to medium USD 8442 (SD 3983; p<0.0971) but were lower than for low volume USD 19325 (SD 19,236; p<0.004). The medical supplies costs per volume category showed mixed results. High-volume specialists had higher total costs compared to medium-volume USD 4496 (SD 5692) and USD 3060 (SD 2372, respectively; p<0.31), but were lower than in low-volume USD 8800 (SD 9043; p<0.0001).	Chi-square analysis with calculating odds ratio (OR) and 95% confidence interval (95% CI) for categorical variables, t test and analysis of variance (ANOVA) for continuous variables, and test for difference between two independent proportions when results were presented as percentage.
Sgroi 2015	USA	Surgeon, numbers unclear	20663 cases	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (ICD-9 codes 433.10, 433.11, 433.30 and 433.31)	Endovascular (Carotid artery stenting ICD-9 code 00.63)	Estimation based on a 10-unit volume difference among centers.	Costs (total hospital charges)	There was little or no difference in adj mean USD 98.39 (95% CI -55.77 to 252.55)	Continuous variables were reported as an average 6 standard deviation, and categorical variables were reported as counts and proportions. Multivariate analyses with logistic regression adj. for age, gender, ethnicity, history of stroke, and Charlson Comorbidity Index score as well as for the hospital's location (urban vs rural) and type (teaching vs nonteaching).

Hospital volume: process measures for all patients for endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Shishehbor 2014	USA	366 hospitals	5240 high risk patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Endovascular (Carotid artery stenting, procedure code not reported)	Low <30, medium 30-100, high >100	Process measures (EPD dwell time technical performance)	The mean time per category was low 14.3, medium 12.5, and high 11.7, p<0.001. The coefficient from the hierarchical multivariable linear regression analysis was –0.0112 (SE 0.0342) p<0.74, and thus hospital volume was not found to predict dwell time (volume studied in hundreds)	Hierarchical multivariable linear regression analysis, adj for age, gender, severity of disease, comorbidities and other risk factors

Surgeon volume: process measures for all patients for endovascular surgery									
Study ID	Set-ting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Shishehbor 2014	USA	Surgeons, numbers unclear	5240 high risk patients	Atherosclerosis/ narrowing of the common carotid artery or internal carotid artery (specific code not reported)	Endovascular (Carotid artery stenting, procedure code not reported)	Low <30, medium 30-100, high >100	Process measures (EPD dwell time technical performance)	The mean time per category was low 14.1, medium 11.3, and high 12.4, p<0.002. The coefficient from the hierarchical multivariable linear regression analysis was –0.0148 (SE 0.0511) p<0.77, and thus surgeon volume was not found to predict dwell time (volume studied in hundreds)	Hierarchical multivariable linear regression analysis, adj for age, gender, severity of disease, comorbidities and other risk factors

Appendix 9. Results peripheral artery disease

The association of volume and quality for all surgery

Hospital volume: mortality for all patients for all procedures										
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis	Study ID
Pearce 1999	USA, Florida	Hospitals, range over time 156 to 165	Unclear, 31172 procedures	Peripherial artery disease (codes not reported. lower-extremity)		Both (ICD-9 39.9 and 39.29)	Unclear	Incidence of hospital death, myocardial infarction or cerebrovascular accident	There was no statistical significant association with volume (Coefficient Relative risk ratio 0.98, p=0.60)	Multiple logistic regression, adj for age, sex, emergency admission status, hospital characteristics, year of discharge.

Surgeon volume: mortality for all patients undergoing all surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis (statistical methods used, for example mulitple-regression, Anova analysis etc.)
Pearce 1999	USA, Florida	Surgeons, range over time 647 to 829	Unclear, 31172 procedures	Peripherial artery disease (codes not reported. lower-extremity)	Both (ICD-9 39.9 and 39.29)	Unclear	Incidence of hospital death, myocardial infarction or cerebrovascular accident	A doubling of surgeon volume was associated with 8% reduction in risk (Coefficient Relative risk ratio 0.91, p=0.0001)	Multiple logistic regression, adj for age, sex, emergency admission status, hospital characteristics, year of discharge.

The association of volume and quality for open surgery

Hospital volume: mortality for all patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Birkmeyer 2002	USA	3184 hospitals	263580 patients	Peripheral artery disease (codes not reported. lower extremity)	Open (Codes not reported.lower-extremity bypass)	1: <22, 2: 22 to 39, 3: 40 to 60, 4: 61 to 94, 5:>94	Mortality (30-day mortality)	The mortality rate by category was: low 5.8%, medium 5.5%, high 5.5% and very high 4.9%. In the multivariate analysis, higher volume was associated with lower mortality rates. Compared to lowest volume quintile, the odds for operative mortality was by quintile; 2: OR 0.94 (95% CI 0.89 to 1.00), 3: OR 0.90 (95% CI 0.85 to 0.97), 4: OR 0.94 (95%CI 0.87 to 1.01), 5 : OR 0.81 (95%CI 0.74 to 0.88).	Multiple logistic regression with adjustment for characteristics of the patients (age, gender, comorbidities, race, year fo procedure, type of admission, and mean income)
Feinglass 2009	USA, California	345 hospitals	>28000 patients	Peripheral arterial disease (no codes. aortoiliac/ femoral)	Open (ICD-9 codes 39.25 or 39.29)	Low volume < 40 patients, medium volume 40 to 60 patients, high volume 61 to 80, and very high volume >80	Mortality (30-day mortality)	Mortality varied inversely by hospital volume level. The highest volume hospitals had lower 30-day mortality (3.0%) compared with high volume (4.0%), medium (4.1%) and low volume institutions (5.1%) (p<0.001).	The significance of bivariate associations between patient demographic, clinical, and hospital-level characteristics and 30-day outcomes were analyzed with **X2** tests. Random ef-

								Compared to very high volume, the OR by volume in the logistic regression were higher for high 1.48 (95% CI 1.14 to 1.92), medium: 1.40 (95% CI 1.07 to 1.83) and low: 1.77 (95% CI 1.37 to 2.28).	fects multiple logistic regression, adj for year of operation, age, sex, race, and ethnicity, clinical characteristics (emergency admission, nursing home admission, comorbidity and type of procedure. Long-term amputation-free survival and limb salvage outcomes were estimated with the Kaplan-Meier procedure for bivariate comparisons and with Cox proportional hazards models for all variables simultaneously. Standard errors for Cox regression models were adjusted for the clustering of patients within hospitals using Huber-White sandwich estimators.
Dimick 2003	USA	483 hospitals	3073 patients	Peripheral arterial disease (no code provided. aortoiliac occlusive disease)	Open (ICD-9 code 39.25)	High >25, low <25	Mortality (in-hospital mortality)	High volume hospitals had a lower mortality rate (3.7% vs 2.2%) compared with low vol-	Univariate comparisons performed with the X2 test, Wilcoxin rank-sum test, Student t test,

								ume hospitals. In a multivariate adjusted analysis having a procedure performed at a high- volume hospital was associated with 42% decreased risk for in-hospital mortality (OR 0.58; 95% CI 0.34-0.97; p=0.04) compared with low-volume hospitals.	simple logistic regression, and simple linear regression. Multiple logistic regression of in-hospital mortality and prolonged LOS, adj for age, sex, nature of admission, and comorbidities.
Feinglass 2009	USA, California	345 hospitals	>28000 patients	Peripheral arterial disease (no codes. aortoiliac/ femoral)	Open (ICD-9 codes 39.25 or 39.29)	Low volume < 40 patients, medium volume 40 to 60 patients, high volume 61 to 80, and very high volume >80	Amputation-free survival over median 62-month follow-up	Compared to very high volume, the hazard OR by volume in the logistic regression were for higher for high volume 1.18 (95% CI 1.08 to 1.29), medium: 1.20 (95% CI 1.09 to 1.32) and low: 1.25 (95% CI 1.14 to 1.37)	**X**2 tests in bivariate analysis. Random effects multiple logistic regression, adj for year of operation, age, sex, race, and ethnicity, clinical characteristics (emergency admission, nursing home admission, comorbidity and type of procedure. Long-term amputation-free survival and limb salvage outcomes were estimated with the Kaplan-Meier procedure for bivariate comparisons and with Cox proportional hazards models for all variables simultaneously. Standard errors for

									Cox regression models were adjusted for the clustering of patients within hospitals using Huber-White sandwich estimators.
Manheim 1998	USA, California	Hospitals, numbers unclear	100963 procedures	Peripheral artery disease (codes not reported. lower extremity)	Open (codes not reported- lower-extremity bypass)	Low <20, moderate 20 to 49, and high 50 to 99, and very high >100	Mortality (in-hospital mortality)	The OR for dying in medium volume hospitals was 0.87 (p<0.001), OR in high was 0.74 (p<0.001), and very high OR 0.67 (p<0.001) compared to low volume	Multiple logistic regression,adj for age, gender, year of surgery, admission type and comorbidities

Hospital volume: mortality for patients undergoing elective admissions for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Kantonen 1998	Finland	25 hospitals	1761 procedures	Perpiheral vascular disease (codes not reported. chronic leg ischemia)	Open (No codes reported. All bypasses, patch-angioplasties and endarterectomies (femoropopliteal, femorocrural or femoropedal, aortoiliacal or artofemoral, femoror-femoral, and axillofemoral)	Low <20, high >20	Mortality (30-day mortality)	In multivariate analysis, low hospital volume was not a statistically significant predictor of mortality. Numbers not reported.	Logistic multiple regression, adj for age, sex, comorbidities, severity.

Surgeon volume: mortality for elective patients for open surgery									
Study ID	Set-ting	Unit (sur-geon/ de-partment/ hospital)	Patients (description and N)	Condition (diagno-sis)	Procedure	Vo-lume cut-off	Outcome	Results	Description of ana-lysis
Kanto-nen 1998	Fin-land	Surgeons, numbers unclear	1761 procedures	Perpiheral vascular disease (codes not reported. chronic leg ischemia)	Open (No codes reported. All bypasses, patch-angioplasties and endarterectomies (femoropopliteal, femorocrural or fem-oropedal, aortoiliacal or artofemoral, fem-oror-femoral, and axillofemoral)	Low <10, high >10	Mortality (30-day morta-lity)	In multivariate anal-ysis, low surgeon volume was not a statistically signifi-cant predictor of mortality. Numbers not reported.	Logistic multiple regression, adj for age, sex, comorbid-ities, severity.

Hospital volume: complications for all patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Feinglass 2009	USA, California	345 hospitals	>28000 patients	Peripheral arterial disease (no codes. aortoiliac/ femoral)	Open (ICD-9 codes 39.25 or 39.29)	Low volume < 40 patients, medium volume 40 to 60 patients, high volume 61 to 80, and very high volume >80	Complications (30-day major amputation/ inpatient MI or stroke)	Amputation varied inversely by hospital volume level. The highest volume hospitals had lower 30-day amputations (1.8%) compared with high volume (2.3%), medium volume (3.0%) and low volume (3.0%) (Confidence intervals or p-value not reported). There was little or no difference in stroke and myocardial infarction by hospital volume level. The highest volume hospitals had 2.4% compared with high volume 2.5%, medium volume 2.3% and low volume 1.9% (confidence intervals or p-value not reported).	X2 tests in bivariate analysis. Random effects multiple logistic regression, adj for year of operation, age, sex, race, and ethnicity, clinical characteristics (emergency admission, nursing home admission, comorbidity and type of procedure. Long-term amputation-free survival and limb salvage outcomes were estimated with the Kaplan-Meier procedure for bivariate comparisons and with Cox proportional hazards models for all variables simultaneously. Standard errors for Cox regression models

									were adjusted for the cluster-ing of patients within hospitals using Huber-White sandwich estimators.

Hospital volume: complications for elective patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Kantonen 1998	Finland	25 hospitals	1761 procedures	Perpiheral vascular disease (codes not reported. chronic leg ischemia)	Open (No codes reported. All bypasses, patch-angioplasties and endarterectomies (femoropopliteal, femorocrural or femoropedal, aortoiliacal or artofemoral, femoror-femoral, and axillofemoral)	Low <20, high >20	Complications (30-day leg amputation rate)	In multivariate analysis, low hospital volume higher odds for amputation rates than high volume. low volume hospitals had higher rates of amputations than high volume hospitals: OR 1.49 (95% CI 1.00 to 2.25, p< 0.05)	Logistic multiple regression, adj for age, sex, comorbidities, severity.

Surgeon volume: complications for elective patients for open surgery									
Study ID	Set-ting	Unit (sur-geon/ de-partment/ hospital)	Patients (descrip-tion and N)	Condition (diagnosis)	Procedure	Vo-lume cut-off	Outcome	Results	Description of analysis
Kanto-nen 1998	Fin-land	Surgeons, numbers unclear	1761 procedures	Perpiheral vascu-lar disease (codes not reported. chronic leg ische-mia)	Open (No codes reported. All bypasses, patch-angioplasties and endarterecto-mies (femoropopliteal, femorocrural or femoropedal, aortoiliacal or artofemo-ral, femoror-femoral, and axillofemoral)	Low <10, high >10	Complica-tions (30-day leg am-putation rate)	In multivariate analysis, low volume surgeons had higher rates of amputations than high volume OR 1.80 (95% CI 1.15 to 2.80, p<0.01)	Logistic multiple regression, adj for age, sex, comor-bidities, severity.

Hospital volume: length of stay for all patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Dimick 2003	USA	483 hospitals	3073 patients	Peripheral arterial disease (no code provided. aortoiliac occlusive disease)	Open (ICD-9 code 39.25)	High >25, low <25	Length of stay	There was little or no difference in proportion of patients with prolonged length of stay at high-volume hospitals (24%) versus low-volume hospitals (25%) (p=0.30). In the multivariate analysis, volume was not found to be a statistically significant predictor of length of stay, however numbers were not reported.	Univariate comparisons performed with the X2 test, Wilcoxin rank-sum test,Student t test, simple logistic regression, and simple linear regression, where appropriate. Multiple logistic regression of in-hospital mortality andprolonged LOS, adj for age, sex, nature of admission, and comorbidities. Not adj for referrals but ok since they evaluate prolonged LOS.

The association of volume and quality for endovascular surgery

Hospital volume: mortality for all patients for endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Arora 2015	USA	Hospitals, numbers unclear	92714 patients	Peripherial artery disease (codes not reported. lower-extremity)	Endovascular (ICD-9 codes 17.56, 39.90, 39.50)	1: <36, 2: 37 to 68, 3: 69 to 126, 4: >126	Mortality (in-hospital mortality)	Rate of in-hospital mortality was lower in high volume hospitals: 1: 1.67%, 2: 1.33%, 3: 1.11%, 4: 0.88% (p <0.001). In the multivariate analysis, volume was a predictor of in-hospital mortality. Compared with the 1st quartile, the OR for the 2nd quartile was 0.86 (0.71 to 1.05; p=0.133), 3rd quartile: OR 0.79 (0.66 to 0.95; p<0.013), and 4th quartile: OR 0.65 (95% CI 0.52 to 0.82, p <0.001).	Hierarchical mixed-effects logistic regression models were used for categorical-dependent variables such as primary and secondary outcomes, and hierarchical mixed-effects linear regression models were used for continuous-dependent variable such as cost of care. Adj for hospital characteristics, age, gender, comorbidities, admission over the weekend, primary payer (with Medicare or Medicaid), admission type (elective admission as referent).

Surgeon volume: mortality for all patients for endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis (statistical methods used, for example mulitple-regression, Anova analysis etc.)
Indes 2011	USA	Surgeons, numbers unclear	818 patients	Peripherial artery disease (codes not reported. lower-extremity)	Endovascular (ICD-9 codes 39.50 and 39.90)	Low <17, high >17	Mortality (in-hospital mortality)	There was no statistical significant differnence by volume in in-hospital mortality (p=0.35). Numbers not reported. In the multivariate analysis, the authors report that there were no statistical significant difference by volume in in-hospital mortality. Numbers not reported.	Bivariate analysis of independent variables by using X2 statistical analysis for categorical variables and analysis of variance for continuous variables. Multivariate linear regression models were used to adjust for significant independent variables for LOS and total inpatient costs. Multivariate logistic regression models were used to adjust for in-hospital patient complications and in-hospital patient mortality. Adj for sex, race, admission type.

Hospital volume: complications for all patients for endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Arora 2015	USA	Hospitals, numbers unclear	92714 patients	Peripherial artery disease (codes not reported. lower-extremity)	Endovascular (ICD-9 codes 17.56, 39.90, 39.50)	1: <36, 2: 37 to 68, 3: 69 to 126, 4: >126	Complications (any/ amputations)	Rate of any complication was lower in high volume hospitals: 1: 15.66%, 2: 15.29%, 3: 13.53%, 4: 13.36% (p<0.001). With the exception of rupture of artery and post-operative stroke, there were also lower rates for specific complications in high-volume institutions for compartment syndrome, arteriovenous fistula, rupture of artery, atheroembolism of lower extremity, injury to blood vessels of lower extremity, vascular complications requiring surgery, post-op hemorrhage requiring transfusion, accidental puncture, vascular device, implant, and graft complications, other nonspecific peripheral vascular complications, latrogenic cardiac complications, respiratory complications, renal and metabolic complications, postoperative DVT/PE and postop infectious complications. In the multivariate analysis, volume was an independent predictor of complications. Compared with the 1st quartile, the OR for the 2nd quartile was 0.96 (0.89 to 1.04; p=0.34), 3rd quartile: OR 0.88 (0.79 to 0.97; p<0.011), and 4th quartile: OR 0.85 (95% CI 0.73 to 0.97, p <0.022). An increasing hospital volume quartile was independently predictive of lower amputation rates (0.52, 0.45 to 0.61, p<0.001).	Hierarchical mixed-effects logistic regression models were used for categorical-dependent variables such as primary and secondary outcomes, and hierarchical mixed-effects linear regression models were used for continuous-dependent variable such as cost of care. Adj for hospital characteristics, age, gender, comorbidities, admission over the weekend, primary payer (with Medicare or Medicaid), admission type (elective admission as referent).

Indes 2011	USA	Hospitals, numbers unclear	818 patients	Peripherial artery disease (codes not reported. lower-extremity)	Endovascular (ICD-9 codes 39.50 and 39.90)	Low <116, high >116	Complications (cardiovascular, vascular, bleeding, or embolic; respiratory or infection; and other (including incisional, neurological, and urology related). Acute posthemorrhagic anemia (ICD-9 code 285.1) was included as a complication only if a concurrent diagnosis of transfusion (ICD-9 codes 99.00, 99.01, 99.02, or 99.03) was present)	In the bivariate analysis, the rate of complications based on hospital volume was 17.4% vs 13.9% for low-volume vs high-volume hospitals; p=0.16). Variable not entered in the multivariate analysis.	Bivariate analysis of independent variables by using X2 statistical analysis for categorical variables and analysis of variance for continuous variables. Multivariate linear regression models were used to adjust for significant independent variables for LOS and total inpatient costs. Multivariate logistic regression models were used to adjust for inhospital patient complications and in-hospital patient mortality. Adj for sex, race, admission type.

Surgeon volume: complications for all patients for endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis (statistical methods used, for example mulitple-regression, Anova analysis etc.)
Indes 2011	USA	Surgeons, numbers unclear	818 patients	Peripherial artery disease (codes not reported. lower-extremity)	Endovascular (ICD-9 codes 39.50 and 39.90)	Low <17, high >17	Complications (cardiovascular, vascular, bleeding, or embolic; respiratory or infection; and other (including incisional, neurological, and urology related). Acute posthemorrhagic anemia (ICD-9 code 285.1) was included as a complication only if a concurrent diagnosis of transfusion (ICD-9 codes 99.00, 99.01, 99.02, or 99.03) was present)	In the bivariate analysis, high-volume physicians had fewer complications when compared with low-volume physicians (12.6% vs 18.7%; p=0.02). In the multivariate analysis, high volume physicians were associated with significantly lower complication rates. Numbers not reported.	Bivariate analysis of independent variables by using X2 statistical analysis for categorical variables and analysis of variance for continuous variables. Multivariate linear regression models were used to adjust for significant independent variables for LOS and total inpatient costs. Multivariate logistic regression models were used to adjust for inhospital patient complications and in-hospital patient mortality. Adj for sex, race, admission type.

Hospital volume: length of stay for all patients for endovascular surgery									
Study ID	Set-ting	Unit (sur-geon/ de-partment/ hospital)	Patients (description and N)	Condition (diagno-sis)	Procedure	Volume cut-off	Out-come	Results	Description of analysis
Indes 2011	USA	Hospitals, numbers un-clear	818 patients	Peripherial artery disease (codes not reported. lower-ex-tremity)	Endovascular (ICD-9 codes 39.50 and 39.90)	Low <116, high >116	Length of stay	In the bivariate analysis, high-volume hospitals had shorter length of stay than low-volume hospitals (2.8 vs 3.3 days; p=0.001). High-volume hospitals were associated with a shorter length of stay in the multivariate analysis. Numbers not reported.	Bivariate analysis of inde-pendent variables by using X2 statis-tical analysis for categorical variables and analysis of variance for continuous variables. Mul-tivariate linear regression models were used to ad-just for significant inde-pendent variables for LOS and total inpatient costs. Multivariate logistic re-gression models were used to adjust for inhospi-tal patient complica-tions and in-hospital patient mortality. Adj for sex, race, ad-mission type. Length of stay was evaluted associ-aced with one admission at one hospital.

Surgeon volume: length of stay for all patients for endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis (statistical methods used, for example mulitple-regression, Anova analysis etc.)
Indes 2011	USA	Surgeons, numbers unclear	818 patients	Peripherial artery disease (codes not reported. lower-extremity)	Endovascular (ICD-9 codes 39.50 and 39.90)	Low <17, high >17	Length of stay	In the bivariate analysis, high-volume physicians had lower length of stay compared with low volume colleagues (2.8 vs 3.3 days; p=0.001).	Bivariate analysis of independent variables by using X2 statistical analysis for categorical variables and analysis of variance for continuous variables. Multivariate linear regression models were used to adjust for significant independent variables for LOS and total inpatient costs. Multivariate logistic regression models were used to adjust for inhospital patient complications and in-hospital patient mortality. Adj for sex, race, admission type. Length of stay was evaluted associaced with one admission at one hospital.

Surgeon volume: costs for all patients for endovascular surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis (statistical methods used, for example mulitple-regression, Anova analysis etc.)
Indes 2011	USA	Surgeons, numbers unclear	818 patients	Peripherial artery disease (codes not reported. lower-extremity)	Endovascular (ICD-9 codes 39.50 and 39.90)	Low <17, high >17	Costs	In the multivariate analysis, there were no statistically significant difference in volume on costs. Numbers not reported.	Bivariate analysis of independent variables by using X2 statistical analysis for categorical variables and analysis of variance for continuous variables. Multivariate linear regression models were used to adjust for significant independent variables for LOS and total inpatient costs. Multivariate logistic regression models were used to adjust for inhospital patient complications and in-hospital patient mortality. Adj for sex, race, admission type. Length of stay was evaluted associaced with one admission at one hospital.

Surgeon volume: costs for elective patients for endovascular surgery										
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis	Study ID
Vogel 2009	USA, New Jersey	383 surgeons	2837 procedures	Perpiheral vascular disease (ICD-codes 440.2x atherosclerosis in native arteries of the extremities)	Patients <18 years, and patients with acute admissions, and cases with ssociated renal, mesenteric, and cerebral disease diagnoses	Endovascular (ICD-9 codes 39.50 and 39.90)	Unclear	Costs	Low volume surgeons were found to have higher charges than high volume (USD 51,014 vs USD 41,730; p<0 .0001)	To test the difference between groups, X2 analysis was used for categorical variables, Student's t test and SAS PROC GLM (general linear model) procedure (for two-way unbalanced design) for continuous variables.

Appendix 10. Results tables renal artery disease

Hospital volume: mortality for all patients for open surgery									
Study ID	Setting	Unit (surgeon/ department/ hospital)	Patients (description and N)	Condition (diagnosis)	Procedure	Volume cut-off	Outcome	Results	Description of analysis
Modrall 2009	USA	>1000 hospitals	7413 patients	Perpiheral vascular disease (renal artery occlusive disease ICD-9 440.1 and 447.3)	Open (ICD-9 codes 39.24 and 39.26)	Low <2, medium 2 to 5, high >5	Mortality (In-hospital mortality)	In the risk adjusted analysis, high volume hospitals had a lower risk of mortality (OR; 0.98; CI 0.96 to 0.99; p=0.015).	Multivariate logistic regression, adj for age, gender, comorbidities, /severity of disease)

Appendix 11. Overview volume thresholds in included studies

Abdominal aortic aneurysms: thresholds hospital volume for elective admissions open surgery

Study	Setting	1	2	3	4	5	6
Brooke 2008	USA (California)	<50	>50				
Kantonen 1997	Finland	<14	>15				
Dimick 2002b	USA	<30	>30				
Dimick 2003	USA	<35	>35				
Dua 2014	USA	<5	>5				
Illonzo 2014	USA	<3	3 to 7	>8			
Dardik 1998	USA (Maryland)	<50	50 to 99	>100			
McPhee 2011	USA	<7	7 to 30	>30			
Manheim 1998	USA (California)	<20	20 to 49	>50			
Amundsen 1990	Norway	<9	10 to 29	30 to 39	>40		
Khuri 1999	USA	<3	4 to 6	7 to 10	>11		
Wen 1996	Canada (Ontario)	<10	10 to 20	21 to 40	>40		
Holt 2007	UK	<7.2	7.3 to 12.6	12.7 to 19.4	19.5 to 32	>32	
Landon 2010	USA	<9	10 to 17	18 to 29	30 to 49	>50	
Eckstein 2007	Germany	<9	10 to 19	20 to 29	30 to 39	40 to 49	>50

*Volume not reported in four studies

Abdominal aortic aneurysms: thresholds hospital volume for acute admissions open surgery

Study	Setting	1	2	3	4	5
Dua 2014	USA	<10	>10			
Kantonen 1997	Finland	<10	>10			
Cowan 2003	USA	<4	5 to 15	>16		
Dardik 1998	USA (Maryland)	<10	10 to 19	>20		
Manheim 1998	USA (California)	<20	20 to 49	>50		
McPhee 2009	USA	<13	13 to 29	>29		
Amundsen 1990	Norway	<9	10 to 29	30 to 39	>40	

Wen 1996	Canada (Ontario)	<2	2 to 4	4 to 8	>8	
Holt 2007	UK	<7.2	7.3 to 12.6	12.7 to 19.4	19.5 to 32	>32
Holt 2007	UK	<2	2.1 to 4.2	4.3 to 6.6	6.7 to 12.2	>12.2

*Volume not reported in two studies

Abdominal aortic aneurysms: thresholds hospital volume for elective admissions endovascular surgery

Study	Setting	1	2	3	4	5
Brooke 2008	USA (California)	<50	>50			
Dua 2014	USA	<8	>8			
Illonzo 2014	USA	<4	5 to 17	>18		
McPhee 2011	USA	<15	16 to 70	>70		
Landon 2010	USA	<9	10 to 17	18 to 29	30 to 49	>50

Abdominal aortic aneurysms: thresholds hospital volume for acute admissions endovascular surgery

Study	Setting	1	2	3
Dua 2014	USA	<8	>8	
McPhee 2009	USA	<19	19 to 40	>40

Abdominal aortic aneurysms: thresholds surgeon volume for elective admissions open surgery

Study	Setting	1	2	3	4
Dimick 2003	USA	<10	>10		
McPhee 2011	USA	<2	3 to 9	>9	
Tu 2001	Canada, Ontario	<5	5 to 13	>13	
Huber 2001	USA	<3	4 to 6	7 to 10	>11

*Volume not reported in two studies

Abdominal aortic aneurysms: thresholds surgeon volume for acute admissions open surgery

Study	Setting	1	2	3
Modrall 2011	USA	<1	>12	
Dardik 1998	USA, Maryland	<4	5 to 9	>10

*Volume not reported in two studies

Abdominal aortic aneurysms: thresholds surgeon volume for elective admissions endovascular surgery				
Study	**Setting**	**1**	**2**	**3**
McPhee 2011	USA	<4	4 to 24	>24

Thoracic and abdominal aortic aneurysms: thresholds hospital volume for elective admissions open surgery					
Study	**Setting**	**1**	**2**	**3**	**4**
Cowan 2003a	USA	<3	2 to 9	5 to 31	
Schermer-horn 2008	USA	<1	2 to 3	3 to 25	
Christian 2003	USA	<15	15-29	30- 44	>45

Thoracic and abdominal aortic aneurysms: thresholds hospital volume for acute admissions open surgery				
Study	**Setting**	**1**	**2**	**3**
Cowan 2003b	USA	<3	2 to 6	>6
Schermerhorn 2008	USA	<1	2 to 3	>3

Thoracic and abdominal aortic aneurysms: thresholds surgeon volume for elective admissions open surgery			
Study	**Setting**	**1**	**2**
Cowan 2003a	USA	<2	>3

Thoracic and abdominal aortic aneurysms: thresholds surgeon volume for elective admissions endovascular surgery				
Study	**Setting**	**1**	**2**	**3**
Modrall 2014	USA	<5	5 to 16	>16

Carotid artery disease: thresholds hospital volume for elective admissions for open surgery						
Study	**Setting**	**1**	**2**	**3**	**4**	**5**
Cowan 2002	USA	<100	>100			
Hannan 1998	USA, New York	<100	>100			
Middleton 2002	USA, New South Wales	<20	>20			
Reames 2014	USA	<32	>100			

Nazarian 2008	USA, Maryland	<130	>130			
Wennberg 1998	USA	<6	7 to 21	>21		
Roddy 2000	USA, Massachusetts	12 to 23	24 to 49	>50		
Westvik 2006	USA, Connecticut	<10	10 to 49	> 50		
Perler 1998	USA, Maryland	<10	11 to 49	> 50		
Matsen 2006	USA, Maryland	<20	21 to 100	>100		
Khuri 1999	USA	<10	11 to 18	19 to 28	>29	
Manheim 1998	USA, California	<20	20 to 49	50 to 99	>100	
Birkmeyer 2002	USA	<40	40 to 69	70 to 109	110 to 164	>164
*Volume not reported in two studies						

Carotid artery disease: thresholds hospital volume for all admissions for endovascular surgery					
Study	**Setting**	**1**	**2**	**3**	**4**
Shishehbor 2014	USA	<30	30-100	>100	
Staubach 2012	Germany	<49	50 to 99	100 to 199	>200

Carotid artery disease: thresholds surgeon volume for all admissions for open surgery							
Study	**Setting**	**1**	**2**	**3**	**4**	**5**	**6**
Boudourakis 2009	USA	<5	>50				
Hannan 1998	USA (New York)	<5	>5				
Birkmeyer 2003	USA	<18	18 to 40	>40			
Cowan 2002	USA	<10	10 to 29	>30			
Matsen 2006	USA (Maryland)	<15	15 to 74	>75			
Middleton 2002	USA (New South Wales)	<12	12 to 30	>30			

Nazarian 2008	USA (Mary-land)	<3	4 to 15	>15			
Kumam-aru 2015	USA	<9	10 to 19	20 to 39	≥40		
O'Neill 2000	USA, Pennsyl-vania	<2	3 to 24	25 to 49	50 to 99	>100	
Huber 2001	USA	<3	4 to 7	8 to 12	13 to 24	25 to 42	>43

Carotid artery disease: thresholds surgeon volume for all admissions for endo-vascular surgery				
Study	**Setting**	**1**	**2**	**3**
Sgroi 2015	USA	<10	>10	
Shishehbor 2014	USA	<30	30 to 100	>100

Peripheral artery disease: thresholds hospital volume for all admissions for open surgery						
Study	**Setting**	**1**	**2**	**3**	**4**	**5**
Feinglass 2009	USA, Cali-fornia	< 40	40 to 60	61 to 80	>80	
Dimick 2003	USA	<25	>25			
Feinglass 2009	USA, Cali-fornia	<40	40 to 60	61 to 80	>80	
Manheim 1998	USA, Cali-fornia	<20	20 to 49	50 to 99	>100	
Birkmeyer 2002	USA	<22	22 to 39	40 to 60	61 to 94	>94

Peripheral artery disease: thresholds hospital volume for all admissions for endovascular surgery					
Study	**Setting**	**1**	**2**	**3**	**4**
Arora 2015	USA	<36	37 to 68	69 to 126	>126

Peripheral artery disease: thresholds surgeon volume for all admissions for endovascular surgery			
Study	**Setting**	**1**	**2**
Indes 2011	USA	<17	>17

Renal artery disease: thresholds hospital volume for all admissions for open surgery				
Study	**Setting**	**1**	**2**	**3**
Modrall 2009	USA	Low <2	2 to 5	>5

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March 2017
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