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Association between operation volume and postoperative mortality in the elective open repair of infrarenal abdominal aortic aneurysms: systematic review

Background and aim

Current national and international guidelines recommend elective repair of infrarenal abdominal aortic aneurysms (AAA) for prevention of rupture and embolism depending on the maximum transverse diameter of the aneurysm and on the physical status and comorbidities of the patient [1, 2]. Repair can be done as an open (OR) or an endovascular (EVAR) approach. The overall number of elective AAA operations in Germany in 2017 was 67,741, with 27,102 (40.0%) as OR and 40,639 (60.0%) as EVAR [3]. Depending on data sources and denominator (in-hospital vs. 60-day mortality), perioperative mortality is estimated at 3.9–5.1% for OR and 0.9–2.8% for EVAR [3, 4].

While in the early years after OR and EVAR had been established most operations were done in high-volume institutions with regard to the specific intervention, relating to both the individual department and the individual surgeon, this has changed over time with increasing adoption of the techniques into clinical routine. Nowadays, OR and EVAR are also carried out in institutions with low operation-specific case volumes. According to the AAA register of the German Institute for Vascular Health Research (DIGG) of the Germany Society of Vascular Surgery (DGG), 60% of hospitals offering OR perform less than five operations annually. Likewise, 20% of hospitals offering EVAR have a volume of less than 20 elective cases per year [4]. Even though large centers with a high volume are probably underrepresented in the register, which thus overestimates the proportion of hospitals with a low annual case volume, it becomes apparent that a relevant number of German hospitals have a low volume for OR of infrarenal AAA. For numerous operations, there is evidence showing an inverse association between case numbers, related to both the hospital and individual surgeon and perioperative mortality [5, 6]. In some healthcare systems this has led to the definition of a minimum volume per hospital and surgeon for certain volume-critical interventions, below which these can no longer be performed or are not reimbursed by the healthcare system [7]. Elective infrarenal AAA repair has been evaluated in numerous studies regarding a possible association between case volume and postoperative outcomes.

This systematic review aims at synthesizing all available data on the association between case volume per hospital and surgeon and postoperative mortality for the elective repair of infrarenal AAA. The present first part of this review covers OR.

Study design and methods

In order to show a possible association between case volume per hospital and surgeon and outcome quality, defined as postoperative mortality, in elective OR of infrarenal AAA, a systematic literature review was carried out. This review used a defined search strategy (see ◘ Table 1) in the databases PubMed, Cochrane Library, Web of Science Core Collection, CINAHL, Current Contents Medicine (CCMed) and ClinicalTrials.gov covering the period from database inception to 17 January 2018. Results were saved in the referencing software Endnote and deduplicated using the Wichor-Bramer

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Table 1 Search strategy for literature search used in the database PubMed and in adapted form in the databases Cochrane Library, Web of Science Core Collection, CINAHL, Current Contents Medicine (CCMed) and ClinicalTrials.gov

Search strategy	Search terms
1. P 2. I 3. X 4. O 5. 1 AND 2 AND 3 AND 4	**P** **″Aortic Aneurysm, Abdominal″ [Mesh] OR** infrarenal Aortic Aneurysm*[tw] OR Abdominal Aortic Aneurysm*[tw]
	I **″General Surgery″ [Mesh] OR** **″Surgical Procedures, Operative″ [Mesh] OR** surgery[tw] OR surgical[tw] OR operative[tw] OR repair[tw] OR EVAR[tw]
	X volume[tw] OR patient number*[tw] OR ″patient data″[tw] OR patient size*[tw] OR ″Inpatient Sample″[tw] OR ″patient Sample″[tw] OR caseload*[tw]
	O outcome*[tw] OR mortality[tw] OR morbidity[tw] OR complication*[tw] OR surviv*[tw]

method [8]. To this end, year, title, volume, and issue were used. PubMed hits were preferred during deduplication. In the case of duplicates, entries from other databases were omitted.

Abstracts and, if not sufficient for a definite assessment, full texts were assessed by two independent reviewers (U.R., M.A.) regarding inclusion criteria. All studies comparing elective OR of an infrarenal AAA in a high volume center with repair in a low volume center, or by a high volume surgeon with repair by a low volume surgeon, were included. For inclusion, at least one of the outcomes overall postoperative mortality, hospital mortality, or 100-day mortality, or a combined endpoint, needed to be reported. Regarding the definition of high volume and low volume centers and study design, there were no exclusion criteria. If both reviewers agreed, the respective study was included or excluded. In the case of divergent votes, consensus between both reviewers was sought by jointly discussing the full text of the respective publication.

From full texts, both reviewers independently extracted the following data and saved them in a database: author, place where the study was conducted, year of publication, number of patients, number of high volume patients, number of low volume patients, age (mean) in the overall study population, age (mean) in the high volume group, age (mean) in the low volume group, number of men in the high volume group, number of men in the low volume group, case number defining high volume versus low volume, mortality in the high volume group, mortality in the low volume group, mortality indicator used (overall postoperative mortality, hospital mortality, or 100-day mortality), odds ratio and 95% confidence interval for the comparison of mortality in the high volume vs. low volume groups, analysis mode (univariable vs. multivariable). If studies assessed the association between case volume and postoperative mortality both for hospital and surgeon volumes, data for both comparisons were extracted separately. The definition of high volume and low volume was used as defined in the respective study. If a study compared several groups with different case volumes, such as quartiles, the comparison of the group with the highest and the group with the lowest volume was used. The association between volume and mortality was described with the effect measure reported in the respective publication (usually the odds ratio). For better comparability of the results of the single studies, the effect measures and corresponding 95% confidence intervals were transformed so that values <1 reflected a lower mortality in the high volume group.

Results were displayed descriptively. Given the heterogeneity of data and the diverging definition of high volume and low volume centers, a meta-analysis for quantifying a possible association between volume and mortality was not done.

Results

The search strategy and deduplication yielded 1021 hits, of which 43 studies met the inclusion criteria for hospital volume and 17 those for surgeon volume.

Characteristics and results of the included studies on hospital volume are displayed in **Table 2**. They included patients between 1980 and 2013 and were published between 1992 and 2017. Of the 43 studies, 30 were conducted in the USA, the remainder in Canada and several European countries. Four studies were done in Germany. One study, which reported results only stratified by perioperative risk and not for the overall study population, was considered as two separate studies in the analysis [9]. Given the specific study question, all studies had a retrospective design. The total number of patients included in the 26 studies reporting group-specific case numbers was 166,812 in the high volume and 120,725 in the low volume groups. A total of 18 studies did not report group-specific case numbers. Study populations were predominantly male with a mean or median age between 64.2 and 75 years. The threshold used for defining low volume (either the value defining the group with the lowest volume if several groups were compared or the value above which the group was considered high volume

Abstract · Zusammenfassung

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U. Ronellenfitsch · K. Meisenbacher · M. Ante · M. Grilli · D. Böckler

Association between operation volume and postoperative mortality in the elective open repair of infrarenal abdominal aortic aneurysms: systematic review

Abstract

Background. An inverse association between the case volume per hospital and surgeon and perioperative mortality has been shown for many surgical interventions. There are numerous studies on this issue for the open treatment of infrarenal aortic aneurysms.
Aim. To present the available data on the association between the case volume per hospital and surgeon and perioperative mortality in the elective open repair of infrarenal aortic aneurysms in a systematic review.
Materials and methods. Using the PubMed, Cochrane Library, Web of Science Core Collection, CINAHL, Current Contents Medicine (CCMed), and ClinicalTrials.gov databases, a systematic search was performed using defined keywords. From the search results, all original papers were included that compared the elective open repair of an infrarenal aortic aneurysm in a "high volume" center with a "low volume" center or by a "high volume" surgeon with a "low volume" surgeon, as defined in the respective study.
Results. After deduplication, the literature search yielded 1021 hits of which 60 publications met the inclusion criteria. Of these, 37/43 studies showed a lower mortality in "high volume" compared to "low volume" centers and 14/17 comparisons showed a lower mortality for "high volume" compared to "low volume" surgeons. The effect measures, usually odds ratios, ranged from 0.37 to 0.99 for volume per hospital and 0.31 to 0.92 for volume per surgeon. Regarding the threshold values for the definition of "high volume" and "low volume," a clear heterogeneity was shown between the individual studies.
Discussion. The available data on the association between the case volume per hospital and surgeon and perioperative mortality in the elective open repair of infrarenal aortic aneurysms show that interventions performed in "high volume" centers or by "high volume" surgeons are associated with lower mortality. To ensure the best possible outcome in terms of low perioperative mortality in the open repair of infrarenal aortic aneurysms, the aim should be centralization with high case volume per hospital and surgeon.

Keywords

Infrarenal aortic aneurysm · Open repair · Case volume · Postoperative mortality · Systematic review

Assoziation zwischen Operationsvolumen und postoperativer Mortalität bei der elektiven offenen Versorgung infrarenaler abdomineller Aortenaneurysmen: systematische Übersichtsarbeit. English version

Zusammenfassung

Hintergrund. Für viele chirurgische Eingriffe konnte eine inverse Assoziation zwischen Fallzahl pro Krankenhaus und Operateur und perioperativer Mortalität gezeigt werden. Auch für die offene Versorgung infrarenaler Aortenaneurysmen gibt es eine größere Anzahl von Studien zu dieser Fragestellung.
Ziel der Arbeit. In einer systematischen Übersichtsarbeit soll die verfügbare Datenlage zur Assoziation zwischen Fallzahl pro Krankenhaus und Operateur und perioperativer Mortalität bei der elektiven offenen Versorgung infrarenaler Aortenaneurysmen dargestellt werden.
Material und Methoden. In den Datenbanken PubMed, Cochrane Library, Web of Science Core Collection, CINAHL, Current Contents Medizin (CCMed) und ClinicalTrials.gov wurde eine systematische Recherche mittels definierter Schlüsselwörter durchgeführt. Aus den Treffern wurden alle Originalarbeiten eingeschlossen, die die elektive offene Versorgung eines infrarenalen Aortenaneurysmas in einem „high volume"-Zentrum mit einem „low volume"-Zentrum oder durch einen „high volume"-Chirurgen mit einem „low volume"-Chirurgen, wie in der jeweiligen Studie definiert, verglichen.
Ergebnisse. Nach Deduplizierung erbrachte die Literatursuche 1021 Treffer. Von diesen erfüllten 60 Publikationen die Einschlusskriterien. Dabei zeigten 37/43 Studien eine niedrigere Mortalität in „high-volume"- verglichen mit „low-volume"-Zentren und 14/17 Vergleichen eine niedrigere Mortalität für „high volume"- verglichen mit „low volume"-Chirurgen. Die Effektmaße, in aller Regel Odds Ratios, lagen zwischen 0,37 und 0,99 für Fallzahl pro Krankenhaus und 0,31 und 0,92 für Fallzahl pro Chirurg. Hinsichtlich der Schwellenwerte zur Definition von „high volume" und „low volume" zeigte sich eine deutliche Heterogenität zwischen den einzelnen Studien.
Diskussion. Die verfügbare Datenlage zur Assoziation zwischen Fallzahl pro Krankenhaus und Operateur und perioperativer Mortalität bei der elektiven offenen Versorgung infrarenaler Aortenaneurysmen zeigt übereinstimmend, dass in „high volume"-Zentren bzw. von „high volume"-Chirurgen durchgeführte Eingriffe mit einer niedrigeren Mortalität assoziiert sind. Um ein möglichst gutes Outcome im Sinne einer niedrigen perioperativen Mortalität bei der offenen Versorgung infrarenaler Aortenaneurysmen zu gewährleisten, sollte eine Zentralisierung mit hohen Fallzahlen pro Krankenhaus und Chirurg angestrebt werden.

Schlüsselwörter

Infrarenales Aortenaneurysma · Offene Versorgung · Operationsvolumen · Postoperative Mortalität · Systematische Übersichtsarbeit

Table 2 Studies meeting the inclusion criteria and comparing postoperative mortality in elective open repair of infrarenal abdominal aortic aneurysm in low and high volume groups, relating to the case volume per hospital

Author (year of publication)	Place	Time	Significant mortality difference	Threshold high vs. low volume or lower threshold high volume	Lower threshold high volume	Patients low volume	Patients high volume or total population	Age (mean) total population	Age (mean) low volume	Age (mean) high volume	Men low volume	Men high volume (or total population)	Mortality total population (%)	Mortality low volume (%)	Mortality high volume (%)	Mortality indicator	Odds ratio (95%-CI)	Multivariable
Conducted until 2000																		
Amundsen S et al. (1990) [23]	NOR	–	Yes	10.0	–	58	194	68 (median)	–	–	–	–	9.79	13.80	5.67	HM	0.37	No
Birkmeyer JD et al. (2003) [19]	USA	1998–1999	Yes	–	–	–	39,794	–	–	–	–	–	–	–	–	"Perioperative"	0.71 (0.63–0.81)	No
Birkmeyer JD et al. (2006) [5]	USA	1994–1997	Yes	11.8	57.3	–	95,295	–	–	–	–	–	–	7.80	4.30	HM	–	Yes
Christian CK et al. (2003) [24]	USA	1999–2000	Yes	50.0	–	5732	4137	64.20	–	–	–	7180	–	–	–	HM	0.79 (0.65–0.96)	Yes
Dardik A et al. (1999) [25]	USA	1990–1995	Yes	8.3	16.7	679	1032	–	70.10	70.60	–	–	–	4.30	2.50	HM	0.48 (0.23–0.96)	Yes
Dimick JB et al. (2002) [26]	USA	1994–1996	Yes	20.0	36.0	1590	1397	–	68.00	68.00	1094	936	–	8.70	5.60	HM	0.63 (0.42–0.92)	Yes
Dimick JB et al. (2002) [27]	USA	1996–1997	Yes	30.0	–	5417	6439	–	–	–	–	–	–	4.70	3.10	HM	0.58 (0.47–0.73)	Yes
Dimick. JB et al. (2003) [28]	USA	1997	Yes	35.0	–	–	3912	–	–	–	–	–	–	5.50	3.00	HM	0.70 (0.49–0.98)	Yes
Goodney PP et al. (2003) "low risk" patients [9]	USA	1994–1999	Yes	17.0	79.0	19,674	20,782	–	–	–	17,207	15,936	–	5.60	3.30	HM/30-Day	0.51 (0.49–0.53)	Yes
Goodney PP et al. (2003) "high risk" patients [9]	USA	1994–1999	Yes	17.0	79.0	7853	6467	–	–	–	4712	4003	–	12.40	7.40	HM/30-Day	0.54 (0.52–0.56)	Yes
Hannan EL et al. (1992) [29]	USA	1982–1987	Yes	10.0	27.0	1000	1397	70.30	–	–	–	2792	7.60	10.40	5.90	HM	0.76	Yes
Kantonen I et al. (1997) [30]	FIN	1991–1995	No	–	–	–	929	–	–	–	–	–	–	–	–	30-Day	–	No
Katz DJ et al. (1994) [31]	USA	1980–1990	Yes	20.0	>21	–	8185	69.60	–	–	–	6716	7.50	8.90	6.20	HM	0.83 (0.67–0.97)	Yes
Kazmers A et al. (1996) [32]	USA	1991–1993	Yes	31.0	32.0	–	3419	–	–	–	–	–	4.86	6.70	4.20	HM	–	Yes
Manheim LM et al. (1998) [33]	USA	1982–1994	Yes	20.0	50.0	–	35,130	–	–	–	–	–	7.56	8.00	6.00	HM	0.84	Yes
Pearce WH et al. (1999) [34]	USA	1992–1996	Yes	–	–	–	13,415	72.00	–	–	–	10,836	5.70	–	–	HM	0.88	Yes
Sollano YES et al. (1999) [35]	USA	1990–1995	Yes	–	–	–	9847	–	–	–	–	–	5.50	–	–	HM	0.78	Yes
Urbach DR et al. (2004) [36]	CAN	1994–1999	Yes	42.0	–	3259	3020	70.70	–	–	–	5168	4.20	5.09	3.28	30-Day	0.62 (0.46–0.83)	Yes

Table 2 (Continued)

Author (year of publication)	Place	Time	Significant mortality difference	Threshold high vs. low volume or lower threshold high volume	Lower threshold high volume	Patients low volume	Patients high volume or total population	Age (mean) total population	Age (mean) low volume	Age (mean) high volume	Men low volume	Men high volume (or total population)	Mortality total population (%)	Mortality low volume (%)	Mortality high volume (%)	Mortality indicator	Odds ratio (95%-CI)	Multivariable
Wen SW et al. (1996) [37]	CAN	1988–1992	Yes	10.0	40.0	696	1934	–	–	–	–	–	–	–	–	–	–	No
Conducted in or after 2000																		
Allareddy V et al. (2010) [38]	USA	2000–2003	Yes	50.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Brooke B et al. (2008) [39]	USA	2000–2005	No	50.0	–	3407	2996	–	73.50	73.10	2702	2366	–	3.85 (2000–2002) 5.05 (2003–2005)	3.96 (2000–2002) 4.39 (2003–2005)	HM	0.98 (0.63–1.51)	Yes
Damiani G et al. (2008) [40]	ITA	2000–2005	Yes	10.0	–	73	229	–	70.76	70.75	69	210	–	6.80	0.40	HM	0.05	Yes
Dimick JB et al. (2008) [41]	USA	2001–2003	Yes	–	–	–	–	–	–	–	–	–	–	–	–	–	0.66	No
Dua A et al. (2014) [42]	USA	1998–2011	Yes	–	–	–	–	–	–	–	–	–	–	–	–	HM	–	No
Eckstein HH et al. (2007) [43]	GER	1999–2004	Yes	9.0	50.0	367	3991	68.00	69.00	68.00	–	–	3.20	5.20	2.60	HM	0.53 (0.31–0.89)	Yes
Esce A et al. (2018) [44]	USA	2000–2010	Yes	Median	–	5786	8673	–	74.20	74.50	4658	6956	–	6.00	4.10	30-Day	–	No
Gonzalez A et al. (2014) [45]	USA	2005–2006	Yes	14.0	169.0	10,451	10,149	–	–	–	–	–	–	–	–	HM/30-Day	0.56 (0.48–0.64)	Yes
Gonzalez A et al. (2017) [46]	USA	2003–2008	Yes	–	–	–	–	–	–	–	–	–	–	10.17	4.67	–	–	No
Hicks CW et al. (2016) [47]	USA	2010–2012	No	50.0	–	3673	30,862	70.40	–	–	–	24,990	–	–	–	HM	0.64 (0.38–1.09)	No
Holt PJ et al. (2007) [48]	UK	2000–2005	Yes	7.2	32.0	3149	3227	72.30	71.20	72.60	2633	2759	7.40	8.50	5.90	HM	0.67	No
Holt. PJ et al. (2009) [49]	UK	2005–2007	Yes	15.5	76.5	1103	1199	–	71.30	71.80	918	992	6.18	7.89	5.09	HM	0.99 (0.99–0.99)	Yes
Ilonzo N et al. (2014) [50]	USA	1995–2011	Yes	2.0	8.0	–	295,851	–	–	–	–	–	–	2.69	0.87	30-Day	–	No
Jibawi A et al. (2006) [51]	UK	1997–2002	Yes	13.0	–	–	31,078	–	–	–	–	–	–	–	–	HM	–	No
Landon BE et al. (2010) [52]	USA	2001–2004	Yes	10.0	50.0	–	22,830	–	–	–	–	–	–	7.30	3.80	30-Day	–	Yes
McPhee JT et al. (2011) [20]	USA	2003–2007	No	7.0	30.0	1423	1032	–	–	–	–	–	–	5.90	3.30	HM	0.63 (0.37–1.02)	Yes
Meltzer AJ et al. (2017) [53]	USA	2000–2011	No	14.0	43.0	1420	1490	–	–	–	–	3268	4.80	5.80	4.60	30 Day	0.78 (0.47–1.27)	Yes

Table 2 (Continued)

Author (year of publication)	Place	Time	Significant mortality difference	Threshold high vs. low volume or lower threshold high volume	Lower threshold high volume	Patients low volume	Patients high volume or total population	Age (mean) total population	Age (mean) low volume	Age (mean) high volume	Men low volume	Men high volume (or total population)	Mortality total population (%)	Mortality low volume (%)	Mortality high volume (%)	Mortality indicator	Odds ratio (95%-CI)	Multivariable
Nimptsch U et al. (2017) [54]	GER	2009–2014	Yes	4.0	33.0	4422	4530	–	–	–	–	–	6.00	7.80	4.70	HM	0.55 (0.45–0.68)	Yes
Rosero EB et al. (2017) [55]	USA	2001–2011	Yes	4	25.0	12,104	9662	–	–	–	–	–	3.20	4.50	3.00	HM	–	No
Sidloff DA et al. (2014) [56]	UK	2008–2012	Yes	60.0	–	–	–	–	–	–	–	–	–	2.70	1.70	HM	–	No
Trenner M et al. (2014) [57]	GER	1999–2010	Yes	20.0	63.0	6295	3670	–	–	–	–	–	3.60	4.40	3.20	HM	0.61 (0.42–0.89)	Yes
Trenner M et al. (2017) [58]	GER	2005–2013	Yes	5.0	41.0	1658	22,867	–	–	–	–	–	5.30	7.60	4.50	HM	0.62 (0.51–0.77)	Yes
Vogel TR et al. (2011) [59]	USA	2005–2007	Yes	–	–	10,517	6693	–	–	–	7569	4886	–	–	–	HM	0.82 (0.69–0.96)	Yes
Zettervall SL et al. (2017) [18]	USA	2001–2008	Yes	5.0	29.0	8919	8743	–	75.00	75.00	6511	6557	–	6.30	3.80	HM	0.67 (0.56–0.77)	Yes

Studies were stratified according to the time of study conduction
If a dash (–) is inserted within a field, the corresponding data were not reported in the publication
For studies dividing hospitals in one low and one high volume group, the volume threshold is presented
For studies dividing hospitals into several groups according to their case volume, the group with the lowest volume was compared with the group with the highest volume and the respective thresholds for both groups are presented
Odds ratios were transformed so that a value <1 reflects a lower mortality in the high volume group
CAN Canada, *CI* confidence interval, *FIN* Finland, *GER* Germany, *HM* hospital mortality, *ITA* Italy, *NOR* Norway, *UK* United Kingdom, *USA* United States of America, *30-day* 30-day mortality, *CI* confidence interval

if only two groups were compared) was between 2 and 50 cases per institution per year. In studies comparing several groups, institutions with a volume between 16 and 169 annual cases were defined as high volume. Unadjusted mortality was between 3.9% and 13.8% in the low volume groups and between 0.4% and 7.4% in the high volume groups. A total of 30 studies reported mortality as hospital mortality and 6 studies as 30-day mortality while 3 studies used a combined endpoint of 30-day and hospital mortality. Four studies did not specify the mortality indicator used. Thirty-seven studies found a significantly lower mortality in the high volume group, 6 studies could not find a mortality difference between groups. Twenty-nine studies did a multivariable analysis. The effect measures (odds ratio) were between 0.37 and 0.99. Stratification according to the study period showed that 1/19 studies completed before 2000 and 4/24 studies completed in or after 2000 found no association between volume and mortality.

Table 3 shows the characteristics and results of the included 17 studies on the association between volume per surgeon and postoperative mortality. These studies recruited patients between 1982 and 2014 and were published between 1992 and 2017. Thirteen studies were conducted in the USA, two in Canada, one in the UK and one in Finland. There were no studies from Germany on the association between surgeon volume and postoperative mortality identified. Given the specific study question, all studies had a retrospective design. In total, in the eight studies reporting group-specific patient numbers, there were 54,723 patients in the high volume and 21,288 patients in the low volume groups. Of the studies, nine reported no group-specific patient numbers. The study populations were predominantly male with a mean and median age of 70.1 years and 75 years, respectively. The threshold used for defining low volume (either the value defining the group with the lowest volume if several groups were compared or the value above which the group was considered high volume in the case only two groups were compared) was between 0.17 and 10 operated cases per

Table 3 Studies meeting the inclusion criteria and comparing postoperative mortality in elective open repair of infrarenal abdominal aortic aneurysm in low and high volume groups, relating to the case volume per surgeon

Author (year of publication)	Place	Time	Significant mortality difference	Threshold high vs. low volume or lower threshold high volume	Lower threshold high volume	Patients low volume	Patients high volume or total population	Age (mean) total population	Age (mean) low volume	Age (mean) high volume	Men low volume	Men high volume (or total population)	Mortality total population (%)	Mortality low volume (%)	Mortality high volume (%)	Mortality indicator	Odds ratio (95%-CI)	Multivariable
Conducted until 2000																		
Birkmeyer JD et al. (2003) [19]	USA	1998–1999	Yes	8.00	17.50	–	39,794	–	–	–	–	–	–	6.20	3.90	"Perioperative mortality"	0.61 (0.54–0.68)	–
Dardik A et al. (1999) [25]	USA	1990–1995	Yes	0.17	1.67	71	1200	–	70.60	70.10	–	–	–	9.90	2.80	HM	0.31 (0.12–0.76)	Yes
Dimick JB et al. (2003) [28]	USA	1997	Yes	10.00	–	–	3912	–	–	–	–	–	–	5.60	2.50	HM	0.60 (0.40–0.88)	Yes
Dueck AD et al. (2004) [60]	CAN	1993–1999	Yes	–	–	–	10,688	–	–	–	–	–	–	–	–	30-day	–	Yes
Hannan EL et al. (1992) [29]	USA	1982–1987	Yes	3.0	10.0	1019	1232	70.30	–	–	–	2792	7.60	9.40	6.20	HM	0.92	Yes
Huber TS and Seeger JM (2001) [61]	USA	1994–1996	Yes	4.00	10.00	–	–	–	–	–	–	–	5.50	7.90	4.00	30-day	–	No
Kantonen I et al. (1997) [30]	FIN	1991–1995	Yes	–	–	–	929	–	–	–	–	–	–	–	–	30-day	–	No
Pearce WH et al. (1999) [34]	USA	1992–1996	Yes	–	–	–	13,415	72.00	–	–	–	10,836	5.70	–	–	HM	0.90	Yes
Tu JV et al. (2001) [62]	CAN	1992–1996	Yes	4.00	14.00	–	–	–	–	–	–	–	–	7.10	3.55	30-day	–	No

surgeon per year. In studies comparing several groups, surgeons performing between 1.67 and 43 OR per year were classified as high volume. Unadjusted mortality was between 3.9% and 13.8% in low volume and between 0.4% and 7.4% in high volume groups. Ten studies reported mortality as hospital mortality and 6 studies as 30-day mortality. One study did not specify the mortality indicator used. Fourteen studies found a significantly lower mortality in the high volume group. Three studies could not find a mortality difference between groups. Eight of the 14 studies did a multivariable analysis. The effect measures (odds ratios) were between 0.31 and 0.92. Stratification by the time of study conduction showed that 0/9 studies completed before 2000 and 3/8 studies completed after 2000 found no association between volume and mortality.

Discussion

This systematic review summarizes the currently available evidence regarding an association between case volume per hospital and surgeon and perioperative mortality in elective OR of infrarenal AAA. For both questions a large number of studies from various healthcare systems could be included. The vast majority of studies showed that patients who are treated in hospitals or by surgeons with a higher case volume have a lower mortality risk for the operation.

Both the absolute mortality in the single subgroups and the magnitude of mortality differences between high volume and low volume groups show considerable differences. These are predominantly a consequence of the time of study conduction, the characteristics of the participating hospitals, and the differences between single studies in defining a high volume and low volume center and surgeon. The inverse association between volume and mortality is, however, present irrespective of the absolute threshold for high volume and low volume. Thus, a class effect, which is robust against possible confounders, can be assumed. Given the study question, the employed study designs were limited to nonrandomized, retrospective analy-

Table 3 (Continued)

Author (year of publication)	Place	Time	Significant mortality difference	Threshold high vs. low volume or lower threshold high volume	Lower threshold high volume	Patients low volume	Patients high volume or total population	Age (mean) total population	Age (mean) low volume	Age (mean) high volume	Men low volume	Men high volume (or total population)	Mortality total population (%)	Mortality low volume (%)	Mortality high volume (%)	Mortality indicator	Odds ratio (95%-CI)	Multi-variable
Conducted after 2000																		
Dubois L et al. (2017) [63]	USA	2005–2014	No	6.00	43.00	475	2926	–	71.20	71.68	380	2323	–	3.01	1.89	HM	0.60 (0.27–1.33)	No
Esce A et al. (2018) [44]	USA	2000–2010	Yes	Median	–	5806	6342	–	71.00	72.10	4157	4674	–	6.30	3.80	30-day	–	No
Mao J et al. (2017) [64]	USA	2000–2014	Yes	1.00	2.00	667	8114	–	70.10	71.80	69	73	–	6.70	3.50	HM	0.48 (0.32–0.71)	Yes
McPhee JT et al. (2011) [20]	USA	2003–2007	Yes	–	–	1420	1094	–	–	–	–	–	–	7.50	3.00	HM	0.50 (0.32–0.77)	Yes
Meltzer AJ et al. (2017) [53]	USA	2000–2011	Yes	4.0	11.0	1443	1440	–	–	–	–	3268	4.80	6.40	3.60	30-day	0.57 (0.35–0.93)	Yes
Modrall JG et al. (2011) [65]	USA	2000–2008	No	1.00	5.00	–	22,988	–	–	–	–	17,064	6.10	10.20	4.50	HM	–	Yes
Sidloff DA et al. (2014) [56]	UK	2008–2012	No	–	–	–	–	–	–	–	–	–	–	–	–	HM	–	No
Zettervall SL et al. (2017) [18]	USA	2001–2008	Yes	3.00	14.00	10,387	8458	–	75.00	75.00	7583	6344	–	6.40	3.80	HM	0.63 (0.53–0.71)	Yes

Studies were stratified according to the time of study conduction
If a dash (–) is inserted within a field, the corresponding data were not reported in the publication
For studies dividing surgeons in one low and one high volume group, the volume threshold is presented
For studies dividing surgeons into several groups according to their case volume, the group with the lowest volume was compared with the group with the highest volume and the respective thresholds for both groups are presented
Odds ratios were transformed so that a value <1 reflects a lower mortality in the high volume group
CAN Canada, *CI* confidence interval, *FIN* Finland, *HM* hospital mortality, *UK* United Kingdom, *USA* United States of America, *30-day* 30-day mortality, *CI* confidence interval

ses. A randomization of patients to being treated in facilities or by surgeons with a high or low volume would be neither feasible nor ethically justifiable. Retrospective studies have a number of limitations with respect to data quality and an increased risk of selection bias. For the specific research question, the case volume and overall mortality constitute the relevant parameters. Usually, they can be reliably ascertained. A possible selection bias seems likely for elective AAA repair in the way that patients with a particularly high perioperative risk tend to be treated in larger centers. Multivariable analyses, which were used in some of the included studies, can achieve at least a partial adjustment for differences in risk profiles. The described selection would lead to higher unadjusted mortality in high volume centers and for high volume surgeons. In other words, a possible association between volume and outcome would be attenuated. Since most studies have nonetheless found a significant inverse association, a true and very stable effect can be assumed.

There are several possible explanations for the causal association between a high case volume and a low perioperative mortality in elective OR of AAA. A surgeon's personal experience, i.e. the continuous and frequent exposure towards a wealth of challenging and complex preoperative, intraoperative, and postoperative situations, probably increases the likelihood of taking the best decision with respect to the patient's outcome in such situations [10, 11]. This obviously holds true not only for the surgeon but also for physicians from other disciplines, for nurses and for all other staff involved in patient treatment. Both the experience of the single team members and of the team as a whole can lead to a better preparedness for critical situations, a proactive avoidance of mistakes, and a more timely and effective management of incident complications. With respect to quality models widely used in medicine, it can be assumed that a higher case volume is associated with higher process and treatment quality, which in turn leads to higher outcome quality [12].

An important link in the causal chain could be the so-called failure to rescue.

This term is commonly used to describe postoperative death following a potentially treatable severe complication, such as hemorrhage, sepsis or respiratory failure [13]. In the true sense of the word, it denotes a failure of the specific actions employed to avert the fatal course. For a number of operations there is sufficient evidence that such a scenario manifests less frequently in high volume hospitals [14]. Such an association was shown for OR of AAA. A study with more than 20,000 patients in the USA yielded an only marginally higher risk for severe postoperative complications in low volume compared to high volume centers, while the risk of dying from a severe postoperative complication was substantially higher in the former [15]. Characteristics associated with the case volume and size of the hospitals probably play an important role in this pattern. One example is an around the clock availability of specific emergency diagnostics and of specialized and experienced staff.

For a number of operations an association between volume and outcome has been demonstrated. For operations in which the individual technical competence and the experience of the surgeon presumably play a large role, such as thyroid, hernia or carotid surgery, the outcome is associated with the volume per surgeon [16, 17]. For these operations, severe complications are relatively infrequent and mortality is low. Conversely, the outcome after major operations such as in esophageal, pancreatic, transplantation and also aortic surgery, depends to a larger degree on the infrastructure and experience of the hospital as a whole [6]. This could explain why for OR of AAA, the volume per hospital is much more strongly associated with postoperative mortality than the volume per surgeon.

A correlation between volume per hospital and volume per single surgeon in a given hospital seems likely; however, the majority of studies included only one of the two variables in their analysis. Consequently, it remains unclear to what extent there is confounding by the other variable. Studies including both variables in multivariable analyses yielded heterogeneous results. An analysis comprising 45,451 Medicare patients showed that the case volume of both the hospital and the individual surgeon were independently inversely associated with postoperative mortality after elective OR of infrarenal AAA [18]. Another analysis with 39,794 Medicare patients, who were operated on by 6276 surgeons, showed a marked attenuation of the effect of hospital volume on mortality after adjustment for surgeon volume [19]. The analysis also included patients who underwent endovascular treatment, but their proportion was probably low because the study was conducted between 1998 and 1999. In contrast, an analysis of 5972 patients from the US National Inpatient Sample showed that after adjustment for surgeon volume, the hospital volume was no longer significantly associated with postoperative mortality [20]. Ultimately, the available data do not allow for a valid conclusion if hospital or surgeon volume has a stronger influence on postoperative mortality. Interpretation of the data is also limited due to the fact that the identified studies partially consist of series where the recruitment period ended more than 20 years ago. Since then, perioperative management has changed and improved in many respects, which makes transferability to the current situation difficult. Moreover, the indications for OR have markedly changed over the years. Before 2000, almost all infrarenal AAA were treated by OR, whereas in the last two decades this has been the case mostly for complex AAA not easily amenable to EVAR [21]. This also limits transferability of the studies included in this review to the current patients. The stratification of study results by study period suggests that the association between hospital and surgeon volume and postoperative mortality might not have been so pronounced in the studies conducted after the year 2000.

Furthermore, none of the included studies assessing the association between surgeon volume and postoperative mortality was conducted in Germany. Thus, it remains unclear to what extent the results are valid for the German healthcare system.

In summary, this systematic review, which includes all available evidence at the time of the literature search, shows a clear inverse association between case volume per hospital and surgeon and postoperative mortality in elective OR of infrarenal AAA. Based on these results, a centralization of elective open aortic surgery in high volume hospitals that can also guarantee a sufficient case volume per single surgeon should be aimed for. A circumscribed threshold for defining a high volume hospital can hardly be inferred from the available studies, because almost every study used its own threshold. Moreover, thresholds are not readily transferable between different institutions and healthcare systems. Accordingly, national and international guidelines are heterogeneous in their recommendation of a minimum threshold per hospital for elective OR of infrarenal AAA. Whereas the guidelines of the US Society of Vascular Surgery (SVS) recommends a minimum of ten cases per year for both OR and EVAR [1], the European Society for Vascular Surgery (ESVS) recommends in its guidelines that AAA should be treated only in centers with an annual volume of at least 30 cases [22]. This number is not specified regarding OR or EVAR. The German S3 guidelines [2] discuss minimum case numbers deduced from a number of meta-analyses and single studies. These differ between 8 and 60 cases per year and in most cases do not discriminate between OR and EVAR. Consequently, the guidelines recommend that infrarenal AAA should be treated in specialized centers, without naming a defined minimum threshold for volume and without differentiating between OR and EVAR. In conclusion, a possible centralization should be done taking the characteristics of an established healthcare system into account.

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