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...
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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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“-Zentren und 14/17 Vergleichen eine niedrigere Mortalität für „high volume“-Chirurgen 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 | Patients low volume | Patients high volume or total population | Age (mean) total population | Age (mean) low volume | Age (mean) high volume | Mortality total population (%) | Mortality low volume (%) | Mortality high volume (%) | Mortality indicator | Odds ratio (95%-CI) | Multi-variable |
|------------------------------|-------|------|---------------------------------|-------------------------------------------------------------|---------------------|----------------------------------------|--------------------------|---------------------|---------------------|--------------------------|----------------------|--------------------------|-----------------|----------------|------------------|
| Amundsen S et al (1990)[23]  | NOR   | –    | Yes                             | 10.0                                                        | 58                  | 194                                    | 68 (median)              | –                   | –                   | –                        | –                    | –                        | HM              | 0.37           | No               |
| Birkmeyer JD et al (2003)[19]| USA   | 1998–1999 | Yes | –                               | –                 | 39,794                                 | –                        | –                   | –                   | –                        | –                    | –                        | HM (0.63–0.81)   | 0.71           | No               |
| Birkmeyer JD et al (2006)[5] | USA   | 1994–1997 | Yes | 11.8                            | 57.3              | 95,295                                 | –                        | –                   | –                   | –                        | –                    | –                        | HM              | 0.70           | Yes              |
| Christian CK et al (2003)[24]| USA   | 1999–2000 | Yes | 50.0                            | 5732              | 4137                                   | 64.30                    | –                   | –                   | 7,180                    | –                    | –                        | HM              | 0.79           | Yes              |
| Dardick A et al. (1999)[25] | USA   | 1990–1995 | Yes | 8.3                             | 16.7              | 679                                    | 1032                     | –                   | 70.10               | 70.60                    | –                    | –                        | HM              | 0.48           | Yes              |
| Dimick JB et al. (2002)[26] | USA   | 1994–1996 | Yes | 20.0                            | 36.0              | 1390                                   | 1397                     | –                   | 68.00               | 68.00                    | 1094                 | 936                     | 8.70            | 5.60          | HM (0.42–0.92)   |
| Dimick JB et al. (2002)[27] | USA   | 1996–1997 | Yes | 30.0                            | –                 | 5417                                   | 6439                     | –                   | –                   | –                        | –                    | –                        | HM              | 0.58           | Yes              |
| Dimick JB et al. (2003)[28] | USA   | 1997    | Yes                             | 35.0                                                        | –                   | 3912                                   | –                        | –                   | –                   | –                        | –                    | –                        | HM              | 0.70           | Yes              |
| Goodney PP et al. (2003)[29] | 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) |
| Goodney PP et al. (2003)[30] | USA   | 1994–1999 | Yes | 17.0                            | 79.0              | 783                                    | 6467                     | –                   | –                   | 4,712                    | 4003                 | 12.40                    | 7.40          | HM/30-Day | 0.54 (0.52–0.56) |
| Hannan EL et al (1992)[29]   | USA   | 1982–1987 | Yes | 10.0                            | 27.0              | 1000                                   | 1397                     | 70.30               | –                   | –                        | 2792                 | 7.60                     | 10.40         | HM          | 0.76            |
| Kantonen 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               | –                   | –                        | 6,716                | 7.90                     | 8.90          | 6.30        | HM (0.67–0.97)   |
| Karmen A et al. (1996)[32]   | USA   | 1991–1993 | Yes | 31.0                            | 32.0              | –                                      | 3419                     | –                   | –                   | –                        | –                    | –                        | HM              | –            | Yes              |
| Manheim UM et al. (1998)[33] | USA   | 1982–1994 | Yes | 20.0                            | 50.0              | 35,130                                 | –                        | –                   | –                   | –                        | 7.56                 | 8.00                     | 6.00          | HM          | 0.84            |
| 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                            | 325.9             | 3030                                   | 70.70                    | –                   | –                   | –                        | 5168                 | 4.20                     | 5.09          | 3.28        | 30-Day | 0.62 (0.46–0.83) |
| 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 |
|-----------------------------|-------|-----------------|-----------------------------------|-------------------------------------------------------------|----------------------------|---------------------|----------------------------------------|-----------------------------|---------------------|----------------------|----------------|----------------------------------------|-------------------------------|--------------------------|------------------------|----------------------|----------------------|-------------------|
| Wen SW et al. (1996)[37]    | CAN   | 1988–1992       | Yes                               | 10.0                                                       | 40.0                      | 696                  | 1934                                   | –                           | –                   | –                    | –              | –                                      | –                             | –                        | –                      | –                    | –                    | No                |
| Alareddy V et al. (2010)[38] | USA   | 2000–2003       | Yes                               | 50.0                                                       | –                         | –                   | –                                      | –                           | –                   | –                    | –              | –                                      | –                             | –                        | –                      | –                    | –                    | Yes               |
| Brooke B et al. (2008)[39]  | USA   | 2000–2005       | No                                | 50.0                                                       | –                         | 3407                | 2996                                   | –                           | 73.5                | 73.10                | 2702          | 2366                                   | –                             | –                        | –                      | –                    | –                    | –                |
| 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                               | –                                                          | –                         | –                   | –                                      | –                           | –                   | –                    | –              | –                                      | –                             | –                        | –                      | –                    | –                    | No                |
| Dua A et al. (2014)[42]     | USA   | 1998–2011       | Yes                               | –                                                          | –                         | –                   | –                                      | –                           | –                   | –                    | –              | –                                      | –                             | –                        | –                      | –                    | –                    | No                |
| Eckstein HH et al. (2007)[43]| GBR   | 1999–2004       | Yes                               | 9.0                                                        | 50.0                      | 367                  | 3991                                   | 68.00                        | 69.00               | 68.00                | –              | 3.20                                   | 3.96                          | 70.40                    | 5.20                   | 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               | 74.00                | 4658          | 6956                                   | –                             | 4.10                     | 30-Day                 | –                    | No                   | –                |
| Gonzalez A et al. (2014)[45]| USA   | 2005–2006       | Yes                               | 14.0                                                       | 1690                      | 10,451              | 10,149                                 | –                           | –                   | –                    | –              | –                                      | –                             | 10.17                    | 4.67                   | –                    | –                    | No                |
| Gonzalez A et al. (2017)[46]| USA   | 2003–2008       | Yes                               | –                                                          | –                         | –                   | –                                      | –                           | –                   | –                    | –              | 10.17                                   | 10.17                          | –                        | –                      | –                    | –                    | No                |
| Hicks CW et al. (2016)[47]  | UK     | 2010–2012       | No                                | 50.0                                                       | 3673                      | 30,862              | 38,190                                 | –                           | –                   | –                    | –              | 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                      | 1108                | 1199                                   | –                           | 71.30               | 71.80                | 917           | 992                                   | 6.18                          | 7.89                     | 5.09                   | HM                   | 0.99                 | (0.99–0.99) Yes |
| Ilonzo Net 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)[53] | USA    | 2003–2007       | No                                | 7.0                                                        | 30.0                      | 1423                | 1032                                   | –                           | –                   | –                    | –              | –                                      | –                             | –                        | –                      | HM                   | 0.63                 | (0.37–1.02) Yes |
| Meltzer AJ et al. (2017)[54]| USA    | 2000–2011       | No                                | 14.0                                                       | 43.0                      | 1430                | 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) | Multi-variable indicator |
|-----------------------------|-------|-----------|----------------------------------|-------------------------------------------------------------|-----------------------------|---------------------|-------------------------------|---------------------------|----------------------|---------------------|----------------|-------------------------------|---------------------------|-------------------------|-------------------------|-----------------|-------------------|------------------------|
| Nimptsch U et al. (2017)[54] | GER   | 2009–2014 | Yes                              | 4.0                                                         | 33.0                        | 44.22               | 45.30                        | –                         | –                    | –                   | –                        | 6.00                      | 7.80                    | 4.70                    | HM                          | 0.35 (0.45–0.68) | Yes            |
| Rosero EB et al. (2017)[55] | USA   | 2001–2011 | Yes                              | 4.0                                                         | 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                              | 24.0                                                        | 63.0                        | 6295                | 3670                         | –                         | –                    | –                   | –                        | 3.60                      | 4.40                    | 3.00                    | HM                          | 0.61 (0.42–0.89) | Yes            |
| Trenner M et al. (2017)[58] | GER   | 2005–2013 | Yes                              | 30.0                                                        | 41.0                        | 16,58                | 22,867                        | –                         | –                    | –                   | –                        | 5.20                      | 6.00                    | 4.50                    | HM                          | 0.62 (0.51–0.77) | Yes            |
| Vogel TR et al. (2011)[59]  | USA   | 2005–2007 | Yes                              | –                                                           | –                           | 10,517              | 6691                         | –                         | –                    | –                   | –                        | 7.50                      | 5.60                    | 4.50                    | HM                          | 0.92 (0.69–0.96) | Yes            |
| Zeiterwall SL et al. (2017)[60] | 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            |

Note: Studies were stratified according to the time of study conducton and studies dividing hospitals into one low and one high volume group, the group that is presented. If a dash (–) is inserted within a field, the corresponding data were not reported in the publication. For studies dividing hospitals into more than one low and high volume group, 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. CIs were calculated using the method of DerSimonian and Laird. 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 mortality, C = confidence interval.

- **Studies were stratified according to the time of study conducton:**
  - If a dash (–) is inserted within a field, the corresponding data were not reported in the publication.

- **For studies dividing hospitals into one low and one high volume group, the group that is presented:**
  - If a dash (–) is inserted within a field, the corresponding data were not reported in the publication.

- **For studies dividing hospitals into more than one low and high volume group, 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.

- **CI = confidence interval:**
  - CIs were calculated using the method of DerSimonian and Laird.

- **CAN = Canada:**
  - CAN = Canada

- **30-day mortality:**
  - 30-day mortality

- **C = confidence interval:**
  - C = confidence interval

- **30 studies reported mortality as hospital mortality:**
  - 30 studies reported mortality as hospital mortality

- **American thoracic surgeons society:**
  - American thoracic surgeons society

- **50 studies reported mortality as hospital mortality:**
  - 50 studies reported mortality as hospital mortality

- **8 studies compared morality between 2 groups:**
  - 8 studies compared morality between 2 groups

- **20 studies comparing several groups per year:**
  - 20 studies comparing several groups per year

- **12 studies comparing several groups per year:**
  - 12 studies comparing several groups per year
### Table 3

| Author (year of publication) | Place | Time | Significant mortality difference | Lower threshold high volume (or total population) | Lower threshold low volume (or total population) | Patients high volume (or total population) | Patients low volume (or total population) | Mortality indicator | Odd ratio (95% CI) |
|-----------------------------|-------|------|----------------------------------|------------------------------------------------|------------------------------------------------|------------------------------------------|------------------------------------------|-------------------|------------------|
| Birkmeyer JD et al. (2003)                           | USA   | 1998–1999 | Yes                            | 8.00                                           | 17.50                                         | –                                        | –                                        | “Perioperative mortality” | 0.61 (0.54–0.68) |
| Dardik A et al. (1999)                           | USA   | 1990–1995 | Yes                            | 0.17                                           | 1.67                                          | 71                                       | 1200                                     | HM                | 0.31 (0.12–0.70) |
| Dimick JB et al. (2003)                           | USA   | 1997 | Yes                            | 10.00                                          | 10.00                                        | 3912                                     | –                                        | HM                | 0.60 (0.60–0.80) |
| Hannan EL et al. (1992)                           | USA   | 1982–1987 | Yes                            | 3.0                                            | 10.00                                        | 1019                                     | 1232                                     | HM                | 0.92             |
| Huber TS and Seeger JM (2001)                    | USA   | 1994–1996 | Yes                            | 10.00                                          | 10.00                                        | –                                        | –                                        | HM                | 0.90             |
| Dueck AD et al. (2004)                           | CAN   | 1993–1999 | Yes                            | 2792                                           | 7.0                                          | 940                                      | 400                                      | 30-day            | 0.60             |
| Dueck AD et al. (2004)                           | CAN   | 1993–1999 | Yes                            | 106.28                                         | 70.00                                        | –                                        | –                                        | 30-day            | –                |
| Dueck AD et al. (2004)                           | CAN   | 1993–1999 | Yes                            | 106.28                                         | 70.00                                        | –                                        | –                                        | 30-day            | –                |
| Dueck AD et al. (2004)                           | CAN   | 1993–1999 | Yes                            | 106.28                                         | 70.00                                        | –                                        | –                                        | 30-day            | –                |
| Dueck AD et al. (2004)                           | CAN   | 1993–1999 | Yes                            | 106.28                                         | 70.00                                        | –                                        | –                                        | 30-day            | –                |
| Dueck AD et al. (2004)                           | CAN   | 1993–1999 | Yes                            | 106.28                                         | 70.00                                        | –                                        | –                                        | 30-day            | –                |
| Dueck AD et al. (2004)                           | CAN   | 1993–1999 | Yes                            | 106.28                                         | 70.00                                        | –                                        | –                                        | 30-day            | –                |
| Dueck AD et al. (2004)                           | CAN   | 1993–1999 | Yes                            | 106.28                                         | 70.00                                        | –                                        | –                                        | 30-day            | –                |
| Dueck AD et al. (2004)                           | CAN   | 1993–1999 | Yes                            | 106.28                                         | 70.00                                        | –                                        | –                                        | 30-day            | –                |
| Dueck AD et al. (2004)                           | CAN   | 1993–1999 | Yes                            | 106.28                                         | 70.00                                        | –                                        | –                                        | 30-day            | –                |
| Dueck AD et al. (2004)                           | CAN   | 1993–1999 | Yes                            | 106.28                                         | 70.00                                        | –                                        | –                                        | 30-day            | –                |
| Dueck AD et al. (2004)                           | CAN   | 1993–1999 | Yes                            | 106.28                                         | 70.00                                        | –                                        | –                                        | 30-day            | –                |
| Dueck AD et al. (2004)                           | CAN   | 1993–1999 | Yes                            | 106.28                                         | 70.00                                        | –                                        | –                                        | 30-day            | –                |

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, low volume) | Age (mean, high volume) | Men low volume | Men high volume (or total population) | Mortality (low population) | 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 |
| Esca 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 |
| Mars 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 (0.32-0.77) | Yes |
| McPhee JT et al. (2013)[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 | 30-day | 0.57 (0.35-0.93) | Yes |
| Modro J Getal. (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 |
| Zetterwall SL et al. (2017)[18] | USA  | 2001–2008 | Yes | 3.00 | 54.00 | 10,387 | 8458 | – | 75.00 | 75.00 | 7583 | 6344 | – | 6.40 | 3.80 | HM | 0.63 (0.53-0.77) | Yes |

Studies were stratified according to the type of study conducted:
If a dash (–) is inserted within a field, the corresponding data were not reported in the publication.
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.

C blush: 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.
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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