Antimicrobial Resistance & Infection Control

REVIEW

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Analysis of antibiotic strategies to prevent vascular graft or endograft infection after surgical treatment for infective native aortic aneurysms: a systematic review

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Abstract

Introduction Some patients with an infective native aortic aneurysm (INAA) develop an aortic vascular graft or endograft infection (VGEI) even after successful open surgical repair or endovascular intervention. The aim of the systematic review and meta-analysis performed herein was to compare the clinical outcomes of different surgical and antibiotic treatment strategies.

Methods We systematically searched PubMed, MEDLINE, EMBASE and Web of Science. The keywords used for the search were "mycotic aortic aneurysm", "infected aortic aneurysm", "infective native aortic aneurysm", "antibiotics", "surgery", and "endovascular". The search was limited to articles written in English and to studies involving humans. Articles published before 2000 were excluded. Case reports and review articles were excluded.

Results Of the 524 studies retrieved from our search of the databases, 47 articles were included in this study. Among the 47 articles (1546 patients, 72.8% of whom were male) retrieved, five articles were excluded from the subgroup analysis because the data concerning open surgical repair and endovascular intervention could not be separated. The remaining 42 articles included a total of 1179 patients who underwent open surgical repair (622 patients) or endovascular intervention (557 patients) for INAA. There was a statistically significant difference ($p=0.001$) in the pooled in-hospital mortality rate between the open surgical repair group (13.2%, 82/622) and the endovascular intervention group (7.2%, 40/557). However, there was a statistically significant difference ($p<0.001$) in the aortic VGEI rate between the open surgical repair group (5.4%). 29/540) and endovascular intervention (13.3%, 69/517) group. For patients who underwent open surgical repair, a lower rate of aortic vascular graft infection was associated with long-term antibiotic use ($p=0.005$). For patients who underwent endovascular intervention, there was a trend of association ($p=0.071$) between the lower rate of aortic endograft infection and lifelong antibiotic use.

Conclusion Infective native aortic aneurysms are life-threatening. The pooled in-hospital mortality rate of the open surgical repair group was significantly higher than that of the endovascular intervention group, whereas the rate of the aortic VGEI in the open surgical repair group was significantly lower than that in the endovascular intervention

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group. Regardless of whether open surgical repair or endovascular intervention is performed, better long-term outcomes can be achieved with aggressive antibiotic treatment, which is especially important for patients who undergo endovascular intervention.

Keywords Infective native aortic aneurysm, Mycotic aortic aneurysm, Antibiotics, Aortic vascular graft infection, Open surgical repair, Aortic endograft infection, Endovascular intervention

Introduction

Infective native aortic aneurysm (INAA) is a life-threatening disease entity. Along with antibiotic treatment [1] immediately after diagnosis, surgical treatment is usually arranged urgently. However, if the general conditions of the patients were stabilized after antibiotics were administered initially, some suggested longer duration of antibiotic use before surgical treatment [2, 3]. Emergency open surgical repair or endovascular intervention is often required if the infection cannot be controlled or if the INAA has ruptured or is in a status of impending rupture. Both surgery and antibiotics play very important roles in the treatment of INAA patients. However, even after successful open surgical repair or endovascular intervention, some patients develop an aortic vascular graft or endograft infection [4] (VGEI) or other infection-related complications. To date, the duration of postoperative antibiotic use varies in the literature, and there is still no clear consensus on the optimal protocol for postoperative antibiotic administration. The primary aim of this study was to collect various related articles published in the literature and compare the clinical outcomes of different surgical and antibiotic treatment strategies via a systematic review and meta-analysis.

Materials and methods

This systematic review was conducted and reported in accordance with the PRISMA 2020 statement for systematic reviews [5]. We systematically searched PubMed, MEDLINE, EMBASE and Web of Science. The key words used for the search included "mycotic aortic aneurysm", "infected aortic aneurysm", "infective native aortic aneurysm", "antibiotics", "surgery", and "endovascular". The search was limited to reports written in English and studies involving humans. Articles published before 2000 were excluded. The literature search was completed on January 19, 2024. Case reports and review articles were not included. The reference lists of all the relevant articles retrieved during the search using the abovementioned keywords were checked carefully. The titles and abstracts of the retrieved articles were reviewed. Reports involving open surgical repair or endovascular intervention for INAAs of the thoracic aorta or abdominal aorta were included in the study. The included articles were published after 2000, and at that time, either open surgical repair or endovascular intervention could be selected by the surgeons or interventionists. Articles concerning INAAs, aortic VGEIs, and infection of the iliac arteries were excluded if the data of INAA patients could not be extracted, as the study focused on aortic infections. Articles involving open surgical repair with in situ aortic replacement or endovascular intervention with aortic stenting were included, whereas articles involving extra-anatomic bypass were excluded. Articles deemed relevant were selected for further consideration (Fig. 1). According to the academic research consortium of INAA [6] (ARC of INAA), diagnostic criteria for INAA consisted of (1) clinical criteria, which included clinical presentation, laboratory results, and imaging, and (2) pathological criteria, which included pus or abscess in the aneurysm wall or positive microbiological culture or histology from guided aspiration from aneurysms. According to the Management of Aortic Graft Infection Collaboration [4] (MAGIC), diagnostic criteria for aortic VGEI were divided into three categories including clinical or surgical criteria, radiological criteria and laboratory criteria. The INAAs and aortic VGEIs reported in all the included articles met the criteria defined by the ARC of INAA and the MAGIC criteria. The extracted data from the included studies included author's name, year of publication, methods of INAA repair, postoperative antibiotic treatment, in-hospital mortality, and aortic VGEI, which was defined as an infection of the aortic vascular graft in the open surgical repair group or of the endograft in the endovascular intervention group. Long-term antibiotic use was defined as total duration of administration of post-operative intravenous and oral antibiotics for more than four to six weeks after open surgical repair or endovascular intervention. Lifelong antibiotic use was defined as the indefinite use of oral antibiotics after discharge from the hospital. The extracted data are compiled in Tables 1 and 2. The pooled in-hospital mortality rates of the open surgical repair and endovascular intervention groups were compared (Table 3). The pathogens detected in the blood and tissue cultures of culture-positive patients are summarized in Table 4. The aortic VGEI rates corresponding to the different postoperative antibiotic strategies were summarized in Table 5. The quality and evidence level of the articles retrieved during the search were assessed and evaluated using the Oxford Evidence-Based Medicine Evidence Scale [7] (range of level 1 ~ 5; level 1: the highest; level 5: the lowest). Among the 47 included articles, 41 were cohort studies, four were nationwide registry studies, and two were multicenter

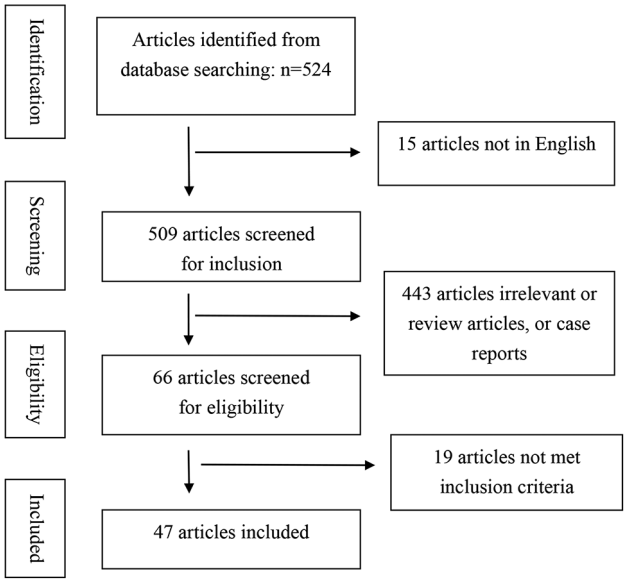

Fig. 1 Schematic representation of flow diaphragm for the articles included in the systematic review

studies. According to the Oxford Evidence-Based Medicine Evidence Scale, the level of evidence was three or four for the articles included in the study. The risk of bias in individual studies was appraised with the Risk of Bias Assessment Tool for Nonrandomized Studies [8]. We assigned a rating of "low", "high", or "unclear" to each of six bias domains (selection of participants, confounding variables, measurement of exposure, blinding of outcome assessment, incomplete outcome data, and selective outcome reporting). The risks of bias of the retrieved studies are presented in Table 6.

Data analysis

Descriptive statistics was performed. Categorical variables are expressed as numbers and percentages. The chi-square test or Fischer exact test was used to compare the in-hospital mortality rate, aortic VGEI rate and major detected pathogens between the open surgical repair group and the endovascular intervention group. STATA statistical software (STATA Corp., Texas, USA) was used for statistical analyses.

Results

Five hundred twenty-four studies were retrieved from the databases during our search. After screening, 47 articles were included in this study (Fig. 1).

Within the 47 articles retrieved from the databases, 1546 INAA patients (male, 72.8%) underwent open surgical repair or endovascular intervention [2, 3, 9–53]. The publication year ranged from 2000 to 2024, and the pooled mortality rate was 10.5% (163/1546), ranging from 0 to 40%. There were five articles in which the data of open surgical repair and endovascular intervention were not separated, seven articles in which the data of open surgical repair and endovascular intervention were reported separately, 17 articles involving open surgical repair, and 18 articles involving endovascular intervention. Therefore, there were 24 articles in which the data regarding open surgical repair were reported, and 25 articles in which the data regarding endovascular intervention were reported. For the five articles in which the data of open surgical repair and endovascular intervention were not separated, the data could not be used for subgroup analysis to elucidate the treatment effect of open surgical repair or endovascular intervention. Therefore, there were a total of 1179 patients who underwent open surgical repair (622 patients) or endovascular intervention (557 patients) for INAA. In the 24 articles involving open surgical repair, there were 622 patients who underwent in situ reconstruction, of whom 540 patients survived open surgical repair (pooled in-hospital mortality rate 13.2%). In the 25 articles involving endovascular intervention, 557 patients underwent endovascular aortic stenting, 517 of whom survived the endovascular intervention (pooled in-hospital mortality rate 7.2%). The pooled in-hospital mortality rate for patients who underwent open surgical repair was significantly higher ($p=0.001$) than that for patients who underwent endovascular intervention (Table 3). The mean or median postoperative follow-up duration ranged from 12 to 84 months for the open surgical repair group and from 8 to 64 months for the endovascular intervention group.

The results of the microbiological examination revealed a pooled culture-positive rate of 71.8% (831/1157). Information on pathogens was presented in all the studies involving open surgical repair; however, this information was not presented in four studies involving endovascular intervention. Notably, four studies involving both open surgical repair and endovascular intervention presented only pooled pathogen information. Articles in which researchers did not report pathogen information specific to open surgical repair or endovascular intervention were not included in the pathogen analysis. Therefore, pathogens were detected in 77.3% (401/519) of the patients in the open surgical repair group and 62.4% (277/444) of the patients in the endovascular intervention group. The most frequently detected pathogen was *Salmonella* species (23.1%), followed by *Staphylococcus* species (17.7%) and *Streptococcus* species (8.9%). The major pathogens detected in INAA patients are listed in Table 4.

Regarding the postoperative antibiotic strategies (Table 5), the duration of postoperative antibiotic administration varied, irrespective of whether open surgical repair or endovascular intervention was performed. For most of the articles involving open surgical repair, the duration of parenteral antibiotic administration ranged from four weeks to six weeks, but some researchers

Table 1 Results and postoperative antibiotic strategies for infective native aortic aneurysms with open surgical repair

Author	Year	Pt No	Antibiotic strategy after surgery	HD No	IAVG No
Liesker[9]	2022	13	Varying durations (Intravenous antibiotics 0 ~ 6 weeks, and then oral antibiotics 0 day to 7 months)	0	5
Sörelius[12]	2019	2	NA	0	0
Kim[13]	2017	19	Intravenous antibiotics for 4 ~ 6 weeks and then oral antibiotics	2	1
Lau[17]	2015	14	6 weeks of intravenous antibiotics for all and then lifelong oral antibiotics	1	0
Chen[18]	2005	17	All treated with appropriate antibiotics for 4 ~ 6 weeks	2	1
Premnath[19]	2021	4	Antibiotics of varying course lengths, and lifelong antibiotics for post-procedural infective complication	0	0
Nemoto[22]	2017	25	Intravenous antibiotics for at least 3 weeks and then lifelong oral antibiotics	3	0
Dang[24]	2020	13	All had antibiotics during hospitalization and the duration of antibiotics after discharge between 6 weeks and ongoing	1	0
Hashimoto[29]	2019	27	Use intravenous antibiotics until WBC count and CRP level normalized and no inflammatory findings on CT inaging	0	0
Dubois[32]	2010	44	Duration of antibiotic treatment was influenced by the type of surgical reconstruction	10	3
Kyriakides[33]	2004	15	Operative survivors were placed on antibiotics for 3 months	4	1
Oderich[35]	2001	42	Antibiotic duration based on surgeon's preference	9	2
Hsu[36]	2004	35	Intravenous antibiotics for at least 6 weeks and after discharge, duration of oral antibiotics determined by the surgeon	4	3
Luo[37]	2003	15	Surgical survivors had intravenous antibiotics for 2 ~ 6 weeks and only 8 survivors had oral antibiotics for 2 weeks to 9 months	2	0
Lin[38]	2014	77	NA	8	4
Kan[40]	2010	21	NA	1	1
Bisdas[42]	2011	33	Intravenous antibiotic use during parenteral nutrition and oral antibiotics continued for at least 2 weeks after discharge	6	2
Weis-Muller[43]	2011	36	Antibiotic for at least 6 weeks	12	1
Ting[44]	2005	7	Intravenous antibiotics for 2 ~ 6 weeks and lifelong antibiotic use except tuberculosis cases	0	0
Fillmore[46]	2003	10	NA	4	0
Sörelius[47]	2016	62	Median duration of antibiotic use 16 weeks (range 0 ~ 144) for the patients with infection-related complications	2	5
Lee[48]	2011	13	Intravenous antibiotics for at least 6 weeks or until clinical or laboratory parameters normalized	1	0
Heinola[49]	2018	56	Median duration of antibiotic use 8.5 weeks (range 1 ~ 35)	5	0
Yamashiro[50]	2013	22	Intravenous antibiotics until WBC and CRP level normalized (range 4 ~ 12 weeks) and oral antibiotic use after discharge	5	0

IAVG: infection of aortic vascular graft; HD: hospital death; WBC: white blood cell; CRP: c reactive protein; CT: computed tomography; NA: not available; No: number

reported the use of antibiotics for one to three weeks; nevertheless, a duration of up to 12 weeks has been reported. The detailed postoperative antibiotic strategies for the open surgical repair group are summarized in Table 1. For most of the articles involving endovascular intervention, the duration of parenteral antibiotic administration similarly ranged from four weeks to six weeks, but some researchers reported the use of antibiotics for less than one week to eight weeks. The detailed postoperative antibiotic strategies for the endovascular intervention group are summarized in Table 2. Oral antibiotics were used in more than half of the articles, but there were some articles in which oral antibiotics were not used and some articles involving the use of lifelong oral antibiotics, irrespective of whether open surgical repair or endovascular intervention was performed. The aortic VGEI rate for the surviving patients (Table 3) was significantly different ($p<0.001$) between the open surgical repair group (5.4%, 29/540) and the endovascular intervention (13.3%, 69/517) group.

Subgroup analysis was performed. For patients who underwent open surgical repair, the aortic VGEI rate did not significantly differ between patients who were treated with intravenous antibiotics for four to six weeks postoperatively (Table 7) (5.1%, 6/118) and those who were not treated with intravenous antibiotics for four to six weeks postoperatively (5.2%, 22/422). For patients who underwent open surgical repair, the rate of aortic vascular graft infection was significantly lower ($p=0.005$) in the group who received long-term antibiotic treatment (2.7%, 8/298) than in the group who did not receive long-term antibiotic treatment (8.3%, 20/242). However, for patients who underwent open surgical repair and received long-term antibiotic treatment, the rate of aortic vascular graft infection was not significantly different between the subgroup who received lifelong antibiotic treatment (1.5%, 1/66) and the subgroup who did not receive lifelong antibiotic treatment (3.0%, 7/232). Nevertheless, for the open surgical repair group with postoperative antibiotic treatment for four to six weeks and lifelong oral antibiotics

Table 2 Results and postoperative antibiotic strategies for infective native aortic aneurysms with endovascular intervention

Author	Year	Pt No	Antibiotic strategy after surgery	HD No	IAEG No
Zhu[2]	2020	16	Intravenous antibiotics for 4 ~ 8 weeks and then oral antibiotics, total duration for a minimum 12 months. Lifelong antibiotic if IRC	0	0
Liesker[9]	2022	7	Varying durations (Intravenous antibiotics 0 ~ 6 months, and then oral antibiotics 0 day, 2 months, lifelong)	0	3
Kazuno[10]	2020	8	Intravenous antibiotics for 5 ~ 35 days and then oral antibiotics for 2 ~ 6 months	0	0
Luo[11]	2017	40	All had intravenous antibiotics for 6 weeks and oral antibiotic use after discharge (duration determined by the surgeon)	1	8
Sörelius[12]	2019	50	Median duration of antibiotic use 14.5 weeks (range 0.5 ~ 220 weeks)	4	3
Huang[15]	2014	12	Surgical survivors had intravenous antibiotics for 0 days to 6 weeks and 4 patients had oral antibiotics	0	1
Lew[16]	2009	9	Surgical survivors has antibiotics for 60 days to 102 days	2	3
Premnath[19]	2021	13	Antibiotics of varying course lengths, and lifelong antibiotics for post-procedural infective complication	0	1
Jones[20]	2005	9	Duration of antibiotics from none, 2 doses, 4 weeks, to 6 weeks	1	2
Lin[3]	2020	22	All had intravenous antibiotics for 6 weeks and oral antibiotic use after discharge (duration determined by the treating clinician)	1	5
Sörelius[21]	2009	11	All had intravenous antibiotics during hospitalization and oral antibiotic use after discharge	1	1
Clough[23]	2009	19	Intravenous antibiotics initially and oral antibiotics after discharge (totally, median duration 42 days, range 28 ~ 91 days)	2	5
Dang[24]	2020	13	Intravenous antibiotics during hospitalization and antibiotic duration after discharge for 6 weeks to 1 year	0	1
Sörelius[25]	2014	123	Mean duration of antibiotic use 30 weeks (range 1 ~ 420 weeks)	11	18
Johnstone[26]	2013	7	Antibiotics: intravenous 2 weeks and oral 6 months for 2 survivors, intravenous 6 weeks for 4 survivors; lifelong antibiotics for 2	1	0
He[28]	2021	11	Mean duration of anti-tuberculosis medicine 13 months (range 8 ~ 44 months)	0	2
Silverberg[30]	2020	8	Antibiotics throughout the hospitalization and after discharge for a minimum of 3 months	1	1
Lin[38]	2014	8	NA	2	2
Kan[39]	2012	12	All had intravenous antibiotics for 4 weeks and then lifelong oral antibiotics were maintained	0	0
Sevidy[41]	2012	32	Surgical survivors has intravenous antibiotics for 4 ~ 8 weeks and at least 4 weeks after normalization of WBC, CRP, procalcitonin and body temperature, and lifelong oral antibiotic use after discharge	6	4
Ting[44]	2005	3	All had intravenous antibiotics for 2 ~ 6 weeks	0	1
Patel[45]	2010	27	All but one had antibiotics for more than 3 weeks	3	4
Sörelius[47]	2016	70	Median duration of antibiotic use 16 weeks (range 0 ~ 144) for the patients with infection-related complications	0	4
Kritpracha[51]	2012	21	Intravenous antibiotics for at least 10 days, until the patient was afebrile for 72 h	4	0
Tiesenhausen[53]	2008	6	Antibiotic use until ESR and CRP normalized or until the patient's death (mean 10.8 months, range2 ~ 18 months)	0	0

IAEG: infection of aortic endograft; HD: hospital death; IRC: infection related complications; WBC: white blood cell; ESR: erythrocyte sedimentation rate; CRP: c reactive protein; NA: not available; No: number

Table 3 Pooled outcomes by surgical options

Pooled outcome	Open surgical repair	Endovascular intervention	*P* value
In-hospital mortality	13.2% (82/622)	7.2% (40/557)	0.001
Aortic VGEI	5.4% (29/540)	13.3% (69/517)	< 0.001

Aortic VGEI: aortic vascular graft or endograft infection

(Table 5), the rate of aortic vascular graft infection was 0% (0/17).

Moreover, for patients who underwent endovascular intervention, there was no statistically significant difference in the aortic endograft infection rate (Table 8) between the group of patients who received intravenous antibiotic treatment for four to six weeks postoperatively (14.6%, 29/198) and the group of patients who did not receive intravenous antibiotic treatment for four to six weeks postoperatively (12.5%, 40/319). Among the patients who underwent endovascular intervention, the aortic endograft infection rate was not significantly different between those who received (14.5%, 57/392) and did not receive (9.6%, 12/125) long-term antibiotic treatment. However, among the patients who underwent endovascular intervention and received long-term antibiotic treatment, there was a trend ($p=0.071$) of lower rate of aortic endograft infection in the subgroup of patients who received lifelong antibiotic treatment (7.9%, 6/76) than in the subgroup of patients who did not receive lifelong antibiotic treatment (16.1%, 51/316). Nevertheless, for patients who underwent endovascular intervention with preoperative administration of antibiotics for four

Table 4 Major pathogens detected by blood culture or tissue culture

Pathogen	Open surgical repair (77.3%*, 401/519)	Endovascular intervention (62.4%*, 277/444)	*P* value
Salmonella	129 (24.9%)	79 (17.8%)	0.009
MSSA	83 (16.0%)	67 (15.1%)	NS
MRSA	28 (5.4%)	8 (1.8%)	0.003
Streptococcus	61 (11.8%)	38 (8.6%)	NS
E. coli	26 (5.0%)	8 (1.8%)	0.008
Pseudomonas	7 (1.3%)	3 (0.7%)	NS
Klebsiella	6 (1.2%)	1 (0.2%)	NS
Enterococcus	6 (1.2%)	7 (1.6%)	NS
Tuberculosis	8 (1.5%)	17 (3.8%)	0.040
Fungus	6 (1.2%)	2 (0.5%)	NS

*culture-positive rate

MSSA: methicillin-sensitive *Staphylococcus aureus*; MRSA: methicillin-resistent *Staphylococcus aureus*

The table is presented as culture-positive patient number (percentage) for major detected pathogens

Table 5 The aortic VGEI by different surgical options with different antibiotic strategies

Antibiotic strategy	Open surgical repair	Endovascular intervention	*P* value
(2)	5.1% (6/118)	14.6% (29/198)	0.009
(3)	2.7% (8/298)	14.5% (57/392)	< 0.001
(4)	1.5% (1/66)	7.9% (6/76)	0.122
(1)+(3)	0.0% (0/82)	12.6% (17/135)	< 0.001
(2)+(4)	0.0% (0/17)	7.5% (5/67)	NS
(1)+(2)+(3)+(4)	0.0% (0/4)	3.4% (1/29)	NS

Aortic VGEI: aortic vascular graft or endograft infection; (1) pre-operative intravenous antibiotics for 4 to 6 weeks; (2) post-operative intravenous antibiotics for 4 to 6 weeks; (3)long-term antibiotic treatment; (4) lifelong antibiotic use; NS: non-significant

to six weeks, postoperative administration of antibiotics for four to six weeks, and lifelong oral antibiotic use (Table 5), the rate of aortic endograft infection was 3.4% (1/29).

Discussion

Mycotic aortic aneurysm is a historical misnomer, and a more appropriate term would be infective native aortic aneurysm [6]. Treatment of INAA is challenging as it is usually based on the patient's conditions to determine surgical timing, surgical options and antibiotic administration. Prior to starting antibiotic treatment, adequate procurement of microbiological specimens to guide the diagnosis and management of INAAs is very important [54]. In this study, the culture-positive rate was higher in the open surgical repair group than in the endovascular intervention group. In addition to blood cultures, tissue cultures from the aortic wall or fluid surrounding the aortic aneurysm could be obtained without difficulty from the group of patients who underwent open surgical repair. For the endovascular intervention group, more efforts, such as polymerase chain reaction [6], repetitive blood culture, and procurement of specimens for culture from urine and respiratory tract or other symptomatic organs, should be considered to improve the pathogen detection rate. In this study, the most frequently detected pathogen was *Salmonella* species (23.1%), followed by *Staphylococcus* species (17.7%) and *Streptococcus* species (8.9%), whereas the most frequently detected pathogen in Sweden [55] was *Staphylococcus* species (20.9%), followed by *Streptococcus* species (20.3%) and *Salmonella* species (10.4%). Therefore, it is important to determine which pathogen is most frequently detected in INAA patients in specific geographical locations to choose the optimal antibiotics.

Moreover, there is no doubt that emergency surgery (open surgical repair or endovascular intervention) is needed if the infection is uncontrollable or if the aneurysm has ruptured or is in a status of impending rupture, as emergency surgery for life-threatening conditions should be prioritized along with the administration of antibiotics. However, according to a systematic review [56], it seems still to be no clear consensus on the optimal timing of surgery for patients whose condition has stabilized after initial medical treatment. Similarly, according to the findings from our systematic review, some researchers preferred to administer antibiotics for four to six weeks preoperatively, sometimes longer, if the patient's condition was stable, some researchers preferred to perform surgery after only 1 week of antibiotic treatment, and others preferred to determine the best time for surgery on the basis of the results of clinical evaluation without consideration for the duration of preoperative antibiotic treatment. However, according to expert consensus [57] from the ARC of INAA, whether delaying surgical treatment to allow a certain period of preoperative antimicrobial therapy is beneficial for infection control and perhaps reducing the risk of infection-related complications is unclear despite the risk of aneurysm rupture. Therefore, according to expert consensus [57] from the ARC of INAA, surgical treatment should be performed as soon as possible and the exact timing depends on the clinical status of the patient.

Surgical mortality is likely strongly related to the general condition of the patient with an INAA; for example, a higher mortality rate could be anticipated for patients with septic shock. According to our study, the mortality rate was significantly higher ($p=0.001$) in the open surgical repair group (13.2%) than in the endovascular intervention group (7.2%). However, other factors likely affect the treatment results, such as the patient's general condition, extent of the INAA, response to antibiotic treatment, and need for emergency surgery. Therefore, risk stratification is necessary and important for the selection of the optimal treatment modality. According to expert

Table 6 The risk of bias of the included studies

Open surgical Repair							**Endovascular Intervention**						
Study	D1	D2	D3	D4	D5	D6	Study	D1	D2	D3	D4	D5	D6
Liesker[7]	⊕	⊖	⊖	⊖	⊕	⊕	Zhu[2]	⊕	⊖	⊖	⊖	⊕	⊕
Sörelius[10]	⊕	⊕	⊕	⊖	⊕	⊕	Liesker[7]	⊕	⊖	⊖	⊖	⊕	⊕
Kim[11]	⊕	⊖	⊖	⊖	⊕	⊕	Kazuno[8]	⊕	⊖	⊖	⊖	⊕	⊕
Lau[15]	⊕	⊖	⊖	⊖	⊕	⊕	Luo[9]	⊕	⊖	⊖	⊖	⊕	⊕
Chen[16]	⊕	⊖	⊖	⊖	⊕	⊕	Sörelius[10]	⊕	⊕	⊕	⊖	⊕	⊕
Premnath[17]	⊕	⊖	⊖	⊖	⊕	⊕	Huang[13]	⊕	⊖	⊖	⊖	⊕	⊕
Nemoto[20]	⊕	⊖	⊖	⊖	⊕	⊕	Lew[14]	⊕	⊖	⊖	⊖	⊕	⊕
Dang[22]	⊕	⊕	⊕	⊖	⊕	⊕	Premnath[17]	⊕	⊖	⊖	⊖	⊕	⊕
Hashimoto[27]	⊕	⊖	⊖	⊖	⊕	⊕	Jones[18]	⊕	⊖	⊖	⊖	⊕	⊕
Dubois[30]	⊕	⊖	⊖	⊖	⊕	⊕	Lin[3]	⊕	⊖	⊖	⊖	⊕	⊕
Kyriakides[31]	⊕	⊖	⊖	⊖	⊕	⊕	Sörelius[19]	⊕	⊖	⊖	⊖	⊕	⊕
Oderich[33]	⊕	⊖	⊖	⊖	⊕	⊕	Clough[21]	⊕	⊖	⊖	⊖	⊕	⊕
Hsu[34]	⊕	⊖	⊖	⊖	⊕	⊕	Dang[22]	⊕	⊕	⊕	⊖	⊕	⊕
Luo[35]	⊕	⊖	⊖	⊖	⊕	⊕	Sörelius[23]	⊕	⊖	⊖	⊖	⊕	⊕
Lin[36]	⊕	⊖	⊖	⊖	⊕	⊕	Johnstone[24]	⊕	⊖	⊖	⊖	⊕	⊕
Kan[38]	⊕	⊖	⊖	⊖	⊕	⊕	He[26]	⊕	⊖	⊖	⊖	⊕	⊕
Bisdas[40]	⊕	⊖	⊖	⊖	⊕	⊕	Silverberg[28]	⊕	⊖	⊖	⊖	⊕	⊕
Weis-Muller[41]	⊕	⊖	⊖	⊖	⊕	⊕	Lin[36]	⊕	⊖	⊖	⊖	⊕	⊕
Ting[42]	⊕	⊖	⊖	⊖	⊕	⊕	Kan[37]	⊕	⊖	⊖	⊖	⊕	⊕
Fillmore[44]	⊕	⊖	⊖	⊖	⊕	⊕	Sevidy[39]	⊕	⊖	⊖	⊖	⊕	⊕
Sörelius[45]	⊕	⊕	⊕	⊖	⊕	⊕	Ting[42]	⊕	⊖	⊖	⊖	⊕	⊕
Lee[46]	⊕	⊖	⊖	⊖	⊕	⊕	Patel[43]	⊕	⊖	⊖	⊖	⊕	⊕
Heinola[47]	⊕	⊖	⊖	⊖	⊕	⊕	Sörelius[45]	⊕	⊕	⊕	⊖	⊕	⊕
Yamashiro[48]	⊕	⊖	⊖	⊖	⊕	⊕	Kritpracha[49]	⊕	⊖	⊖	⊖	⊕	⊕
							Tiesenhausen[51]	⊕	⊖	⊖	⊖	⊕	⊕

D1, Selection of participants; D2, Confounding variables; D3, Measurement of exposure; D4, Blinding of outcome assessment; D5, Incomplete outcome data; D6, Selective outcome reporting; ⊕, Low risk of bias; ⊙, Unclear risk of bias; ⊖, High risk of bias

Table 7 The aortic VGEI by different postoperative antibiotic strategies for the group of open surgical repair

Antibiotic strategy	With	Without	*P* value
IV Ab for 4 ~ 6 weeks	5.1% (6/118)	5.2% (22/422)	NS
Long-term Ab	2.7% (8/298)	8.3% (20/242)	0.005
Lifelong Ab (for pts with long-term Ab)	1.5% (1/66)	3.0% (7/232)	NS

Aortic VGEI: aortic vascular graft or endograft infection; IV: intravenous; Ab: antibiotics; NS: non-significant; pts: patients;

Table 8 The re-infection rate of the aortic grafts by different postoperative antibiotic strategies for the group of endovascular intervention

Antibiotic strategy	With	Without	*P* value
IV Ab for 4 ~ 6 weeks	14.6% (29/198)	12.5% (40/319)	NS
Long-term Ab	14.5% (57/392)	9.6% (12/125)	NS
Lifelong Ab (for pts with long-term Ab)	7.9% (6/76)	16.1% (51/316)	0.071

IV: intravenous; Ab: antibiotics; NS: non-significant; pts: patients

consensus [57] from the ARC of INAA, the surgical treatment for INAAs should be tailored to each individual patient, taking age, comorbidities, clinical status and anatomical location of the aneurysm into account, coupled with the surgical expertise of the team.

In most of our retrieved articles, the researchers reported that intravenous antibiotics were used perioperatively, while very few patients [9, 15] received oral antibiotic treatment instead of intravenous antibiotic treatment postoperatively. According to expert consensus [57] from the ARC of INAA, empirical intravenous antibiotic therapy should be initiated immediately after extensive sampling for blood or tissue culture. For INAA patients, intravenous antibiotic treatment for an active infection is a rational treatment modality, as the efficacy of oral antibiotics may be adversely affected by the drug absorption rate or impaired gastrointestinal function. The focus of our study was to identify the factors correlated with postoperative aortic VGEI, and we found that the surgical options and duration of postoperative antibiotic use were two of the most important factors. Open surgical repair is more invasive, and extensive debridement of the aneurysms and adjacent necrotic materials is possible, whereas endovascular intervention is less invasive, and debridement cannot be performed. Therefore, it is rational to believe that open surgical repair combined with long-term or even lifelong antibiotic use decreases the rate of aortic vascular graft infection (Table 5). Regarding surgical options, it is reasonable that endovascular intervention has been preferred by many surgeons and many patients because of its lower degree of invasiveness and therefore lower periprocedural mortality rate. Our study revealed a significantly higher rate of aortic VGEI in the endovascular intervention group than in the open surgical repair group, and we believe that nondebridement of the aneurysms and adjacent necrotic materials in the endovascular intervention group could be among the most important factors. Therefore, for the endovascular intervention group, the duration of postoperative antibiotic use and even long-term or lifelong antibiotic use should be considered critical for the prevention of an aortic VGEI. According to expert consensus [57] from the ARC of INAA, after open surgical repair with synthetic grafts or after endovascular aortic repair, antimicrobial therapy should be continued for at least three to six months and, in selected cases, should be lifelong. As shown in our study, the duration of preoperative and postoperative antibiotic use varies in the literature, and discrepancies exist in the administration of long-term or lifelong oral antibiotics. However, subgroup analysis revealed the important role of long-term or lifelong antibiotic use for preventing aortic VGEIs in both the open surgical repair and endovascular intervention groups.

In summary, although open surgical repair is more invasive and has a higher surgical mortality rate than endovascular intervention, open surgical repair could be a treatment option with a lower aortic VGEI rate for the patients with low surgical risk. In contrast, endovascular intervention is less invasive and has a lower surgical mortality rate than open surgical repair; thus, it should be preferred for high-risk patients. In this context, long-term and even lifelong antibiotic use should be considered to lower the rate of aortic endograft infection and improve long-term survival.

Limitations

All the included studies were non-randomized control studies, which limited implications of the comparison between the open surgical repair and endovascular intervention groups. In addition, non-English articles were excluded as the comprehensiveness of the review was reduced. There was heterogeneity among the retrieved studies, which was inevitable. However, for our study, we think the intra-group analysis is more important than intergroup analysis because improvement in treatment outcomes is the most important goal, irrespective of whether open surgical repair or endovascular intervention is performed. Regardless of which treatment modality was selected, our study revealed the importance of aggressive antibiotic treatment postoperatively.

Conclusion

Infective native aortic aneurysm is a life-threatening disease. The pooled in-hospital mortality rate of the open surgical repair group was significantly higher than that of the endovascular intervention group, whereas the rate of aortic VGEI in the open surgical repair group was

significantly lower than that in the endovascular intervention group. Open surgical repair is more invasive and has a higher surgical mortality rate; thus, it could be a treatment option for INAA patients with a low surgical risk, as the rate of aortic vascular graft infection is lower. Moreover, endovascular intervention is less invasive and has a lower surgical mortality rate; thus, it is preferable for INAA patients with higher surgical risk despite the higher rate of aortic endograft infection. According to expert consensus [57] from the ARC of INAA, after open surgical repair with synthetic grafts or after endovascular aortic repair, antimicrobial therapy should be continued for at least three to six months and, in selected cases, should be lifelong. In our study, regardless of whether open surgical repair or endovascular intervention was performed, better long-term outcomes were achieved with aggressive antibiotic treatment, which is especially important for patients who undergo endovascular intervention.

Author contributions

S.J.: study design, literature searching, literature review, statistical analysis, manuscript writing, manuscript approvalS. S.: study design, literature review, manuscript approvalY. H.: study design, literature searching, manuscript approvalC. Y.: study design, literature review, manuscript approval.

Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethical approval

Because the study is a systematic review, there is no need for ethical approval.

Sources of financial or non-financial support for the review

Nil.

Competing interests

The authors declare no competing interests.

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