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Risk factors for pneumonia after radical gastrectomy for gastric cancer: a systematic review and meta-analysis

Siyue Fan[1,2], Hongzhan Jiang[3], Qiuqin Xu[4], Jiali Shen[5], Huihui Lin[6], Liping Yang[2], Doudou Yu[2], Nengtong Zheng[2] and Lijuan Chen[1,2*]

Abstract

Objective The objective is to systematically gather relevant research to determine and quantify the risk factors and pooled prevalence for pneumonia after a radical gastrectomy for gastric cancer.

Methods The reporting procedures of this meta-analysis conformed to the PRISMA 2020. Chinese Wan Fang data, Chinese National Knowledge Infrastructure (CNKI), Chinese Periodical Full-text Database (VIP), Embase, Scopus, CINAHL, Ovid MEDLINE, PubMed, Web of Science, and Cochrane Library from inception to January 20, 2024, were systematically searched for cohort or case–control studies that reported particular risk factors for pneumonia after radical gastrectomy for gastric cancer. The pooled prevalence of pneumonia was estimated alongside risk factor analysis. The quality was assessed using the Newcastle–Ottawa Scale after the chosen studies had been screened and the data retrieved. RevMan 5.4 and R 4.4.2 were the program used to perform the meta-analysis.

Results Our study included data from 20,840 individuals across 27 trials. The pooled prevalence of postoperative pneumonia was 11.0% (95% CI = 8.0% ~ 15.0%). Fifteen risk factors were statistically significant, according to pooled analyses. Several factors were identified to be strong risk factors, including smoking history (OR 2.71, 95% CI = 2.09 ~ 3.50, I^2 = 26%), prolonged postoperative nasogastric tube retention (OR 2.25, 95% CI = 1.36–3.72, I^2 = 63%), intraoperative bleeding ≥ 200 ml (OR 2.21, 95% CI = 1.15–4.24, I^2 = 79%), diabetes mellitus (OR 4.58, 95% CI = 1.84–11.38, I^2 = 96%), male gender (OR 3.56, 95% CI = 1.50–8.42, I^2 = 0%), total gastrectomy (OR 2.59, 95% CI = 1.83–3.66, I^2 = 0%), COPD (OR 4.72, 95% CI = 3.80–5.86, I^2 = 0%), impaired respiratory function (OR 2.72, 95% CI = 1.58–4.69, I^2 = 92%), D2 lymphadenectomy (OR 4.14, 95% CI = 2.29–7.49, I^2 = 0%), perioperative blood transfusion (OR 4.21, 95% CI = 2.51–7.06, I^2 = 90%), and hypertension (OR 2.21, 95% CI = 1.29–3.79, I^2 = 0%). Moderate risk factors included excessive surgery duration (OR 1.51, 95% CI = 1.25–1.83, I^2 = 90%), advanced age (OR 1.91, 95% CI = 1.42–2.58, I^2 = 94%), nutritional status (OR 2.62, 95% CI = 1.55–4.44, I^2 = 71%), and history of pulmonary disease (OR 1.61, 95% CI = 1.17–2.21, I^2 = 79%).

Conclusions This study identified 15 independent risk factors significantly associated with pneumonia after radical gastrectomy for gastric cancer, with a pooled prevalence of 11.0%. These findings emphasize the importance of targeted preventive strategies, including preoperative smoking cessation, nutritional interventions, blood glucose and blood pressure control, perioperative respiratory training, minimizing nasogastric tube retention time, and optimizing perioperative blood transfusion strategies. For high-risk patients, such as the elderly, those undergoing

*Correspondence:
Lijuan Chen
xmetchenlijuan@163.com
Full list of author information is available at the end of the article

prolonged surgeries, experiencing excessive intraoperative blood loss, undergoing total gastrectomy, or receiving open surgery, close postoperative monitoring is essential. Early recognition of pneumonia signs and timely intervention can improve patient outcomes and reduce complications.

Keywords Stomach neoplasms, Pneumonia, Risk factors, Meta-analysis, Systematic review

Introduction

According to the Global Cancer Statistics 2018, gastric cancer is the fifth most common cancer worldwide and the third leading cause of cancer deaths [1]. Although radical gastrectomy is the only curative treatment, postoperative complications remain significant [2–7]. Notably, the incidence of postoperative pneumonia after radical gastrectomy ranges from 2.2% to 26% [8–13], leading to longer hospital stays, increased costs (up to $40,000) [14, 15], and a mortality rate as high as 30% [16, 17].

A previous meta-analysis on gastric endoscopic submucosal dissection identified various risk factors for postoperative pneumonia [18]. However, since radical gastrectomy remains the standard treatment for gastric cancer, a focused meta-analysis on risk factors specific to radical gastrectomy is of critical clinical significance.

Research on risk factors for postoperative pneumonia following radical gastrectomy has yielded inconsistent results. For example, while some studies suggest that total gastrectomy [3, 10, 19] and male gender [7, 20] are associated with a higher pneumonia risk, others do not support these associations [8, 12, 21]. These discrepancies likely stem from diverse study designs, where variations in patient demographics, such as some studies focused on elderly patients over the age of 75 [12], and some studies focused on patients after laparoscopic surgery [3], which may lead to differences in results and surgical settings [7], introduce heterogeneity, compounded by biases common in retrospective analyses. Statistical methods also play a role, as smaller sample sizes in some studies [13], combined with inadequate control of confounders, such as smoking or COPD, could obscure true relationships [21]. Beyond methodology, individual responses to surgical trauma differ, with some patients experiencing greater diaphragmatic impairment or immunosuppression, potentially heightening pneumonia risk [20]. Over time, technical progress and optimized preoperative care, may reduce risks, reflecting evolving surgical practice [22].

International guidelines provide practical strategies for pneumonia prevention that align with our findings. For example, the ERAS Society recommends preoperative nutritional optimization and smoking cessation [23], along with minimizing operative time and promoting early postoperative mobilization and respiratory physiotherapy [24]. Similarly, the American College of Physicians [25] and WHO emphasize preoperative risk assessments, respiratory training, and postoperative early mobilization to reduce pulmonary complications [26]. Additionally, NCCN guidelines advocate comprehensive preoperative assessments and tailored antibiotic prophylaxis for high-risk oncology patients [27], while ATS/IDSA guidelines recommend cautious antimicrobial use to prevent resistance [28, 29]. These recommendations underscore the clinical relevance of our study by translating empirical risk factors into actionable preventive strategies.

For identifying the risk factors and strength and correlations linked to pneumonia after radical gastrectomy for gastric cancer, a thorough systematic review and meta-analysis, determined solely through multivariable logistic regression analyses to reduce the influence of confounding factors, are necessary. Such a study would provide healthcare providers with a solid scientific basis to identify populations at high risk of postoperative pneumonia and develop effective plans for symptom management.

Methods

This meta-analysis adhered to the PRISMA 2020 guidelines [30] and was registered on PROSPERO (CRD42024506161).

Inclusion and exclusion criteria

Inclusion criteria

The PECOs principles (P: Participants; E: Exposures; C: Comparisons; O: Outcomes; s: Study Design) were strictly adhered to by the inclusion criteria.

- P: Patients (aged ≥ 18 years) undergoing radical gastrectomy for gastric cancer, including both open and laparoscopic surgery.
- E: Multivariate logistic regression was utilized in the initial investigation to pinpoint at least one risk factor for pneumonia.
- C: Lack of risk factors for pneumonia.
- O: Any approved, globally recognized diagnostic standards or evaluation instruments for pneumonia [31].
- S: Cohort and case–control studies.

Exclusion criteria

- The entire research text couldn't be available.
- Relevant information was either unavailable or inconsistent, or it could not be found by getting in touch with the original writers.
- The following types of studies were excluded: case studies, reviews, editorials, duplicate publications, and incomplete articles.
- Animal studies.
- Low-quality literature (NOS < 4).

Search strategy

From January 20, 2024, to the date of their respective inception, two reviewers independently searched the following databases: Chinese National Knowledge Infrastructure (CNKI), Chinese Periodical Full-text Database (VIP), Chinese Wan fang Data, PubMed, Web of Science, Cochrane Library, CINAHL, Ovid MEDLINE, Embase, and Scopus. Additionally, a backward search was carried out to find more references from the included papers and pertinent earlier reviews or meta-analyses. The reviewers combined Mesh terms with free words and appropriately used Boolean logic operators to develop search strategies. The Mesh terms and free words used included "stomach neoplasms (MeSH)", "stomach cancer", "gastric cancer", "gastric neoplasms", "radical gastrectomy", "gastrectomy surgery", "pneumonia (MeSH)", "lung infection", "pulmonary infection", "hospital acquired pneumonia", "aspiration pneumonia", "risk factors (MeSH)", "influence factors", "predicted factors", "relevant factors", "dangerous factors". The details of the utilized PubMed search approach are provided in Appendix 1. This meta-analysis only included studies published in English or Chinese. The titles and abstracts obtained from the electronic search were independently scanned by two reviewers to find possible applicable studies, which were then filtered in accordance with the inclusion criteria. Any disagreements were resolved by a third reviewer. To ensure a comprehensive literature review, we attempted to retrieve unpublished data by directly contacting the corresponding authors of eligible studies. Authors were asked to provide additional methodological details or subgroup data relevant to our analysis. Furthermore, we searched for gray literature, including conference abstracts, research proposals, and dissertations, to minimize potential publication bias.

Data extraction

Two experienced reviewers separately extracted the data. If there were any differences, these were worked out by consensus-building discussions or consultations with a third reviewer. Data extraction utilized a standardized Microsoft Excel spreadsheet, capturing the following details: first author, study type, publication year, total sample size, country or region, age, sex ratio, pneumonia incidence, pneumonia diagnosis, surgical procedures, and associated risk factors. Furthermore, risk factors for pneumonia were obtained from multifactorial logistic regression analysis, including odds ratio (OR), 95% confidence intervals (CI), and *p*-values.

Quality evaluation and certainty assessment

Literature quality was independently evaluated by 2 investigators. For cross-sectional studies, the Agency for Healthcare Research and Quality (AHRQ) assessment tool was utilized, comprising 11 items where each item was scored as "yes", "no", or "unclear". The total score ranges from 0 to 11, with studies categorized as: low quality (0–3), medium quality (4–7), or high quality (≥ 8) [32]. For case–control and cohort studies, the Newcastle–Ottawa Scale (NOS) was applied, classifying studies as low (1–3), medium (4–6), or high quality (7–9) based on cumulative scores [33].

Statistical analysis

The meta-analysis in this study was conducted using RevMan 5.4 software and R 4.4.2. Risk difference (RD) was selected as an indicator to evaluate the prevalence of pneumonia after radical gastrectomy, and the aggregated effect size was calculated using the general inverse variance method. Risk factors for pneumonia after radical gastrectomy were expressed using odds ratios (ORs) and 95% confidence intervals (CIs). The OR values of the risk factors were extracted from the multivariate logistic regression analyses of the original studies, and their standard errors (SE) were calculated for meta-analysis. Meta-analyses were performed for risk factors reported in two or more studies, and descriptive analyses were performed for risk factors reported in fewer than two studies. Specifically, we extracted risk factor names, adjusted ORs, and their 95%CIs from each study and qualitatively described them in the results. Risk factors exhibiting statistical significance were categorized as high risk (OR ≥ 2), moderate risk (1 < OR < 2), or protective (OR < 1). Heterogeneity among the studies was analyzed using the Q test and I^2 statistic. An I^2 value of 0–25% indicated low heterogeneity, 26–50% indicated moderate heterogeneity, and 51–100% indicated high heterogeneity. In cases where $P \geq 0.1$ and $I^2 \leq 50\%$, indicating no significant statistical heterogeneity among studies, a fixed-effects model was employed for the meta-analysis. Alternatively, for $P < 0.1$ or $I^2 > 50\%$, which was indicative of significant heterogeneity, a random-effects model was adopted. Sensitivity analysis was carried out using

the leave-one-out method and by changing the effect model. In cases of significant heterogeneity, subgroup analyses and meta-regression were conducted to explore the influence of study characteristics on the effect size. When at least 10 studies reported the prevalence rate or a particular risk factor, funnel plots were generated using R 4.4.2, and Begg's and Egger's tests were used to assess publication bias [34, 35]. A significance level of $P < 0.05$ was considered statistically significant. In the presence of publication bias, the trim and fill method was applied to adjust for potential missing studies and to re-estimate the combined effect size.

Results

Study process

After a preliminary search found 2287 publications, only 27 of them were ultimately included. The flow chart for the literature screening procedure is shown in Fig. 1.

Study characteristics

There were 3 case–control studies, 23 retrospective cohort studies, and 1 prospective cohort research among the included studies. 12 of these studies were published in English, and 15 in Chinese. With a cumulative case group of 1,435 and a case–control group of 19,405, the studies' total sample size was 20,840. Pneumonia ranged in incidence or prevalence from 2.1% to 26.38%. The research, most of which were from China ($n = 19$) and Japan ($n = 8$), were published between 2008 and 2023. The main methods for diagnosing pneumonia include imaging, lab work, and clinical presentation. The main features of the 27 assessed studies are shown in Table 1.

Quality evaluation of included studies

Among the included studies, 24 studies were rated as high quality according to the NOS, while the other 3 studies were rated as moderate quality. The main weaknesses in the studies rated as moderate quality were in the Outcome and Comparability domains. The Outcome domain included unclear methods for outcome assessment, no mention of follow-up time, and no reporting of follow-up results. The main issue in the Comparability domain was the lack of mention of methods to control for confounding factors (Table 2). These limitations may lead to inaccurate or incomplete reporting of outcome events, and the lack of control for potential confounding factors may mean that the study results are influenced by other factors, potentially introducing some bias to our overall conclusions. For example, in studies with unclear outcome assessment methods, the incidence of postoperative pneumonia might be over- or underestimated. Similarly, the lack of control for important confounding

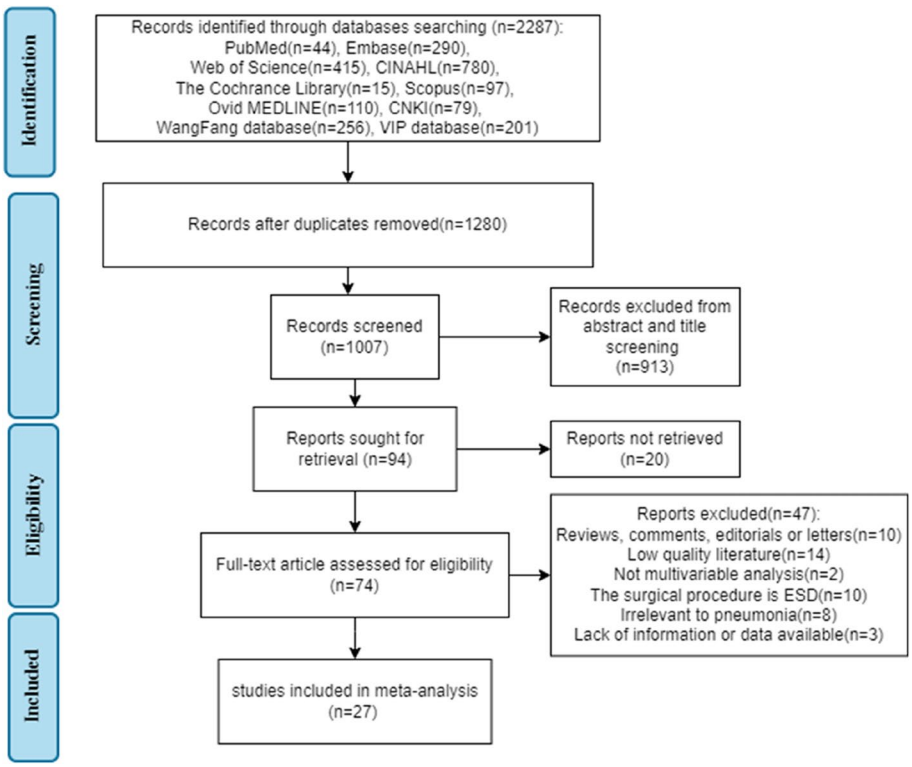

Fig.1 Flowchart of study selection

Table 1 Characteristics of the included studies

Author (year)	Country	Study design	Age (year)	Male/female	Total patients	Cases number	Controls number	Pneumonia incidence (%)	Pneumonia diagnosis	Surgical Procedures	Risk factors
Yao et al. 2019 [36]	China	Retrospective cohort	N/A	277/96	373	50	323	13.4	Symptom + laboratory data + imaging (X-ray/CT)	Radical D2 lymph node dissection for gastric cancer (total Gastrectomy, distal gastrectomy, proximal gastrectomy)	Preoperative comorbidities, abdominal infection, wound pain
Han et al 2017 [37]	China	Retrospective cohort	59.1(22 ~ 80)	265/106	371	38	333	10.2	Symptom + laboratory data + imaging (X-ray/CT)	Radical D2 lymph node dissection for gastric cancer (total gastrectomy:173, distal gastrectomy:15, proximal gastrectomy:183)	Postoperative gastric intubation > 6 d, smoking history, intraoperative blood loss ≥ 200 ml
Xiao et al 2014 [38]	China	Case Control	54.3(19 ~ 81)	504/261	765	32	733	4.18	Symptom + laboratory data + imaging (X-ray/CT)	Radical D2 lymph node dissection for gastric cancer (total gastrectomy:118, distal gastrectomy:548, proximal gastrectomy:45, combined organ removal:48, residual gastrectomy:6)	Diabetes mellitus, post-operative complications other than pulmonary infection, intra-operative blood loss ≥ 300 ml, post-operative nasogastric tube ≥ 5 days
Xiao et al. 2019 [39]	China	Retrospective cohort	55.4(19–86)	1624/845	2469	65	2404	2.63	Imaging (X-ray/CT)	Radical D2 lymph node dissection for gastric cancer (subtotal gastrectomy:1888, total gastrectomy:581)	COPD, open operative procedure, operation time ≥ 4 h, intra-operative blood transfusion, tumor located at middle third

Table 1 (continued)

Author (year)	Country	Study design	Age (year)	Male/female	Total patients	Cases number	Controls number	Pneumonia incidence (%)	Pneumonia diagnosis	Surgical Procedures	Risk factors
Mohri et al. 2008 [7]	Japan	Prospective cohort	68(22–91)	359/170	529	20	509	3.8	Symptom + imaging (X-ray/CT)	Radical D2 lymph node dissection for gastric cancer (total gastrectomy:177, distal gastrectomy or proximal gastrectomy:352)	Male gender, intra-and/or postoperative blood transfusion
Kamiya et al 2022 [9].	Japan	Retrospective cohort	77(75–87)	109/58	167	44	123	26	Imaging (CT)	Gastrectomy with D1 or D1 plus dissection	Preoperative sarcopenia
Meng et al [40]	China	Retrospective cohort	73.7	235/111	346	51	295	14.7	Symptom + laboratory data + imaging (X-ray/CT)	N/A	Mf 1
Tu et al. 2017. [13]	China	Retrospective cohort	59.54 ± 11.24	4028/1299	5327	383	4944	7.2	Imaging (X-ray/CT) + laboratory data	D1 + (D1 plus Nos. 8a, 9, 11p in total or proximal gastrectomy, or D1 plus Nos. 8a, 9 in distal gastrectomy)/ D2 (D1 plus Nos. 8a, 9, 10, 11p, 11 d, 12a in total gastrectomy, or D1 plus Nos. 8a, 9, 11p, 12a in distal gastrectomy) lymphadenectomy with digestive tract reconstruction	Age, ASA classification ≥ 3, tumor diameter, open gastrectomy, operative time, blood loss
Kiuchi et al 2016 [3]	Japan	Retrospective cohort	N/A	955/458	1413	31	1382	2.2	Symptom + laboratory data + imaging (X-ray/CT)	D1 or $D1^{+}$ lymphadenectomy, D2 or $D2^{+}$ lymphadenectomy	Older age, lower nutritious status, advanced stage, concurrent hypertension, total gastrectomy

Table 1 (continued)

Author (year)	Country	Study design	Age (year)	Male/female	Total patients	Cases number	Controls number	Pneumonia incidence (%)	Pneumonia diagnosis	Surgical Procedures	Risk factors
Suzuki et al 2017 [20]	Japan	Retrospective cohort	79.0 ± 3.7	169/81	250	32	218	12.8	Symptom + laboratory data + imaging (X-ray/CT)	D1 or $D1^+$ lymphadenectomy, D2 or $D2^+$ lymphadenectomy	Male gender, D2 lymphadenectomy
Miki et al 2016 [21]	Japan	Retrospective cohort	68(19–90)	530/220	750	32	718	4.3	Symptom + laboratory data + imaging (X-ray/CT)	Total gastrectomy:206, distal gastrectomy: 378, pylorus-preserving gastrectomy:128, proximal gastrectomy: 38, D1–D1 + :409, ≥ D2:335	Age, impaired postoperative respiratory function, diabetes mellitus, blood transfusion
Kimura et al [12]	Japan	Retrospective cohort	Older group: 79(75–90), younger group: 63 (27–74)	495/233	728	30	698	4.2	Symptom + laboratory data + imaging (X-ray/CT)	Laparoscopic assisted gastrectomy, total laparoscopic gastrectomy $D1^+$ lymphadenectomy: older group:87, younger group: 310. D2 lymphadenectomy: older group: 79, younger group: 252	Age, presence of COPD, D2 lymphadenectomy
Ntutumu et al 2016 [19]	China	Retrospective cohort	55 ± 12	822/383	1205	56	1149	4.6	Symptom + laboratory data + imaging (X-ray/CT)	Subtotal gastrectomy:862, total gastrectomy:343	Advanced age, COPD, operative method (total gastrectomy), time to first diet, postoperative hospital stay

Table 1 (continued)

Author (year)	Country	Study design	Age (year)	Male/female	Total patients	Cases number	Controls number	Pneumonia incidence (%)	Pneumonia diagnosis	Surgical Procedures	Risk factors
Cho et al [8]	Japan	Retrospective cohort	No post operative pneumonia: 81 Post operative pneumonia: 79	171/80	251	15	236	6.0	Symptom + imaging (X-ray/CT)	Total gastrectomy, distal gastrectomy, proximal gastrectomy, laparoscopic, robotic approaches	Male, poor performance status, cardia-non-preserving gastrectomy
Shoka et al 2020 [10]	Japan	Retrospective cohort	68(26–91)	1.009:406	1415	42	1373	3.0	Laboratory data + imaging (X-ray/CT)	Total gastrectomy:345, partial gastrectomy:1070, open surgery:926, laparoscopic:489, D2 lymph node dissection:664	Systemic Inflammation Score, pulmonary comorbidities, total gastrectomy
Zhao et al. 2019 [41]	China	Retrospective cohort	N/A	192/148	340	32	308	9.41	Symptom + laboratory data + imaging (X-ray)	Laparoscopic	Diabetes mellitus, hypoproteinemia, perioperative blood transfusion
Wang et al 2020 [42]	China	Retrospective cohort	61.13 ± 11.40	243/76	319	13	306	4.07	Symptom + laboratory data + imaging (X-ray)	Laparoscopic	Preoperative complications of diabetes, previous history of lung disease, operation time
Guo et al 2016 [43]	China	Case Control	62 ~ 85	N/A	1238	26	1212	2.1	Symptom + laboratory data + imaging (X-ray)	Total gastrectomy, distal gastrectomy, proximal gastrectomy	Age, history of smoking, history of cardiopulmonary disease, combined anemia, proximal gastrectomy, long surgery time, prolonged mechanical ventilation

Table 1 (continued)

Author (year)	Country	Study design	Age (year)	Male/female	Total patients	Cases number	Controls number	Pneumonia incidence (%)	Pneumonia diagnosis	Surgical Procedures	Risk factors
Bai et al 2020 [44]	China	Retrospective cohort	N/A	97/46	143	27	116	18.88	Symptom + laboratory data + imaging (X-ray)	Laparoscopic, $D1^+$ lymphadenectomy, D2 or $D2^+$ lymphadenectomy	Diabetes mellitus, operation duration, catheter indwelling time, postoperative complication, perioperative blood transfusion, nutritional risk
Xiao et al 2020 [45]	China	Retrospective cohort	Infection group: 62.53 ± 7.47, non-infection group: 55.76 ± 6.23	189/141	330	66	264	20	Symptom + laboratory data + imaging (X-ray)	Laparoscopic subtotal gastrectomy	High age, smoking, preoperative use of antibiotics, long time in bed postoperative, high level of MMP- 2 and TIMP- 1
Liu et al 2017 [46]	China	Retrospective cohort	N/A	110/40	150	31	119	20	Symptom + laboratory data + imaging (X-ray)	$D1^+$ lymphadenectomy, D2 or $D2^+$ lymphadenectomy. Laparoscopic:35, open surgery:146	Blood transfusion, smoking, FEV 1
Xie et al 2020 [47]	China	Retrospective cohort	26 ~ 87	582/274	856	113	743	13.2	Symptom + laboratory data + imaging (X-ray)	Laparoscopic	Age, smoking, pulmonary insufficiency, pre—operative chemotherapy
Xiao et al 2023 [48]	China	Retrospective cohort	Infection group: 62.19 ± 3.47, non-infection group: 62.32 ± 3.54	68/30	98	21	77	21	Symptom + laboratory data + imaging (X-ray)	Distal gastrectomy:74, proximal gastrectomy:24	History of smoking, diabetes mellitus, catheterization time
Lu et al 2023 [49]	China	Retrospective cohort	N/A	172/76	212	36	176	16	Symptom + laboratory data + imaging (X-ray)	Laparoscopic:148, open surgery:100	Diabetes mellitus, operation duration, catheter indwelling time

Table 1 (continued)

Author (year)	Country	Study design	Age (year)	Male/female	Total patients	Cases number	Controls number	Pneumonia incidence (%)	Pneumonia diagnosis	Surgical Procedures	Risk factors
Tan et al 2023 [50]	China	Case Control	66.72 ± 8.22	Infection group: 28/14, Non infected group: 39/21	102	42	60	41.4	Symptom + laboratory data + imaging (X-ray)	Total gastrectomy, distal gastrectomy, proximal gastrectomy	long-term smoking, history of chronic respiratory diseases, operation time > 3 h, intraoperative bleeding ≥ 200 mL, history of diabetes, postoperative gastric tube retention time > 6 d
Yu et al 2022 [51]	China	Retrospective cohort	57.63 ± 12.59	171/155	326	86	240	26.38	Symptom + laboratory data + imaging (X-ray)	Total gastrectomy, distal gastrectomy, proximal gastrectomy	Age ≥ 60, smoking history, hypertension, diabetes mellitus, operation duration no less than 240 min, intraoperative bleeding volume no less than 200 ml
Shen et al 2021 [52]	China	Retrospective cohort	59.0 ± 11.6	241/126	367	21	346	5.7	Symptom + laboratory data + imaging (X-ray)	Laparoscopic (total gastrectomy, distal gastrectomy)	Age ≥ 65 years old

Table 2 Quality assessment of the included studies using the Newcastle–Ottawa Scale

Study	NOS			
	Selection	Comparability	Outcome	Total score
Yao et al. 2019 [36]	3	2	2	7
Han et al 2017 [37]	4	2	1	7
Xiao et al 2014 [38]	3	1	3	7
Xiao et al 2019 [39]	3	1	2	6
Mohri et al 2008 [7]	4	2	2	8
Kamiya et al 2022 [9]	3	2	2	7
Meng et al 2021 [40]	3	2	2	7
Tu et al 2017 [13]	3	1	2	6
Kiuchi et al 2016 [3]	3	2	2	7
Suzuki et al 2017 [20]	3	2	2	7
Miki et al 2016 [21]	3	2	2	7
Kimura et al 2021 [12]	3	2	2	7
Ntutumu et al 2016 [19]	4	2	2	8
Cho et al 2021 [8]	4	2	2	8
Shoka et al 2020 [10]	3	2	2	7
Zhao et al. 2019 [41]	3	2	2	7
Wang et al 2020 [42]	3	2	2	7
Guo et al 2016 [43]	3	1	3	7
Bai et al 2020 [44]	4	1	3	8
Xiao et al 2020 [45]	3	2	3	8
Liu et al 2017 [46]	3	2	2	7
Xie et al 2020 [47]	4	2	2	8
Xiao et al 2023 [48]	4	1	3	8
Lu et al 2023 [49]	3	2	1	6
Tan et al 2023 [50]	3	1	3	7
Yu et al 2022 [51]	3	2	2	7
Shen et al 2021 [52]	3	2	3	8

factors could mean that the associations we observed are confounded by other unmeasured factors.

Prevalence of pneumonia after radical gastrectomy for gastric cancer

In the 27 studies included in our meta-analysis, the prevalence of pneumonia following radical gastrectomy exhibited considerable variation, ranging from 2.1% to 41.4%. Due to the substantial heterogeneity observed ($I^2 = 95.8\%$, $P < 0.001$), a random-effects model was utilized to calculate the pooled prevalence. Our analysis revealed that the combined prevalence of pneumonia after radical gastrectomy was 11.0% (95% CI, 8.0%–15.0%) (Fig. 2).

Sensitivity analyses

Sensitivity analysis confirmed the robustness of our findings, as the sequential exclusion of individual studies did not significantly alter the pooled prevalence (Fig. 3). This consistency underscores the reliability of the meta-analysis results, even in the presence of high heterogeneity. However, future research should address the methodological and contextual differences contributing to the observed heterogeneity.

Publication bias testing

To evaluate potential publication bias, we initially performed a visual inspection using a funnel plot (Fig. 4). The plot exhibited asymmetry, indicating the possible presence of publication bias. Subsequent analysis with Egger's test confirmed a significant small-study effect ($t = 6.0095$, $P < 0.001$), reinforcing evidence of potential publication bias (see Appendix 2). To mitigate this bias, we employed the trim-and-fill method for adjustment. The results revealed that, after imputing 11 studies, the original effect size (OR = 1.1196) decreased to OR = 1.0472, reflecting minimal change in the adjusted effect size despite the presence of publication bias.

Subgroup analyses and meta-regression

To investigate the sources of heterogeneity, we conducted subgroup analyses stratified by gender, age, surgical approach, type of gastrectomy, nasogastric tube retention time, operation duration, country, publication year, and study design (Table 3). Additionally, meta-regression was employed to quantitatively assess the impact of these covariates on between-study variance (Table 4).

The subgroup analysis results indicate that the prevalence of postoperative pneumonia was 13.71% in male patients, which is higher than the 9.42% observed in female patients. In addition, elderly patients showed a prevalence rate of 17.9%, significantly higher than the 9.0% observed in patients younger than 60 years. With

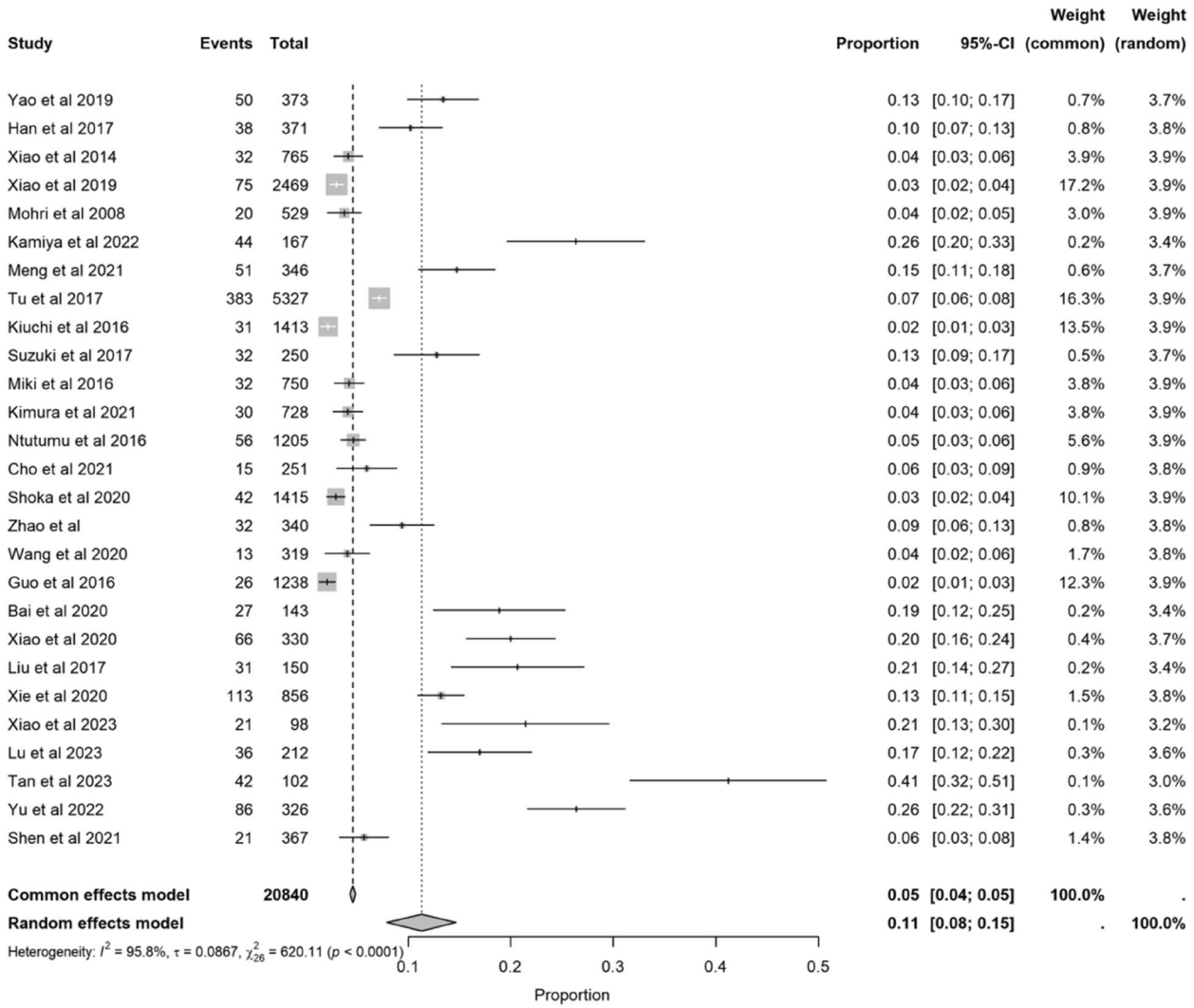

Fig. 2 Forest plot of the prevalence of pneumonia after radical gastrectomy for gastric cancer

regard to surgery type, patients undergoing total gastrectomy had a prevalence of 13.64%, which was higher than the 9.90% observed in those undergoing partial gastrectomy. Similarly, the prevalence after open surgery was 13.07%, exceeding that of laparoscopic surgery. Furthermore, patients with Intraoperative blood loss ≥200 ml had a prevalence of 15.84%, significantly higher than the rate for those with blood loss <200 ml. For operation duration, cases lasting ≥200 min showed a prevalence of 16.62%, compared to 9.93% for cases lasting <200 min. In terms of geographical differences, the prevalence in China was 12.9%, higher than the 7.34% observed in Japan. When comparing studies by time, those conducted before 2020 reported a prevalence of 15.33%, which was considerably higher than the 7.03% reported in studies conducted post-2020. Finally, the prevalence in case–control studies was 15.40%, exceeding the 10.89% observed in cohort studies.

Meta-regression was further performed to evaluate the effects of these factors, and among the variables analyzed, only the variable "Years" was statistically significant. This finding is consistent with the subgroup analysis results; however, a substantial portion of the heterogeneity remains unexplained.

Risk factors for pneumonia after radical gastrectomy

Among the 27 studies are multivariate analysis identified 35 risk factors in total. A risk factor was selected out and combined for the meta-analysis if it was reported in two or more studies. In the end, 16 risk factors were found for pneumonia after radical

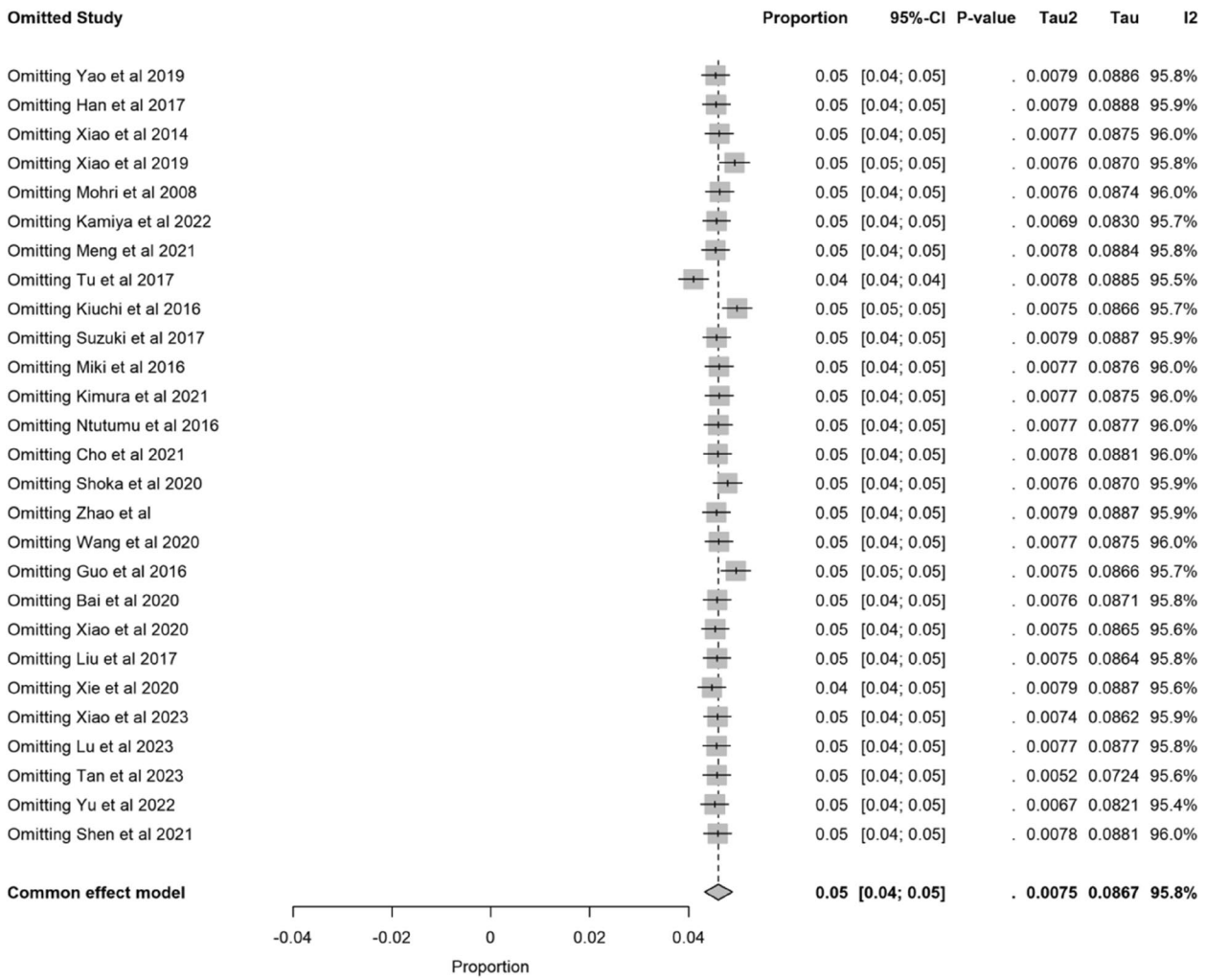

Fig. 3 Leave-one-out results

gastrectomy for gastric cancer were identified, and detailed information was shown in Table 5. Forest plots of risk factors are shown in the Appendix 3.

Meta-analysis results

Smoking history There were eight studies that included 2,615 patients undergoing radical gastrectomy; the data included information on a history of smoking [37, 43, 45–48, 50, 51]. For this meta-analysis, a fixed effects model was used because there was no discernible heterogeneity between the trials ($I^2 = 26\%$, $P = 0.22$). Across the eight investigations, the overall OR was 2.71, with a 95% CI ranging from 2.09 to 3.50. The combined data showed that in patients undergoing radical gastrectomy for gastric cancer, a history of smoking was an independent predictor of pneumonia ($P < 0.001$).

Prolonged postoperative nasogastric tube retention Six eligible studies were included in the meta-analysis ($n = 1691$) [37, 38, 44, 48–50]. The random-effects model revealed a significant association between prolonged postoperative nasogastric tube retention and the risk of pneumonia after radical gastrectomy for gastric cancer, as indicated by the overall pooled OR of 2.25 (95% CI: 1.36 to 3.72, $P = 0.002$). The studies exhibited significant heterogeneity ($I^2 = 63\%$, $P = 0.02$).

Intraoperative bleeding ≥200 ml Data on intraoperative bleeding ≥200 ml were reported by five studies ($n = 6,789$) [13, 37, 38, 50, 51]. Testing revealed statistical heterogeneity amongst the studies ($I^2 = 79\%$, $P = 0.0009$). Random-effects models showed that intraoperative bleeding ≥200 ml was associated with pneumonia after radical gastrectomy. The OR was 2.21, and the 95% CI ranges from 1.15 to 4.24 ($P = 0.02$).

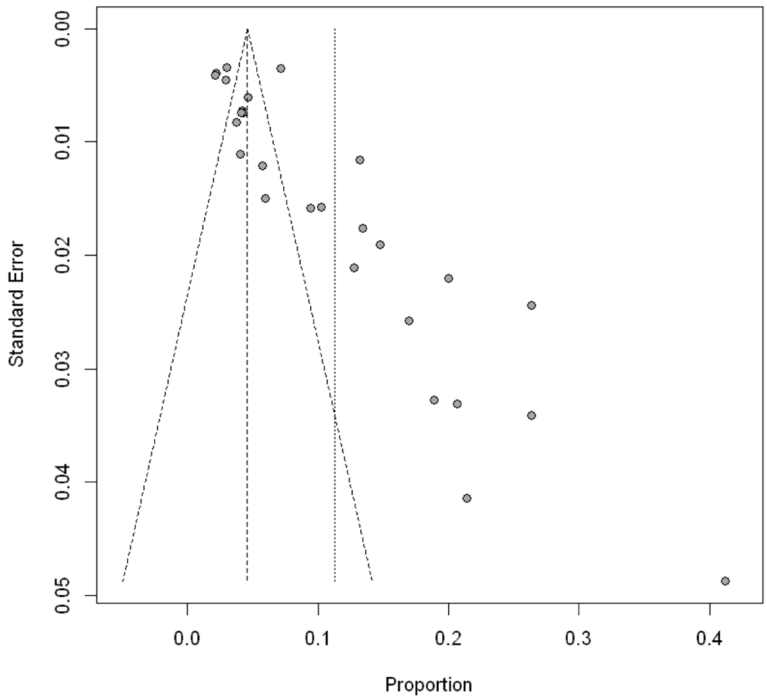

Fig. 4 Funnel plot of the publication bias

Diabetes mellitus Nine studies ($n=$ 3,055) provided data on diabetes mellitus [21, 38, 41, 44, 48–51, 53]. According to the significant heterogeneity in the number of trials ($I^2=$ 96%, $P<$ 0.00001), the summary effect was estimated using a random-effects model. With a pooled OR of 4.58 and a 95% CI ranging from 1.84 to 11.38, diabetes mellitus was found to significantly increase the incidence of pneumonia after radical gastrectomy for gastric cancer ($P=$ 0.001).

Excessive duration of surgery Eight studies totaling 10,136 people were included in this meta-analysis and systematic review to provide information on the prolonged duration of surgical [13, 39, 43, 44, 49–51, 53]. As a result of the notable heterogeneity between the trials ($I^2=$ 90%, $P<$ 0.0001), this independent meta-analysis used a random-effects model. The pooled OR was determined to be 1.51, with a 95% CI ranging from 1.25 to 1.83 ($P<$ 0.0001). The results showed a strong correlation between the incidence of pneumonia after a radical gastrectomy for gastric cancer and the duration of the surgical procedure.

Perioperative blood transfusion Data on perioperative blood transfusion were obtained from six studies with a total of 8,543 participants [7, 21, 39, 41, 44, 54]. Statistical testing revealed significant heterogeneity among the studies ($I^2=$ 90%, $P<$ 0.00001). The random-effects model demonstrated an independent association between perioperative blood transfusion and pneumonia following radical gastrectomy for gastric cancer, with an OR of 4.21 and a 95% CI ranging from 2.51 to 7.06 ($P<$ 0.00001).

Male gender Two studies ($n=$ 779) examining the association between pneumonia and male sex found statistical significance without heterogeneity, as validated by a meta-analysis [7, 20] ($I^2=$ 0%, $P=$ 0.55). The overall OR was 3.56, with a 95% CI ranging from 1.50 to 8.42. The findings demonstrated that, after a radical gastrectomy for gastric cancer, male sex was an independent prognostic factor for pneumonia.

Advanced age Age-related data were extracted from eight studies involving a total of 10,760 individuals [12, 13, 19, 21, 43, 45, 47, 51]. This independent meta-analysis utilized a random-effects model due to the substantial heterogeneity observed among the trials ($I^2=$ 94%, $P<$ 0.00001). The pooled OR was estimated at 1.91, with a 95% CI ranging from 1.42 to 2.58. The findings revealed a significant association between the advanced age of subjects and the incidence of pneumonia following radical gastrectomy for gastric cancer ($P<$ 0.0001).

Nutritious status Nutritional status was evaluated in four eligible studies ($n=$ 3,134) [3, 41, 43, 44]. The random-effects model demonstrated a significant association

Table 3 Subgroup analysis of the prevalence of pneumonia after radical gastrectomy for gastric cancer

Subgroups	Number of included reports	Heterogeneity			Pneumonia		Difference between groups	
		I^2	*P* value	Model	Prevalence (95% CI) (%)		*Z* value	*P* value
Gender							1.6587	0.0972
Male	26	94.1%	< 0.001	Random	13.71	(9.94–17.49)		
Female	26	89.5%	< 0.001	Random	9.42	(6.03–12.81)		
Age							2.5522	0.0107
≥ 60	24	92.8%	< 0.001	Random	17.9	(11.93–22.26)		
< 60	20	93.7%	< 0.001	Random	9.0	(5.54–12.46)		
Surgical approach							1.8745	0.0609
Open surgery	11	94.8%	< 0.001	Random	13.07	(7.49–18.64)		
Laparoscopic surgery	16	93.6%	< 0.001	Random	7.30	(4.99–9.60)		
Types of gastrectomy							1.1048	0.2692
Total gastrectomy	19	88.3%	< 0.001	Random	13.64	(8.64–18.63)		
Partial gastrectomy	20	93.4%	< 0.001	Random	9.90	(5.54–14.26)		
Nasogastric tube retention time							2.0762	0.0379
≥ 4 days	9	92.5%	< 0.001	Random	31.25	(13.84–48.65)		
< 4 days	9	89.8%	< 0.001	Random	12.03	(6.92–17.15)		
Intraoperative blood loss							2.5036	0.0123
≥ 200 ml	20	91.7%	< 0.001	Random	15.84	(9.86–21.83)		
< 200 ml	21	92.8%	< 0.001	Random	7.36	(4.47–10.24)		
Operation duration							1.8186	0.069
≥ 200 min	21	90.7%	< 0.001	Random	16.62	(10.32–22.93)		
< 200 min	23	93.4%	< 0.001	Random	9.93	(6.44–13.43)		
Country							2.8642	0.0910
China	19	96.4%	< 0.001	Random	12.98	(8.86–17.11)		
Japan	8	91.4%	< 0.001	Random	7.34	(2.26–12.42)		
Years							7.0621	0.0079
≥ 2020	14	96.4%	< 0.001	Random	7.03	(9.81–20.86)		
< 2020	13	94.8%	< 0.001	Random	15.33	(4.39–9.67)		
Study design							0.1354	0.7197
Cohort study	24	95.6%	< 0.001	Random	10.89	(7.89–13.89)		
Case Control	3	97.1%	< 0.001	Random	15.40	(2.11–39.86)		

Table 4 Meta-regression results of the prevalence of pneumonia after radical gastrectomy for gastric cancer

Variable	B-Coefficient	95% CI	*SE*	*P* Value
Gender	0.0105	− 0.2433–0.2643	0.1295	0.9354
Age	0.0563	− 0.0810–0.1935	0.0700	0.4217
Surgical approach	− 0.0339	− 0.2323–0.1645	0.1012	0.7376
Types of gastrectomy	− 0.1189	− 0.4453–0.2074	0.1665	0.4751
Nasogastric tube retention time	0.0246	− 0.2786–0.3277	0.1547	0.8738
Intraoperative blood loss	0.0737	− 0.0695–0.2169	0.0737	0.3131
Operation duration	− 0.1447	− 0.3289–0.0394	0.0939	0.1234
Country	0.0564	− 0.0134–0.1264	0.0357	0.1131
Years	0.0142	0.0055–0.0230	0.0045	0.0015
Study design	0.0383	− 0.0708–0.1473	0.0556	0.4913

Table 5 Meta-analysis of risk factors for pneumonia after radical gastrectomy

Risk factor	Included study number	Sample size	I^2	Model	OR(95%CI)	*P* value
Smoking history	8	2,615	26%	Fixed	2.71(2.09–3.50)	< 0.001
Prolonged postoperative nasogastric tube retention	6	1691	63%	Random	2.25(1.36–3.72)	0.002
Intraoperative bleeding ≥ 200 ml	5	6,789	79%	Random	2.21(1.15–4.24)	0.02
Diabetes mellitus	9	3,055	96%	Random	4.58(1.84–11.38)	0.001
Excessive duration of surgery	8	10,136	90%	Random	1.51(1.25–1.83)	< 0.001
Perioperative blood transfusion	6	8,543	90%	Random	4.21(2.51–7.06)	< 0.001
Male gender	2	779	0%	Fixed	3.56(1.50–8.42)	< 0.001
Advanced age	8	10,760	94%	Random	1.91(1.42–2.58)	< 0.001
Nutritious status	4	3,134	71%	Random	2.62(1.55–4.44)	0.0003
Total gastrectomy	3	4,033	0%	Fixed	2.59(1.83–3.66)	< 0.001
COPD	3	4,402	0%	Fixed	4.72(3.80–5.86)	< 0.001
Impaired pulmonary function	3	1,756	92%	Random	1.29(0.82–2.03)	0.83
History of pulmonary disease	3	2,972	79%	Random	1.61(1.17–2.21)	0.003
D2 lymphadenectomy	2	1,030	0%	Fixed	4.14(2.29–7.49)	< 0.001
Hypertensive	2	1,739	0%	Fixed	2.21(1.29–3.79)	0.004
Open operative procedure	2	7,796	98%	Random	2.81(0.78–10.19)	0.11

between nutritional status and the risk of postoperative pneumonia following radical gastrectomy for gastric cancer, with a pooled OR of 2.62 and a 95% CI ranging from 1.55 to 4.44 ($P = 0.0003$). Substantial heterogeneity was observed among the studies ($I^2 = 71\%$, $P = 0.02$).

Total gastrectomy Relevant data were provided by three trials, totaling 4,033 individuals who had total gastrectomy [3, 10, 19]. For this meta-analysis, a fixed-effects model was used because there was no discernible heterogeneity between the trials ($I^2 = 0\%$, $P = 0.91$). Across the six trials, the overall OR was 2.59, with a 95% CI ranging from 1.83 to 3.66. Based on the combined data, total gastrectomy was found to be a significant independent predictor of postoperative pneumonia after radical gastrectomy for gastric cancer ($P < 0.0001$).

COPD Three studies, involving 4,402 patients who underwent radical gastrectomy for gastric cancer, provided data on patients with chronic obstructive pulmonary disease (COPD) [12, 19, 39]. The pooled analysis revealed that COPD was a significant risk factor for postoperative pneumonia following radical gastrectomy for gastric cancer, with an OR of 4.72 and a 95% CI ranging from 3.80 to 5.86 ($P < 0.00001$). The heterogeneity test did not reveal any statistically significant heterogeneity ($I^2 = 0\%$, $P = 0.39$).

Impaired pulmonary function There were three studies [21, 47, 54] ($n = 1{,}756$) that provided information on pulmonary function. Significant heterogeneity amongst the trials was found by statistical analysis ($I^2 = 92\%$, $P < 0.00001$). With an OR of 1.29 and a 95% CI spanning from 0.82 to 2.03, the random-effects model did not reveal a correlation between impaired pulmonary function and postoperative pneumonia after radical gastrectomy for gastric cancer ($P = 0.83$).

History of pulmonary disease Three separate trials totaling 2,972 participants who provided information on a history of pulmonary disease were included in this analysis [10, 43, 53]. The meta-analysis utilized a random-effects model because of the significant heterogeneity among the studies ($I^2 = 79\%$, $P = 0.008$). With a 95% CI spanning from 1.17 to 2.21 ($P = 0.003$), the calculated pooled OR was 1.61. The results showed a significant correlation between a history of lung illness and pneumonia after radical gastrectomy for gastric cancer.

D2 lymphadenectomy Two studies ($n = 1{,}030$) [12, 20] investigating the relationship between pneumonia and D2 lymphadenectomy showed statistically significant results without heterogeneity, as confirmed by a meta-analysis ($I^2 = 0\%$, $P = 0.73$). With a 95% CI spanning from 2.29 to 7.49, the combined OR was 4.14. These results indicate that, after radical gastrectomy for gastric cancer, D2 lymphadenectomy is an independent predictor of pneumonia.

Hypertensive Results from two trial [3, 51] s (n = 1,739) examining the association between pneumonia and hypertension proved statistically significant and showed no heterogeneity. For this meta-analysis, a fixed-effects model (I^2 = 0%, P = 1.0) was used. The combined OR was estimated to be 2.21, with a 95% CI ranging from 1.29 to 3.79. These results imply that after a radical gastrectomy for gastric cancer, hypertension is an independent predictor of pneumonia (P = 0.004).

Open operative procedure Data on the practice of open operative procedure were reported by two research [13, 39] (n = 7,796). A statistical analysis of the studies showed that there was a high amount of heterogeneity (I^2 = 98%, P < 0.00001). They show that there is no association between an open surgical procedure and pneumonia after a radical gastrectomy for gastric cancer (OR = 2.81, 95% CI: 0.78 to 10.19, P = 0.11).

Descriptive analysis

A descriptive analysis of risk factors that could not be combined was performed in 27 studies. Preoperative comorbidities (OR = 4.008, 95 CI% = 1.768 ~ 9.086) [36], wound pain (OR = 3.428, 95 CI% = 1.557 ~ 7.548) [36], tumor located at middle third (OR = 1.86, 95 CI% = 1.14 ~ 2.64) [39], preoperative sarcopenia (OR = 5.38, 95 CI% = 1.77 ~ 16.3) [9], modified frailty index (OR = 2.72, 95 CI% = 2.02 ~ 3.31) [40], ASA classification ≥ 3 (OR = 2.202, 95 CI% = 1.398 ~ 2.866) [13], tumor diameter (OR = 1.068, 95 CI% = 1.024 ~ 1.114) [13], advanced stage (OR = 2.35, 95 CI% = 1.05 ~ 5.67) [3], time to first diet (OR = 1.175, 95 CI% = 1.06 ~ 1.302) [19], postoperative hospital stay (OR = 1.015, 95 CI% = 1.002 ~ 1.028) [19], poor performance status (OR = 17.54, 95 CI% = 3.17 ~ 97.33) [8], cardia-non-preserving gastrectomy (OR = 5.33, 95 CI% = 1.53 ~ 18.93) [8], systemic Inflammation score (OR = 2.31, 95 CI% = 1.19 ~ 4.48) [10], mechanical ventilation time (OR = 1.697, 95 CI% = 1.189 ~ 2.821) [43], preoperative use of antimicrobials (OR = 3.543, 95 CI% = 1.312 ~ 9.571) [45], excessive postoperative bed rest (OR = 2.724, 95 CI% = 1.241 ~ 5.977) [45], pathologic MMP-2 in gastric cancer (OR = 2.754, 95 CI% = 1.062 ~ 7.139) [45], pathology of gastric cancer TIMP1 (OR = 2.683, 95 CI% = 1.091 ~ 6.597) [45] and preoperative chemotherapy (OR = 2.115, 95 CI% = 1.047 ~ 4.269) [47] were the other 19 individual risk factors identified via multiple regression analysis. Our meta-analysis did not include these 19 risk factors.

Sensitivity analyses

(1) Change effect model: Sensitivity analysis was conducted by applying both random-effects and fixed-effects models to assess the influence of various factors. The results revealed no significant changes in the effect sizes of individual factors, suggesting that the findings are relatively robust (Table 6).
(2) Leave-one-out elimination method: For studies exhibiting substantial heterogeneity (I^2 > 50%) and involving more than two influential factors, sensitivity was further evaluated using the leave-one-out elimination method. The analysis demonstrated that heterogeneity was significantly reduced for

Table 6 Results of the risk factor transition effect model

Risk factor	Fixed-effects model	Random-effects model
Smoking history	2.71(2.09–3.50)	2.71(2.09–3.50)
Prolonged postoperative nasogastric tube retention	2.31(1.29–3.62)	2.25 1.36–3.72)
Intraoperative bleeding	2.19(1.09–3.14)	2.21(1.15–4.24)
Diabetes mellitus	3.32(1.64–9.24)	4.58(1.84–11.38)
Operation duration	1.50(1.07–1.70)	1.51(1.25–1.83)
Perioperative blood transfusion	4.19(2.32–7.01)	4.21(2.51–7.06)
Gender	3.20(1.38–8.01)	3.56(1.50–8.42)
Age	1.76(1.36–2.71)	1.91(1.42–2.58)
Nutritious status	1.62(1.02–3.24)	2.62(1.55–4.44)
Types of gastrectomy	2.59(1.83–3.66)	2.59(1.83–3.66)
COPD	4.72(3.80–5.86)	4.72(3.80–5.86)
Impaired pulmonary function	1.24(0.76–1.97)	1.29(0.82–2.03)
History of pulmonary disease	1.57(1.07–2.10)	1.61(1.17–2.21)
D2 lymphadenectomy	4.14(2.29–7.49)	4.14(2.29–7.49)
Hypertensive	2.21(1.29–3.79)	2.21(1.29–3.79)
Open operative procedure	2.36(0.68–9.75)	2.81(0.78–10.19)

six risk factors—prolonged postoperative nasogastric tube retention, intraoperative bleeding ≥200 ml, diabetes mellitus, nutritional status, impaired pulmonary function, and history of pulmonary disease—allowing the adoption of a fixed-effects model for these factors. In contrast, the heterogeneity of the remaining four risk factors showed no significant reduction, and a random-effects model was retained. Other meta-analysis results remained largely unchanged, indicating overall stability of the findings (Table 7, Appendix 4).

Subgroup analysis of risk factors

This study conducted subgroup analyses on five variables—diabetes mellitus, nutritional status, history of pulmonary disease, perioperative blood transfusion, and prolonged postoperative nasogastric tube retention—with country, surgical approach, and age as covariates. Regarding diabetes mellitus as a risk factor, country-specific differences emerged: in China, diabetes was a significant risk factor for postoperative pneumonia (OR = 2.37, $p < 0.001$), whereas in Japan, no significant association was observed (OR = 0.95, $p = 0.90$). By surgical approach, diabetes increased the risk of postoperative pneumonia in laparoscopic surgery (OR = 2.14, $p = 0.02$) but not in open surgery (OR = 1.89, $p = 0.14$). Across age groups, diabetes consistently posed a risk, with OR = 1.90 ($p = 0.007$) for patients aged ≥60 years and OR = 1.92 ($p = 0.011$) for those <60 years.

For nutritional status, malnutrition was a significant risk factor for postoperative pneumonia following radical gastrectomy in the Chinese population (OR = 2.19, $p = 0.01$), but not in the Japanese population (OR = 1.16, $p = 0.85$). Malnutrition did not significantly influence postoperative pneumonia across age groups (OR = 1.46, $p = 0.211$ for ≥60 years; OR = 1.41, $p = 0.337$ for <60 years) or surgical approaches (OR = 1.53, $p = 0.42$ for open surgery; OR = 1.69, $p = 0.20$ for laparoscopic surgery), indicating it is not a consistent risk factor.

Regarding history of pulmonary disease, no significant association with postoperative pneumonia was found in Chinese patients (OR = 1.34, $p = 0.64$), whereas it was a significant risk factor in Japanese patients (OR = 2.16, $p = 0.003$). The effect of pulmonary disease history was similar across age groups (OR = 1.55, $p = 0.34$ for ≥60 years; OR = 1.42, $p = 0.53$ for <60 years), suggesting age does not substantially modulate this relationship. However, the risk was higher in laparoscopic surgery (OR = 2.61, $p < 0.001$) than in open surgery (OR = 1.62, $p = 0.005$), with both indicating independent risk. Further analysis of country-age interactions revealed no significant association in China across age groups (OR = 1.23, $p = 0.7694$), but in Japan, the elderly subgroup (≥ 60 years) showed a significant risk (OR = 2.16, $p = 0.0014$).

Perioperative blood transfusion was a significant risk factor for postoperative pneumonia in both countries—China (OR = 3.20, $p < 0.0001$) and Japan (OR = 3.68, $p < 0.0001$)—and across surgical approaches (OR = 3.12, $p < 0.0001$ for open surgery; OR = 2.90, $p < 0.0001$ for laparoscopic surgery). This effect persisted across age groups (OR = 3.64, $p < 0.001$ for ≥60 years; OR = 4.13, $p < 0.001$ for <60 years). Interaction analysis indicated a stronger effect in younger patients (< 60 years), particularly in Japan (OR = 4.61, $p < 0.0001$) compared to China (OR = 3.96, $p < 0.0001$).

Due to limited studies, analysis of prolonged postoperative nasogastric tube retention was restricted to China. Prolonged retention was a risk factor for postoperative pneumonia (OR = 2.47, $p < 0.0001$), with a higher risk in open surgery (OR = 1.82, $p = 0.02$) and an independent risk in laparoscopic surgery (OR = 1.67, $p < 0.001$). Across age groups, prolonged retention remained a consistent risk factor (OR = 2.39, $p < 0.001$). The specific results are shown in Table 8.

Table 7 Results of leave-one-out method for risk factors

Risk factor	Exclusion study	Before exclusion			After exclusion		
		Model	OR(95%CI)	*P* value	Model	OR(95%CI)	*P* value
Prolonged postoperative nasogastric tube retention	Bai 2020 [44]	Random	2.25(1.36–3.72)	0.002	Fixed	2.88(1.93–4.28)	0.26
Intraoperative bleeding ≥ 200 ml	Tu 2017 [13]	Random	2.21(1.15–4.24)	0.02	Fixed	2.51(1.64–3.83)	< 0.001
Diabetes mellitus	Zhao 2019 [41]	Random	4.58(1.84–11.38)	0.001	Fixed	2.67(2.13–3.36)	< 0.001
Nutritious status	Zhao 2019 [41]	Random	2.62(1.55–4.44)	0.0003	Fixed	1.89(1.32–4.69)	< 0.001
Impaired pulmonary function	Liu 2017 [54]	Random	1.29(0.82–2.03)	0.83	Fixed	2.72(1.58–4.69)	< 0.001
History of pulmonary disease	Wang 2020 [42]	Random	1.61(1.17–2.21)	0.003	Fixed	1.52(1.10–2.09)	0.01

Table 8 Subgroup analysis of risk factors

Risk factor	Subgroups	Number of included reports	OR(95%CI	*P* value	I^2	*P* value (Heterogeneity)
Diabetes mellitus	China	13	2.3676 (1.5612–3.5905)	< 0.001	57.3%	0.0053
	Japan	5	0.9459 (0.3934–2.2742)	0.9011	71.8%	0.0068
	Open surgery	6	1.8982 (0.7942–4.5368)	0.1494	77.9%	< 0.001
	Laparoscopic surgery	10	2.1436 (1.1005–4.1752)	0.0250	73.9%	< 0.001
	≥ 60	16	1.9006 (1.1831–3.0534)	0.0079	68.1%	< 0.001
	< 60	15	1.9275 (1.1616–3.1984)	0.0111	70.1%	< 0.001
Nutritious status	China	10	2.1919 (1.1518–4.1711)	0.0168	74.4%	< 0.001
	Japan	4	1.1607 (0.2380–5.6612)	0.8538	85.3%	< 0.001
	Open surgery	7	1.5359 (0.5400–4.3682)	0.4210	80.9%	< 0.001
	Laparoscopic surgery	9	1.6927 (0.7531–3.8044)	0.2027	77.8%	< 0.001
	≥ 60	12	1.4677 (0.8036–2.6807)	0.2118	72.7%	< 0.001
	< 60	10	1.4149 (0.6966–2.8739)	0.3371	76.6%	< 0.001
History of pulmonary disease	China	9	1.3351 (0.3931–4.5339)	0.6432	89.2%	< 0.001
	Japan	4	2.0478 (1.2583–3.3326)	0.0039	0.0%	0.6369
	Open surgery	5	1.6270 (1.1546–2.2927)	0.0054	0.0%	0.5305
	Laparoscopic surgery	8	2.6105 (1.5242–4.4710)	< 0.001	61.5%	0.0111
	≥ 60	12	1.5534 (0.6214–3.8836)	0.3461	85.6%	< 0.001
	< 60	10	1.4216 (0.4718–4.2835)	0.5320	87.8%	< 0.001
Perioperative blood transfusion	China	7	3.2074 (2.3789–4.3245)	< 0.001	0.0%	0.5205
	Japan	3	3.6842 (1.9768–6.8661)	< 0.001	0.0%	0.3844
	Open surgery	6	3.1215 (2.2283–4.3727)	< 0.001	0.0%	0.5196
	Laparoscopic surgery	7	2.9034 (2.1228–3.9710)	< 0.001	0.0%	0.5565
	≥ 60	8	3.6480 (2.7172–4.8976)	< 0.001	0.0%	0.6117
	< 60	6	4.1390 (2.9861–5.7371)	< 0.001	0.0%	0.8062
Prolonged postoperative nasogastric tube retention	China	9	2.4757 (1.6358–3.7469)	< 0.001	58.7%	0.0130
	Japan	0				
	Open surgery	4	1.8991 (1.2259–2.9420)	0.0041	25.1%	0.2606
	Laparoscopic surgery	5	1.7034 (1.2672–2.2896)	0.0004	5.9%	0.3732
	≥ 60	8	2.3913 (1.5498–3.6895)	< 0.001	62.0%	0.0102
	< 60	8	2.3913 (1.5498–3.6895)	< 0.001	62.0%	0.0102

Discussion

This study represents the first systematic review and meta-analysis conducted to evaluate the risk factors associated with postoperative pneumonia following radical gastrectomy for gastric cancer. Through the analysis of 27 studies involving 20,840 individuals, we identified a total of 16 risk factors for postoperative pneumonia in gastric cancer patients. Among these risk factors, 15 were independently associated with pneumonia after radical gastrectomy for gastric cancer. Smoking history, prolonged postoperative nasogastric tube retention, intraoperative bleeding ≥ 200 ml, diabetes mellitus, male gender, total gastrectomy, COPD, impaired respiratory function, D2 lymphadenectomy, perioperative blood transfusion, and hypertension were identified as strong risk factors (OR: 2.21–4.72), while excessive duration of surgery, advanced age, nutritional status, and history of pulmonary disease were identified as moderate risk factors (OR: 1.51–1.91). Our descriptive analysis identified 19 risk factors that could not be meta-analyzed, such as preoperative comorbidities and wound pain. Although these findings are not generalizable based on a single study or data, they suggest potential directions for future research. The risk factors identified in this study can be classified into four categories: general, disease-related, surgical, and treatment-related factors. Regarding general factors, advanced age, gender, and smoking history independently contribute to the risk of pneumonia after radical gastrectomy for gastric cancer.

General factors

Advanced age

The study findings revealed that elderly patients had a 1.91-fold higher risk of developing postoperative pneumonia compared to non-elderly patients. In terms of prevalence, the prevalence of postoperative pneumonia in patients over 60 years old (17.9%) was significantly higher than that in patients under 60 years old (9.0%). Significant heterogeneity was observed among studies, which may be attributed to variations in the definition of "advanced age." Some studies included patients aged 65 years and older, while others defined "elderly" as those aged 70 years and above, contributing to the observed heterogeneity.

This increased vulnerability in the elderly patients may stem from multiple factors. Age-related declines in organ function and reduced respiratory capacity impair the airway's defensive mechanisms and diminish clearance efficiency. In elderly gastric cancer patients, decreased lung elasticity and chest wall compliance, coupled with increased alveolar residual volume, predispose them to respiratory muscle fatigue and upper airway obstruction, thereby elevating the risk of postoperative pulmonary infections [11]. Studies have shown that an American Society of Anesthesiologists (ASA) score >3 is an independent risk factor for postoperative complications following gastric cancer surgery [55, 56]. Elderly patients often have comorbidities—such as hypertension and cardiovascular or neurological diseases—that impair immune defenses and lead to higher ASA scores, thereby increasing complication risk [6, 57]. Additionally, the reduced tension of the esophageal sphincter in older patients makes them more susceptible to gastroesophageal reflux when lying down [58]. This, coupled with diminished self-care ability and deteriorating oral hygiene, facilitates the entry of pathogenic bacteria from the oropharynx into the airway, significantly heightening the pneumonia risk.

In view of the significant impact of postoperative pneumonia on overall survival after radical gastrectomy in elderly patients, comprehensive perioperative management for elderly gastric cancer patients is strongly recommended. A study implemented Comprehensive Preoperative Assessment and Support (CPAS) including: (1) Rehabilitation Services: Customized exercise regimens; (2) Nutritional Support: Dietitian-evaluated personalized nutrition plans; (3) Social Support: Social worker-coordinated caregiver collaboration for sustained recovery support; (4) Oral Frailty Management: Multidisciplinary evaluation by otolaryngologists and speech therapists to address oral health decline; (5) Mental Health Support: Psychiatric nurse-led interventions pre- and post-surgery. Results demonstrated improved short-term postoperative outcomes: pneumonia incidence decreased from 10.8% to 2.4%, intraoperative blood loss reduction, and enhanced recovery metrics [59]. The results indicate that comprehensive preoperative assessment, personalized exercise and nutritional supplement can significantly improve the postoperative health status of elderly patients with gastric cancer [60, 61].

Smoking history

In this study, smokers had a 2.71-fold higher likelihood of developing postoperative pneumonia following radical gastric cancer surgery compared to non-smokers. Continuous smoking disrupts the normal mucosal barrier through bronchial irritation caused by toxic gases, impeding respiratory cilia motility and compromising cilia clearance function [62]. In addition, tissue hypoxia caused by exposure to smoke can lead to reduced fibroblast migration, impeding wound healing [63, 64]. Long-term smoking leads to hyperplasia and hypertrophy of the bronchial submucosal glands, increased mucus secretion, and squamous metaplasia of the bronchial mucosa, which collectively reduce bronchial clearance [65, 66]. Moreover, persistent spasms in the small airways elevate airway resistance, and these cumulative changes adversely affect lung function [36, 37].

Research indicates a positive correlation between cigarette dose and postoperative pneumonia risk, with >20 pack-years significantly increasing complications [67], and patients quitting smoking >4 weeks before surgery showing a significantly lower risk [68]. The ERAS Chinese Expert Consensus recommends that patients cease smoking for at least 2 weeks preoperatively [69]. However, a prospective observational study from the UK found that a preoperative smoking cessation period of less than 6 weeks does not reduce the incidence of postoperative pulmonary infections [66]. Consequently, whether a 2-week preoperative smoking cessation period can lower the risk of postoperative pulmonary infections remains to be further investigated. Each additional week of preoperative smoking cessation is associated with a 19% reduction in pneumonia risk, underscoring the importance of early cessation [70].

Therefore, patients are strongly advised to quit smoking at least 4 weeks before surgery, supported by counseling, nicotine replacement therapy, and psychological support [23]. Patients are instructed to perform deep-breathing exercises and use incentive spirometry (IS) to facilitate secretion clearance. These interventions promote the release and distribution of surfactants, reduce alveolar surface tension, and support alveolar re-expansion after surgery [71]. IS further enhances deep breathing, lung

expansion, and gas exchange. It is recommended that patients use IS 10 times per hour while awake, in combination with deep-breathing exercises [72]. Whenever possible, patients should be trained preoperatively in proper spirometer use and effective coughing techniques. However, an updated Cochrane review does not support the use of IS as a standalone intervention; therefore, IS should be combined with deep-breathing exercises. In the early to middle phases of anesthesia recovery, the cascade cough technique can effectively promote the clearance of thick secretions [73]. Maintaining an upright position and regular positional changes help expand the lungs, keep the airway open, prevent aspiration, mobilize secretions, and reduce atelectasis. Although few studies have defined early ambulation, rapid recovery protocols reported in the Cochrane database include early walking as a component of postoperative care. Early activity stimulates coughing and deep breathing, aids in the removal of viscous secretions, increases surfactant production, and reduces alveolar surface tension and atelectasis, thereby improving ventilation [74]. Depending on the procedure and patient condition, early activity may safely commence 4 to 8 h after recovery from general anesthesia [75]. Moreover, optimal pain management remains a critical consideration for postoperative patients. These strategies can effectively mitigate smoking-related risks, improving outcomes for gastric cancer patients undergoing surgery [76].

Gender

In this study, male patients exhibited a 3.56-fold higher likelihood of developing postoperative pneumonia following radical gastrectomy for gastric cancer compared to female patients, with a prevalence of 13.71% versus 9.42%, respectively, underscoring their elevated risk and the need for targeted perioperative management.

This sex difference may arise from anatomical, immunological, and lifestyle factors. Anatomically, female patients have smaller bronchial tubes [20], facilitating better secretion clearance and reducing infection risk, while male airways may be more prone to pathogen accumulation [7, 77]. Immunologically, females benefit from stronger innate immunity [78], potentially due to X chromosome genes and estrogen effects [79–82], with higher NOS-3 activation producing bacteria-killing factors [83]. Males, conversely, show a heightened inflammatory response [82], with increased neutrophils and cytokines such as TNF-α, IL-1β, and IL-8, and male neutrophils express higher levels of TLR4 under LPS exposure, releasing more TNF-α [84]. It has also been suggested that the gut microbes of different sex groups have an effect on the immune system, but the mechanism is not clear [85–87]. Lifestyle-wise, males have higher smoking rates, damaging lung tissue by inducing TNF-α, IL-1, and IL-6 production [88], impairing immune function [89]. Female patients often display heightened health awareness and postoperative care diligence, exhibiting greater adherence to medical advice.

Clinically, males also face worse outcomes, with a 30% higher mortality risk from postoperative pneumonia [90], increased ICU admissions [91], and more interventions like chest CT and invasive mechanical ventilation [92].

To mitigate these risks, specific perioperative strategies are recommended for male patients. Preoperatively, conduct pulmonary function testing and implement daily deep breathing exercises to optimize lung capacity. Intraoperatively, prioritize minimally invasive techniques to reduce trauma. Postoperatively, enhance infection monitoring, such as checking temperature every 6 h, and intervene promptly [93].

Disease-related factors

Regarding disease-related factors, independent risk factors for postoperative pneumonia following radical gastric cancer surgery included nutritious status, diabetes mellitus, impaired pulmonary function, hypertension, history of pulmonary disease, and COPD.

Nutritional status

In this study, patients with compromised nutritional status exhibited a 2.62-fold higher risk of developing postoperative pneumonia following radical gastrectomy for gastric cancer compared to those with normal nutritional status, significantly extending hospital stays (average 7–9 days) and increasing infection-related complications, thus impacting recovery and survival.

Studies indicate that malnutrition incidence in gastroesophageal malignancy patients can reach 40–80% [94–97], a key risk factor for pneumonia, linked to hypoproteinemia, impaired immune function, and postoperative metabolic stress. Malnutrition, particularly hypoproteinemia [3], can lead to pulmonary edema and impaired immune function [98], both of which increase the susceptibility to pneumonia. Additionally, the metabolic stress from surgery exacerbates these issues in malnourished patients [99, 100]. Hypoproteinemia reduces plasma osmotic pressure, causing pulmonary edema [101], affecting gas exchange, and facilitating bacterial reproduction, while low albumin levels delay wound healing and heighten infection risk [102]. Immunologically, malnutrition decreases immune cell production, with reduced T cell function, weakened phagocyte activity, and abnormal cytokine levels, lowering disease resistance [103]. Radical gastrectomy, being traumatic, disrupts digestive function, inducing metabolic stress

that depletes energy reserves in malnourished patients, hindering recovery and elevating pneumonia risk [104].

Therefore, medical personnel should implement comprehensive nutritional management for patients. Existing studies demonstrate that preoperative immunonutrition—comprising amino acids (arginine, glutamine), unsaturated fatty acids (omega-3), nucleotides, and RNA—can effectively reduce the incidence of postoperative pneumonia and shorten hospital stays, particularly in patients with preoperative malnutrition [105, 106]. The impact of a Nutritional Support Team (NST) on postoperative pneumonia in gastric cancer patients has also been investigated [107]. An NST, which includes clinicians, nurses, pharmacists, and dietitians, conducts daily nutritional risk screening from pre-surgery onward, formulates tailored nutritional support plans, and provides patient education. Enteral nutrition (EN) is prioritized, with parenteral nutrition (PN) or total parenteral nutrition (TPN) used as needed. Studies indicate that such interventions improve short-term immune indices and significantly reduce infection-related complications. For gastric cancer patients, preoperative nutritional risk can be assessed using tools such as the Nutrition Risk Screening (NRS) 2002 and the Patient-Generated Subjective Global Assessment (PG-SGA). A multidisciplinary team then develops a personalized nutritional regimen [108], with an emphasis on minimally invasive surgical techniques to reduce metabolic stress, maintain fluid and electrolyte balance, and prevent pulmonary edema. Postoperatively, continuous nutritional monitoring, dietary adjustments, early mobilization, respiratory therapy, rigorous hand hygiene, diligent wound care, and the rational use of antibiotics are recommended to further improve outcomes [109].

Our subgroup analysis revealed that nutritional status is a significant risk factor for postoperative pneumonia after radical gastrectomy in the Chinese population (OR = 2.19, $p = 0.01$), but not in the Japanese population (OR = 1.16, $p = 0.85$). This difference may be attributed to the distinct nutritional assessment methods employed: albumin levels were used in China, whereas the CONUT score was applied in Japan. Additionally, variations in regional medical practices may play a role. Japan's advanced medical technology and greater emphasis on preoperative nutritional optimization and postoperative complication management may mitigate the impact of poor nutritional status on pneumonia risk.

Diabetes mellitus

Our study demonstrated that diabetic patients have a 4.58-fold higher risk of developing postoperative pneumonia compared to non-diabetic patients. This elevated risk may be explained by five key factors: impaired immune function, a hyperglycemic environment, microangiopathy, neuropathy, and surgical stress [110]. Specifically, hyperglycemia impairs macrophage function, reducing chemotaxis and bactericidal activity, while aberrant cytokine production (e.g., IL-6, TNF-α) further weakens the body's defense against infections [36, 111]. Moreover, elevated blood glucose creates a favorable environment for bacterial growth, promoting the proliferation of pathogens and increasing the risk of pulmonary infection [45, 112]. Diabetes also induces nitric oxide release, oxidative stress, and inflammatory mediator production, leading to aberrant angiogenesis and impaired endothelial repair, which in turn cause microvascular damage that compromises lung gas exchange [113]. Additionally, diabetes-associated neuropathy reduces respiratory muscle strength and cough reflex, impairing effective deep breathing and clearance of secretions [114]. Finally, the metabolic stress induced by radical gastrectomy can exacerbate postoperative blood glucose fluctuations, further increasing the risk of pulmonary infection.

Research indicates that the incidence of postoperative adverse events in diabetic patients is 7.7%, and that each 1 mmol/L increase in postoperative blood glucose raises the risk by 1.31-fold [115]. Consequently, rigorous perioperative blood glucose management is essential to reduce complications such as pneumonia. Preoperative evaluation of HbA1c is crucial; the CPOC guidance recommends achieving an HbA1c level below 69 mmol/mol (8.5%) when clinically feasible [116]. Additionally, assessing a patient's medication regimen—including both insulin and non-insulin therapies, which may predispose patients to hypoglycemia or diabetic ketoacidosis—is important. A preoperative medication review by a pharmacist can further minimize errors [117]. Given the procedure's extensive nature, insulin administration is recommended to stabilize blood glucose during the 72 h prior to surgery. Surgery should be scheduled once underlying conditions are well-controlled and the patient's nutritional status is optimal [118]. Intraoperatively, trauma and anesthesia may elevate glucocorticoid secretion, induce insulin resistance, and increase blood glucose levels; therefore, minimizing the use of sympathetic agonists, controlling bleeding, protecting vascular and nerve integrity, and optimizing surgical duration are critical. Postoperatively, initiating fasting and parenteral nutrition can accelerate gastrointestinal recovery and promote anastomotic healing, while early use of diabetes-specific enteral nutrition may help stabilize blood glucose levels. Insulin therapy should be maintained for at least 3 days post-surgery, with close monitoring to keep blood glucose within the target range of 6–12 mmol/L. Furthermore, rational antibiotic use, timely dressing changes,

and prompt catheter removal are important to prevent infections [119]. Although the same perioperative blood glucose management regimen is applied to both T1DM and T2DM patients, glycemic control tends to be poorer in T1DM [120]. Currently, differences in pneumonia risk after radical gastrectomy between T1DM and T2DM patients remain unclear, warranting further investigation to define optimal perioperative strategies for these populations.

Our subgroup analysis revealed that diabetes is a risk factor for postoperative pneumonia in patients undergoing laparoscopic surgery but not in those undergoing open surgery, with significant heterogeneity observed (I^2 =77.9% and 73.9%, respectively). These differences may be attributed to regional variations and differences in preoperative blood glucose management. Notably, while diabetes is not a risk factor for pneumonia following radical gastrectomy in Japan, it is a significant risk factor in China. This disparity may reflect differences in healthcare quality and patient management practices between regions. Future studies should directly compare surgical methods and explore regional influences on postoperative outcomes.

Hypertension

Our study found that hypertensive patients have a 2.21-fold higher risk of developing postoperative pneumonia after radical gastrectomy for gastric cancer compared to non-hypertensive patients, with no observed heterogeneity (I^2 =0%).

Hypertension increases the risk of postoperative pneumonia through several interrelated mechanisms. First, it induces vascular endothelial dysfunction [51], compromising the integrity of blood vessels and predisposing patients to infections [121]. This endothelial impairment can extend to pulmonary vessels, contributing to lung tissue damage and airway obstruction [122]. Second, hypertension is associated with pulmonary hypertension and reduced arterial and airway elasticity, which adversely affects gas exchange [123]. Third, it disrupts adaptive immune responses by altering the function of key immune cells—such as neutrophils, monocytes, and eosinophils—that are essential for T lymphocyte activation and maintaining perivascular integrity [124], thereby impairing overall immune defense [3, 125]. Fourth, hypertension is often comorbid with chronic obstructive pulmonary disease (COPD), further diminishing lung function and exacerbating the risk of pulmonary complications [126]. Finally, hypertensive patients are prone to postoperative blood pressure fluctuations, which can contribute to additional pulmonary complications [15].

Effective perioperative blood pressure management is crucial for hypertensive patients undergoing radical gastrectomy for gastric cancer. Preoperatively, healthcare providers should counsel patients on lifestyle modifications—including weight loss, healthy eating, smoking cessation, increased physical activity, and reduced alcohol consumption—to optimize blood pressure control [127]. Although no universal standard exists for blood pressure management in gastric cancer patients, current guidelines recommend maintaining perioperative blood pressure at 70–100% of baseline values to prevent hypertachycardia [128]. Oral antihypertensive medications should generally be continued until surgery; however, abrupt discontinuation of β blockers or clonidine must be avoided to prevent severe blood pressure surges [129]. For angiotensin-converting enzyme inhibitors (ACEI) and angiotensin-II receptor blockers (ARBs), anesthesia guidelines advise discontinuing these agents 24 h preoperatively to minimize the risk of intraoperative hypotension, especially in gastric cancer surgery [130]. While the American College of Cardiology/American Heart Association (ACC/AHA) supports their continued use in some cases, given their neutral effect on respiratory outcomes [129]. Preoperative comprehensive pulmonary function assessment should also be performed, because general anesthesia may lead to hypotension, and patients with hypertension have a higher risk of intraoperative vascular instability [131]. Intraoperatively, minimally invasive techniques are preferred to reduce trauma and maintain hemodynamic stability [128]. Continuous blood pressure monitoring and careful fluid management are essential to prevent pulmonary edema, particularly in hypertensive patients who exhibit greater cardiovascular instability. Postoperatively, adjunctive measures such as deep breathing exercises, incentive spirometry, coughing exercises, early ambulation, and optimal pain management are vital for preventing pulmonary complications [132]. Since certain opioids may suppress the cough reflex and impair mucociliary clearance, their use should be judiciously managed, with close monitoring for sedation and respiratory depression (e.g., from fentanyl or morphine) [133].

This comprehensive, phase-specific approach to blood pressure management not only stabilizes hemodynamics but also contributes to reducing pulmonary complications and improving overall outcomes in hypertensive patients.

Lung disease and impaired lung function

The results showed that patients with a history of lung disease had a 1.61-fold higher risk of developing pneumonia after radical surgery for gastric cancer, a 4.72-fold higher risk for COPD, and a 1.29-fold higher risk for patients with impaired lung function. Significant heterogeneity was observed in studies assessing lung disease

history and lung function impairment. A leave-one-out sensitivity analysis revealed that the studies by Wang [53] and Liu [54] were the primary sources of heterogeneity in lung disease history and lung function impairment, respectively, and heterogeneity was no longer significant after their exclusion. This heterogeneity may be due to these studies not specifying the types of lung disease, thereby introducing confounding factors. Moreover, the assessment of lung function varied among studies; some used MVV% while others used FEV_1 or FEV_1/FVC, and some merely identified pulmonary insufficiency as a risk factor without specifying detailed evaluation indicators, resulting in high heterogeneity. A subgroup analysis of lung disease history indicated that in Japan, a history of lung disease was a risk factor with no significant heterogeneity. Furthermore, it was a risk factor in both laparoscopic and open surgery, with open surgery showing no significant heterogeneity ($I^2 = 0.0\%$). Further analysis of variable interactions indicated that a history of lung disease is an important risk factor in the elderly population in Japan, likely due to a higher incidence of lung disease among the elderly and differences in perioperative management across national healthcare systems.

Multiple studies have demonstrated that preoperative reductions in forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC) are independent risk factors for pneumonia following radical gastrectomy [134]. Specifically, when FEV1% is less than 70%, the risk of postoperative pneumonia increases significantly. Moreover, a vital capacity percentage (%VC) of less than 80% is not only associated with an elevated risk of postoperative pneumonia but also correlates significantly with reduced overall survival [21, 135].

Impaired pulmonary function often indicates weakened respiratory muscles, directly affecting the effectiveness of coughing [136]. This results in a diminished cough reflex and reduced mucus clearance, thereby increasing the risk of infection [137]. Patients with compromised lung function frequently experience reduced lung capacity, which, combined with factors such as postoperative pain, the effects of anesthetic agents, and prolonged bed rest, predisposes them to atelectasis and consequently a higher risk of pneumonia [138]. Additionally, impaired lung function may be linked to systemic immune dysfunction, rendering patients more susceptible to infections caused by various pathogens [139].

COPD has been shown to significantly elevate the risk of postoperative pneumonia. Characteristic pathological changes in COPD—including chronic airway inflammation [140], increased mucus secretion [141], pulmonary hyperinflation, and gas trapping [142, 143]—impair respiratory muscle function and oxygenation, while associated immune dysfunction further compromises the clearance of pathogens [139]. Preexisting hypoxemia in COPD patients may exacerbate postoperative oxygenation disorders, increasing the risk of pneumonia [12, 39, 144].

In addition to COPD, a history of other pulmonary diseases significantly increases the risk of postoperative pneumonia following radical gastrectomy for gastric cancer. Patients with asthma, for instance, have a higher risk than those without [145], as their airways are particularly sensitive to stimuli, predisposing them to bronchospasm and airway narrowing, which impairs ventilation [146]. Moreover, chronic airway inflammation in asthma increases susceptibility to pathogenic invasion, with one large-scale study demonstrating that asthma significantly elevates the risk of postoperative pneumonia [10, 53], sepsis, and urinary tract infections—especially in patients with poorly controlled asthma requiring recent emergency treatment or long-term systemic corticosteroids [145]. A history of pulmonary tuberculosis also increases pneumonia risk due to structural lung damage that compromises lung function and secretion clearance [147, 148], with active tuberculosis further elevating surgical risks and postoperative complications [149]. Similarly, interstitial lung disease is associated with pulmonary complications, including pneumonia [150], due to inflammation and fibrosis that reduce lung capacity and oxygenation [151], and mechanical ventilation may further exacerbate lung injury in these patients, potentially leading to acute exacerbations and respiratory failure [151]. Patients with bronchiectasis are similarly at increased risk because chronic airway inflammation and excessive mucus retention impair effective secretion clearance [46], and these individuals often have coexisting conditions such as chronic bronchitis or emphysema [152].

Optimizing perioperative management for patients with impaired lung function is crucial. Preoperatively, patients should be advised to cease smoking at least eight weeks before surgery to reduce the risk of postoperative pulmonary complications [153]. In addition, respiratory training—including deep and diaphragmatic breathing exercises and the use of incentive spirometry [154]—can improve lung capacity and ventilation [155], bronchodilators may be used when indicated [46]. Nutritional support and tight control of existing comorbidities are also essential [156]. Intraoperatively, optimal anesthetic management is vital [155]: minimizing excessive sedation and neuromuscular blockade can facilitate prompt recovery of spontaneous breathing and coughing, while lung-protective ventilation strategies (e.g., low tidal volumes and appropriate PEEP) and careful fluid management help prevent pulmonary edema [157]. Postoperatively, early mobilization, effective coughing and deep breathing exercises, and optimal pain management are key to maintaining lung expansion and clearing secretions [158].

For patients with excessive secretions, airway management techniques—such as nebulized inhalation, postural drainage, and suctioning—should be considered [159].

For those with COPD, in addition to smoking cessation and respiratory training, optimizing pharmacological therapy and implementing a preoperative respiratory rehabilitation program are critical for improving exercise tolerance and lung function [160]. In patients with other pulmonary diseases (e.g., asthma, tuberculosis, interstitial lung disease, or bronchiectasis), individualized perioperative interventions are recommended. This includes optimizing asthma control and avoiding triggers, assessing tuberculosis activity and postponing surgery if active disease is present [161], tailoring anesthetic and surgical plans for interstitial lung disease to minimize lung injury [150], and enhancing airway clearance for bronchiectasis. For patients with bronchiectasis, airway cleaning should be enhanced before surgery, such as postural drainage and aerosol inhalation, to reduce sputum retention [150].

Multidisciplinary collaboration among physicians, nurses, and rehabilitation therapists is essential, and risk assessment tools such as the ARISCAT and GUPTA scores may help identify high-risk patients, enabling the implementation of more proactive preventive measures [162–165].

Surgical factors

Intraoperative bleeding and operation time

Our study demonstrated that patients with intraoperative blood loss ≥200 mL and those with prolonged operative time had a 2.21-fold and 1.51-fold increased risk of developing postoperative pneumonia after radical gastrectomy for gastric cancer, respectively, with significant heterogeneity observed among studies. A leave-one-out sensitivity analysis revealed that, after excluding the study by Tu [13]—which defined intraoperative blood loss risk as increasing per 50 mL—the heterogeneity became non-significant. Moreover, meta-analysis of prevalence data showed that the incidence of postoperative pneumonia was 15.84% in patients with blood loss ≥200 mL compared to 7.36% in those with blood loss <200 mL, consistent with existing literature indicating that greater intraoperative blood loss increases the risk of postoperative complications [166, 167]. Excessive intraoperative blood loss can result in significant loss of immunological factors and albumin [167], leading to impaired immune function and an increased susceptibility to pulmonary infections [168]. Severe hemorrhage may cause profound anemia and hypoalbuminemia, resulting in pulmonary edema, increased intrapulmonary shunting, and reduced ventilation efficiency, further elevating the risk of postoperative pulmonary infections [169].

To minimize intraoperative blood loss and reduce the associated risk of pneumonia, multiple perioperative interventions are warranted. Meticulous surgical techniques to minimize unnecessary vascular injury are crucial, and transfusions should be administered judiciously according to established guidelines. Some studies have suggested that a prophylactic increase in blood pressure at the end of surgery may aid in the detection and control of bleeding [170],however, its specific impact on pneumonia requires further investigation. Additionally, perioperative antithrombotic management should carefully balance the risks of bleeding against thromboembolic events [171].

Our study demonstrated that patients with an operative time of ≥200 min had a postoperative pneumonia incidence of 16.62%, compared to 9.93% in patients with an operative time of <200 min, consistent with previous research [172]. Prolonged operative time may lead to increased use of anesthetic agents—particularly neuromuscular blocking drugs—resulting in residual neuromuscular blockade [173, 174], prolonged mechanical ventilation, impaired upper airway defenses, reduced mucociliary clearance, lower residual lung volume, and atelectasis, thereby weakening the lower respiratory defenses [175, 176]. Additionally, longer surgery typically involves more extensive tissue manipulation and a heightened inflammatory response, which may trigger systemic inflammation and further increase pneumonia risk [177, 178]. Although the precise operative time threshold for increased pneumonia risk remains debated—with current studies suggesting cutoff values of 180, 200, or 215 min [13, 39, 53]—our findings, using a 200-min threshold, revealed a significant difference in incidence. For patients with comorbidities such as diabetes or hypertension, prolonged surgery may also lead to blood glucose fluctuations and hemodynamic instability [179, 180], further elevating the risk of postoperative pneumonia; however, optimal operative time ranges for these patients are yet to be defined. Factors such as tumor stage, surgical complexity, the extent of gastrectomy, reconstructive procedures (e.g., Roux-en-Y anastomosis), and a high ASA score may all contribute to longer operative times [181]. Furthermore, evidence suggests that the start time of surgery can influence operative duration and postoperative recovery; surgeries commencing before 13:00 tend to be longer, with less intraoperative blood loss and faster resumption of oral intake, highlighting the potential impact of surgeon fatigue on outcomes [42].

Current evidence suggests that, to reduce the risk of complications associated with prolonged operative time, a comprehensive perioperative strategy is

essential. Meticulous surgical planning and efficient execution are critical, and an experienced, well-coordinated surgical team can perform operations more effectively. Unnecessary procedural steps and delays should be minimized throughout the operation. When appropriate, minimally invasive techniques should be considered; although these approaches may initially require longer operative times, they are generally associated with improved overall outcomes [182, 183].

Total gastrectomy and D2 lymphadenectomy

Patients undergoing total gastrectomy and D2 lymphadenectomy exhibit a 2.59-fold and 4.14-fold increased risk of postoperative pneumonia, respectively, with no significant heterogeneity among studies. A meta-analysis of prevalence data demonstrated that the incidence of postoperative pneumonia was 13.64% in patients undergoing total gastrectomy, significantly higher than the 9.90% observed with other resection methods, which is consistent with previous research [156]. Notably, in elderly patients, non–cardia-preserving gastrectomy is an independent risk factor for postoperative pneumonia [184]. Mechanistically, total gastrectomy results in the loss of the lower esophageal sphincter (LES), thereby increasing the risk of gastroesophageal reflux and aspiration pneumonia [156]. Additionally, alterations in gastric emptying and motility elevate the risk of aspiration, while more pronounced weight loss and sarcopenia may compromise respiratory muscle strength and diminish the cough reflex [19], further increasing pneumonia susceptibility [115, 185]. Moreover, the more extensive surgical procedures and longer operative times required for total gastrectomy may indirectly elevate this risk [186].

To mitigate these complications, specific perioperative management strategies are recommended for total gastrectomy patients. These include rigorous pulmonary hygiene, early and frequent respiratory exercises, prompt mobilization, cautious postoperative positioning (e.g., semi-recumbent), aggressive nutritional support, and the consideration of antireflux reconstructive techniques (e.g., Roux-en-Y anastomosis), as these measures can help reduce reflux, aspiration, and ultimately, the incidence of pneumonia [8].

D2 lymphadenectomy is associated with an increased risk of postoperative pneumonia, and several studies [13]—particularly in elderly patients—have identified it as an independent risk factor [20]. Research indicates that D2 lymphadenectomy correlates with poorer overall survival in elderly patients with an ASA score of 3, with postoperative pneumonia serving as a contributing factor [20]. The potential mechanisms include a more extensive lymph node dissection, which may prolong operative time—a known risk factor for pulmonary complications—and significant disruption of the sympathetic nerve plexus around the celiac artery [187], potentially leading to diarrhea, decreased appetite, and gastroesophageal reflux, the latter predisposing patients to aspiration pneumonia [12, 188].

Moreover, studies comparing laparoscopic distal gastrectomy and open surgery, both employing D2 lymphadenectomy, have found no significant differences in overall complication rates, suggesting that the surgical approach may mitigate some risks associated with extensive dissection [189]. When considering D2 lymphadenectomy, it is essential to balance oncologic benefits against pulmonary complication risks; careful patient selection based on age, frailty, and preoperative pulmonary status is critical. For frail elderly patients with an ASA score of 3, limiting the extent of lymph node dissection to D1 or D1 + may reduce postoperative pneumonia risk without compromising cancer-specific survival in certain cases [20].

Surgical approach

In our study, open surgery was not identified as an independent risk factor for postoperative pneumonia, likely due to the limited number of included studies ($n = 2$) and substantial heterogeneity, which reduced the statistical power to detect a true association. The prevalence of postoperative pneumonia was 13.07% following open gastrectomy, compared to 7.30% with laparoscopic surgery, a finding consistent with the literature indicating that laparoscopic gastrectomy—and related minimally invasive techniques are associated with a lower risk of pneumonia [190–192]. Furthermore, in elderly patients, laparoscopic gastrectomy is linked to a lower pneumonia risk and fewer discharges to nursing facilities [190]. The study by Hu et al. demonstrated that laparoscopic distal gastrectomy with D2 lymphadenectomy, when performed by experienced surgeons, resulted in reduced intraoperative blood loss, earlier recovery of bowel function and oral intake, and shorter hospital stays [193]. Current guidelines recommend prioritizing minimally invasive surgical techniques, as laparoscopic procedures—although sometimes requiring longer operative times—are generally associated with reduced trauma, lower blood loss, and shorter hospitalizations compared with open surgery [69]. Moreover, studies have shown that robotic-assisted and laparoscopic-assisted radical gastrectomy yield superior postoperative outcomes and comparable survival rates relative to open surgery [194–196]. The benefits of minimally invasive surgery in reducing pneumonia risk are multifactorial: smaller incisions lead to less postoperative pain, which facilitates effective breathing

and coughing to clear secretions and prevent atelectasis; earlier mobilization enhances lung function; a reduced systemic inflammatory response helps preserve immune function; and shorter hospital stays may lower the risk of nosocomial infections [136, 163, 190, 197]. While laparoscopic surgery may take longer, the other benefits it brings may make it a better option for some patients.

Treatment factors

Prolonged postoperative nasogastric tube retention

Generally, if patients exhibit preoperative pyloric obstruction, intraoperative gastric wall edema, or a high risk of anastomotic leakage or bleeding, the placement of a nasogastric tube for gastrointestinal (NG tube) decompression is recommended to accelerate the recovery of gastrointestinal function, monitor drainage, and promptly detect bleeding, thereby reducing postoperative complications. However, a randomized controlled trial demonstrated that omitting postoperative NG tube placement did not increase the incidence of pulmonary infections, and was associated with earlier passage of flatus, shorter fasting durations, and reduced hospital stays [198]. Similarly, Kim et al. reported that prolonged NG tube retention increases the risk of postoperative pulmonary infections [199]. Routine use of NG tubes postoperatively is associated with delayed recovery of gastrointestinal function and oral intake, and is linked to an increased risk of respiratory infections and atelectasis [200].

Our study found that patients with prolonged NG tube retention had a 2.25-fold higher risk of postoperative pneumonia, with significant heterogeneity that was resolved after excluding Bai's study [44]. Subgroup analysis revealed that prolonged NG tube retention is a risk factor across different age groups and surgical approaches, with a postoperative pneumonia prevalence of 31.25% in patients with NG tube retention ≥ 4 days compared to 12.03% in those with retention < 4 days, consistent with existing studies [15].

Prolonged NG tube retention may increase the risk of postoperative pneumonia through several mechanisms. Primarily, it raises the risk of aspiration by impairing the function of the lower esophageal sphincter, thereby promoting reflux and aspiration—especially when patients have not fully regained consciousness or their swallowing reflex is impaired [201, 202]. Additionally, the NG tube may interfere with diaphragmatic movement and lung expansion, resulting in inadequate ventilation and atelectasis [201]. Kehlet et al. [199] demonstrated that NG tube placement can cause discomfort and stress, impeding effective coughing [49], respiratory exercises, and early oral intake, which delays recovery and increases infection risk [203]. Furthermore, the NG tube may serve as a conduit for bacterial colonization [53, 204], facilitating the migration of pathogens to the pharynx or lower respiratory tract [205].

To mitigate these risks, early removal of the NG tube within 24–48 h postoperatively and selective use based on individual clinical assessments are recommended [200, 206]. ERAS protocols, which emphasize early oral intake and reduced NG tube dependency, further support improved postoperative recovery and reduced complications [207]. Since the incidence of reflux is influenced by the feeding tube tip's position—6% when the tip is in the duodenum, 4% when near the ligament of Treitz, and only 0.4% when placed distal to it—several published guidelines recommend small bowel feeding for patients at risk of aspiration. Accordingly, positioning enteral nutrition tubes at least 40 cm distal to the ligament of Treitz is considered the optimal method [208–211]. Existing studies suggest that prokinetic agents may reduce the risk of aspiration pneumonia in patients with nasogastric tubes by directly stimulating gastrointestinal motility [212, 213]. However, other studies have reported contrary findings—particularly in elderly populations and in patients who have used nasogastric tubes for more than seven months—indicating that the use of prokinetic agents does not prevent pneumonia in these groups [214–216].

Although some studies report no significant difference in pneumonia rates between early and delayed NG tube removal [217], such discrepancies may be related to differences in surgical technique, patient population, or the precise timing of NG tube removal.

Perioperative blood transfusion

Several studies have demonstrated that perioperative blood transfusion (PBT) is associated with an increased risk of postoperative pneumonia following radical gastrectomy for gastric cancer [218, 219]. In our study, patients receiving perioperative transfusions had a 4.21-fold higher risk of developing postoperative pneumonia compared to those without transfusions. Subgroup analyses indicated that PBT is a risk factor across different countries, age groups, and surgical approaches. Moreover, interaction analysis revealed that, compared with Chinese patients, PBT is a particularly significant risk factor for postoperative pneumonia in Japanese patients under 60 (OR = 4.61), possibly due to differences in immunosuppression, blood management, and medical practices.

PBT may increase the risk of postoperative pneumonia following radical gastrectomy for gastric cancer through multiple mechanisms. Research indicates that patients with a history of transfusions exhibit alterations in their immune system [220], including T-cell suppression

and changes in T-cell subpopulations [221–223]. Furthermore, transfusion can trigger a cascade of immune responses, such as the inhibition of the immunoregulatory cytokine IL-2 and the release of immunosuppressive prostaglandins 3 [224]. Transfusion-related immunomodulation (TRIM) is a primary mechanism [225]; by inhibiting the function of macrophages and monocytes, it diminishes immune surveillance and may enhance tumor growth and metastasis [226, 227]. Moreover, even leukocyte-depleted blood products may contain residual leukocytes or soluble immune mediators that interfere with the patient's immune system [228], leading to immunosuppression and an increased susceptibility to postoperative pneumonia [229]. In addition, PBT may provoke or exacerbate inflammatory responses [230]. Although inflammation is a protective mechanism against infection, an excessive or dysregulated inflammatory response can damage lung tissue and impair pathogen clearance, thereby increasing pneumonia risk [231]. Notably, the need for transfusion may itself indicate a more complex or severe clinical condition; significant intraoperative blood loss and associated physiological stress can independently elevate the risk of postoperative pneumonia [230]. Therefore, when assessing the causal relationship between PBT and postoperative pneumonia, these potential confounding factors must be taken into account.

To reduce the risk of postoperative pneumonia associated with perioperative blood transfusion, multiple interventions should be implemented. A patient blood management (PBM) strategy, which optimizes a patient's endogenous blood and minimizes allogeneic transfusions, includes the preoperative identification and treatment of anemia, intraoperative measures to reduce blood loss, and optimized postoperative blood management [219, 232, 233]. A restrictive transfusion strategy—administering transfusions only when hemoglobin levels fall below 7–8 g/dL—has been shown to reduce unnecessary transfusions without compromising outcomes [234]. When transfusions are unavoidable, the use of leukocyte-depleted red blood cells may help mitigate immunomodulatory effects. Although most studies support an association between perioperative blood transfusion and an increased risk of postoperative infections, some research has reported conflicting results. For instance, Liu et al. [235] found that in elderly patients undergoing radical gastrectomy for gastric cancer, perioperative transfusion did not significantly affect complications other than fever or overall prognosis, possibly due to the unique physiological characteristics of elderly patients or limitations in study design.

Limitations

This study has several limitations. First, there was substantial heterogeneity among the included studies. Although subgroup analysis and meta-regression were performed, the exact sources of heterogeneity could not be fully identified. Additionally, the limited number of studies in certain subgroups may have reduced the reliability of the results. Second, most of the included cohort studies were retrospective, and while low-quality studies were excluded, the inherent recall bias in retrospective designs may have introduced some degree of deviation in the findings. Third, access to unpublished data was limited. Despite our efforts to contact the corresponding authors of eligible studies for additional methodological details and subgroup data, the response rate was low, and no new datasets were obtained. Moreover, unpublished studies, including those with negative results, may not have been accessible despite our search of gray literature sources. Future research should adopt more systematic approaches to acquiring non-public data to mitigate publication bias and enhance the robustness of meta-analyses. Fourth, due to language constraints, only studies published in English and Chinese were included, which may have led to the exclusion of relevant research published in other languages. Fifth, some of the risk factors in this study may be related to each other, but their interactions have not been explored. Future studies should use more advanced analytical methods, such as structural equation models and network analysis, to elucidate these complex interactions. Finally, as all included studies were conducted in Asian countries, the generalizability of our findings to other populations may be limited. Future research should aim to address these limitations and provide a more comprehensive investigation into pneumonia following radical gastrectomy.

Implications for clinical practice

Clinical interventions targeting patients at risk of postoperative pneumonia after radical gastrectomy for gastric cancer have the potential to significantly decrease pneumonia incidence, enhance patients' quality of life, and alleviate caregivers' workload. Important measures such as preoperative smoking cessation, nutritional supplementation to improve immunity and respiratory exercises should be incorporated into the patient care plan. Current research on postoperative pneumonia following radical gastrectomy has primarily focused on cases classified as grade II or higher according to the Clavien-Dindo system. While milder pneumonia generally correlates with a more favorable prognosis and severe pneumonia

with poorer outcomes, it remains unclear whether the risk factors differ between mild (grades I–II) and severe (grades III–IV) pneumonia. Further research is warranted to elucidate these potential differences.

Conclusions

This study conducted a meta-analysis to identify multiple associated risk factors as well as prevalence of pneumonia after radical gastrectomy for gastric cancer. This can assist nursing staff in identifying high-risk patients and formulating tailored prevention and care strategies in clinical practice. More well-designed prospective studies are needed in the future to assess the predictive role of risk factors and the effectiveness of prophylactic measures targeting pneumonia after radical gastric cancer surgery.

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

Supplementary Material 3.

Supplementary Material 4.

Authors' contributions

SY designed this study. SY and HZ were responsible for the literature search, data extraction and quality assessment. SY and QQ wrote the manuscript. JL and HH provided statistical support for the meta-analysis. SY, LP, DD, NT and LJ played an important role in the process of revision. All authors have read and approved the final manuscript.

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Data availability

The study's original contributions are available in the article and supplementary material. For additional inquiries, don't hesitate to get in touch with the corresponding author.

Declarations

Competing interests

The authors declare no competing interests.

Author details

[1]Department of General Surgery, Zhongshan Hospital of Xiamen University, Xiamen 361004, China. [2]Nursing College, Fujian University of Traditional Chinese Medicine, Fuzhou 350122, China. [3]School of Nursing, Beijing University of Chinese Medicine, Beijing, China. [4]Xiamen Hospital of Traditional Chinese Medicine, Xiamen, China. [5]Nursing Department, The First Affiliated Hospital of Xiamen University, Xiamen, China. [6]Clinical Oncology School of Fujian Medical University, Fujian Cancer Hospital, Fuzhou, China.

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