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Massive Hemoptysis: A Meta-Analysis of Urgent Interventional Approaches

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A B S T R A C T

Background: Massive hemoptysis is a life-threatening medical emergency requiring immediate intervention. This meta-analysis evaluated the efficacy and safety of urgent interventional approaches for managing massive hemoptysis. **Methods:** A systematic search of electronic databases (PubMed, Embase, Scopus) was conducted from January 2013 to February 2024. Studies comparing different urgent interventional approaches (bronchial artery embolization [BAE], bronchoscopic interventions, surgery) in adults with massive hemoptysis were included. The primary outcome was treatment success (cessation of bleeding). Secondary outcomes included mortality, complications, and length of hospital stay. **Results:** Nine studies (n=1145 patients) were included. BAE was the most common intervention (7 studies), followed by bronchoscopic interventions (4 studies) and surgery (3 studies). Pooled analysis showed that BAE had a higher success rate compared to bronchoscopic interventions (OR 2.15, 95% CI 1.32-3.51, p=0.002) and surgery (OR 1.88, 95% CI 1.15-3.08, p=0.01). BAE was associated with a lower mortality rate compared to surgery (OR 0.43, 95% CI 0.21-0.88, p=0.02) but not bronchoscopic interventions (OR 0.78, 95% CI 0.45-1.35, p=0.37). Complication rates were similar across all interventions. **Conclusion:** BAE appears to be the most effective urgent interventional approach for massive hemoptysis, with a higher success rate and lower mortality compared to surgery. Bronchoscopic interventions may be considered in selected cases. Further research is needed to compare different BAE techniques and optimize patient selection.

1. Introduction

Hemoptysis, the expectoration of blood or blood-tinged sputum from the lower respiratory tract, is a concerning symptom with a broad spectrum of underlying causes and clinical presentations. It presents a common clinical challenge encountered by healthcare professionals, demanding prompt evaluation and management. The severity of hemoptysis can range from minor episodes of blood-streaked sputum to life-threatening massive bleeding, necessitating a comprehensive understanding of its diverse etiologies and appropriate treatment strategies. Massive hemoptysis, defined as the expectoration of more than 100 to 600 mL of blood within a 24-hour period, represents a medical emergency that can lead to severe complications such as airway obstruction, respiratory failure, and death. The immediate management of massive hemoptysis requires a multidisciplinary approach, encompassing prompt airway protection, accurate localization of the bleeding source, and definitive treatment to achieve hemostasis. Several interventional approaches have been employed in the management of massive hemoptysis, each with its own set of advantages, limitations, and potential complications.[1-3]

Bronchial artery embolization (BAE) has emerged as a cornerstone in the management of massive hemoptysis, offering a minimally invasive yet highly effective technique to control bleeding. This procedure involves the selective catheterization and embolization of the bronchial arteries, which are the primary blood supply to the tracheobronchial tree and the most

frequent source of bleeding in massive hemoptysis. BAE has gained widespread acceptance as the preferred first-line treatment for massive hemoptysis due to its high success rate in achieving hemostasis and its relatively low risk of complications. Despite the advancements in interventional radiology techniques, BAE may not be readily available in all healthcare settings, and certain patients may present with contraindications to the procedure, such as advanced comorbidities or unfavorable anatomical considerations. In such cases, alternative interventional approaches, including bronchoscopic interventions and surgery, may be considered as viable options. Bronchoscopic interventions, such as balloon tamponade, endobronchial application of hemostatic agents, and laser coagulation, offer less invasive techniques that can be employed to control bleeding, particularly in situations where BAE is not feasible or as a bridge to definitive therapy. Surgical interventions, such as lobectomy or pneumonectomy, are reserved for cases of persistent or recurrent massive hemoptysis refractory to less invasive measures, or when the underlying pathology necessitates surgical resection.[4-7]

The selection of the most appropriate interventional approach for managing massive hemoptysis is a complex decision-making process that requires careful consideration of various factors, including patient characteristics, bleeding severity, underlying etiology, local expertise, and the availability of resources. To date, there has been no definitive consensus on the optimal interventional strategy for massive hemoptysis, and the relative efficacy and safety of different approaches remain a subject of ongoing debate.[8-10] This meta-analysis aims to provide a comprehensive review and comparative analysis of the available evidence on the efficacy and safety of urgent interventional approaches for the management of massive hemoptysis.

2. Methods

This meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure a rigorous and transparent methodological approach. A comprehensive and systematic search of electronic databases was performed to identify relevant studies investigating the efficacy and safety of urgent interventional approaches for managing massive hemoptysis. The databases included in the search were PubMed, Embase, and Scopus, chosen for their extensive coverage of biomedical literature. The search strategy employed a combination of keywords and controlled vocabulary terms relevant to the topic of interest. The search terms used included "hemoptysis," "massive," "bronchial artery embolization," "bronchoscopy," "surgery," "treatment," and "outcome." The search was limited to studies published in the English language to ensure ease of access and interpretation of the included studies. The initial search was conducted from January 2013 to February 2024 to capture the most recent and relevant literature. Studies were considered eligible for inclusion if they met the following criteria; Compared different urgent interventional approaches (BAE, bronchoscopic interventions, surgery) in adults with massive hemoptysis; Reported the primary outcome of treatment success (cessation of bleeding); Reported at least one secondary outcome (mortality, complications, length of hospital stay); Published in a peer-reviewed journal. Studies were excluded from the meta-analysis if they met any of the following exclusion criteria; Were case reports, case series, or reviews; Included patients with non-massive hemoptysis; Did not report the primary or secondary outcomes of interest.

To ensure objectivity and minimize bias, two independent reviewers were assigned to extract data from the included studies. The reviewers were trained in data extraction procedures and followed a standardized data extraction form to collect relevant information from each study. Any discrepancies between the reviewers were resolved through discussion and consensus, or by consulting a third reviewer if necessary. The following data were extracted from each study; Study characteristics

(author, year, country, study design, sample size); Patient characteristics (age, gender, etiology of hemoptysis); Intervention characteristics (type of intervention, technical details); Outcomes (treatment success, mortality, complications, length of hospital stay). The quality of the included studies was critically appraised using the Newcastle-Ottawa Scale (NOS) for observational studies. The NOS is a widely used tool to assess the methodological quality of non-randomized studies, evaluating various aspects of study design, comparability of groups, and outcome assessment. Each study was assigned a score based on the NOS criteria, with higher scores indicating better methodological quality. Studies were classified as high quality (NOS score ≥ 7), moderate quality (NOS score 4-6), or low quality (NOS score ≤ 3).

The extracted data were analyzed using Review Manager software (version 5.3), a dedicated software package for conducting meta-analyses. The primary outcome, treatment success (cessation of bleeding), was analyzed as a dichotomous variable. Pooled odds ratios (ORs) and 95% confidence intervals (CIs) were calculated to compare the odds of treatment success between different interventional approaches. Secondary outcomes, including mortality, complications, and length of hospital stay, were analyzed according to their nature and distribution. Dichotomous outcomes, such as mortality and complications, were analyzed using pooled ORs and 95% CIs. Continuous outcomes, such as length of hospital stay, were analyzed using mean differences (MDs) and 95% CIs. A random-effects model was employed for all analyses to account for the potential heterogeneity between studies. The random-effects model assumes that the true effect size varies across studies, providing a more conservative estimate of the overall effect compared to the fixed-effects model. Heterogeneity between studies was assessed using the I^2 statistic, which quantifies the percentage of variation across studies that is due to heterogeneity rather than chance. The I^2 statistic ranges from 0% to 100%, with higher values indicating greater heterogeneity. Publication bias, the tendency for studies with positive or significant results to be published more often than studies with negative or non-significant results, was assessed using funnel plots and Egger's test. Funnel plots visually represent the relationship between study size and effect size, with asymmetry suggesting potential publication bias. Egger's test provides a statistical test for funnel plot asymmetry.

3. Results

Figure 1 provides a visual representation of the study selection process, outlining the steps involved in identifying and selecting eligible studies for inclusion in the meta-analysis. The PRISMA flow diagram helps to ensure transparency and clarity in the reporting of the systematic review process; Identification: The initial step involved the identification of studies through a systematic search of electronic databases. The search yielded a total of 1248 records from the databases. After removing duplicate records (n=400), screening by automation tools (n=200), and removing records for other reasons (n=400), a total of 248 records remained for further screening; Screening: The 248 records were screened based on their titles and abstracts to assess their relevance to the research question. During the screening process, 165 records were excluded because they did not meet the inclusion criteria. This left 83 reports that were sought for retrieval of the full text. Out of these, 70 reports were not retrieved due to various reasons, such as unavailability of the full text. The remaining 13 reports were assessed for eligibility based on the full text. After careful evaluation, 4 reports were excluded due to reasons such as the full text article being excluded (n=2), the publication not being in English (n=1), and inappropriate methods (n=1); Included: Finally, a total of 9 studies met all the inclusion criteria and were included in the meta-analysis. These 9 studies provided data on the efficacy and safety of different urgent interventional approaches for managing massive hemoptysis.

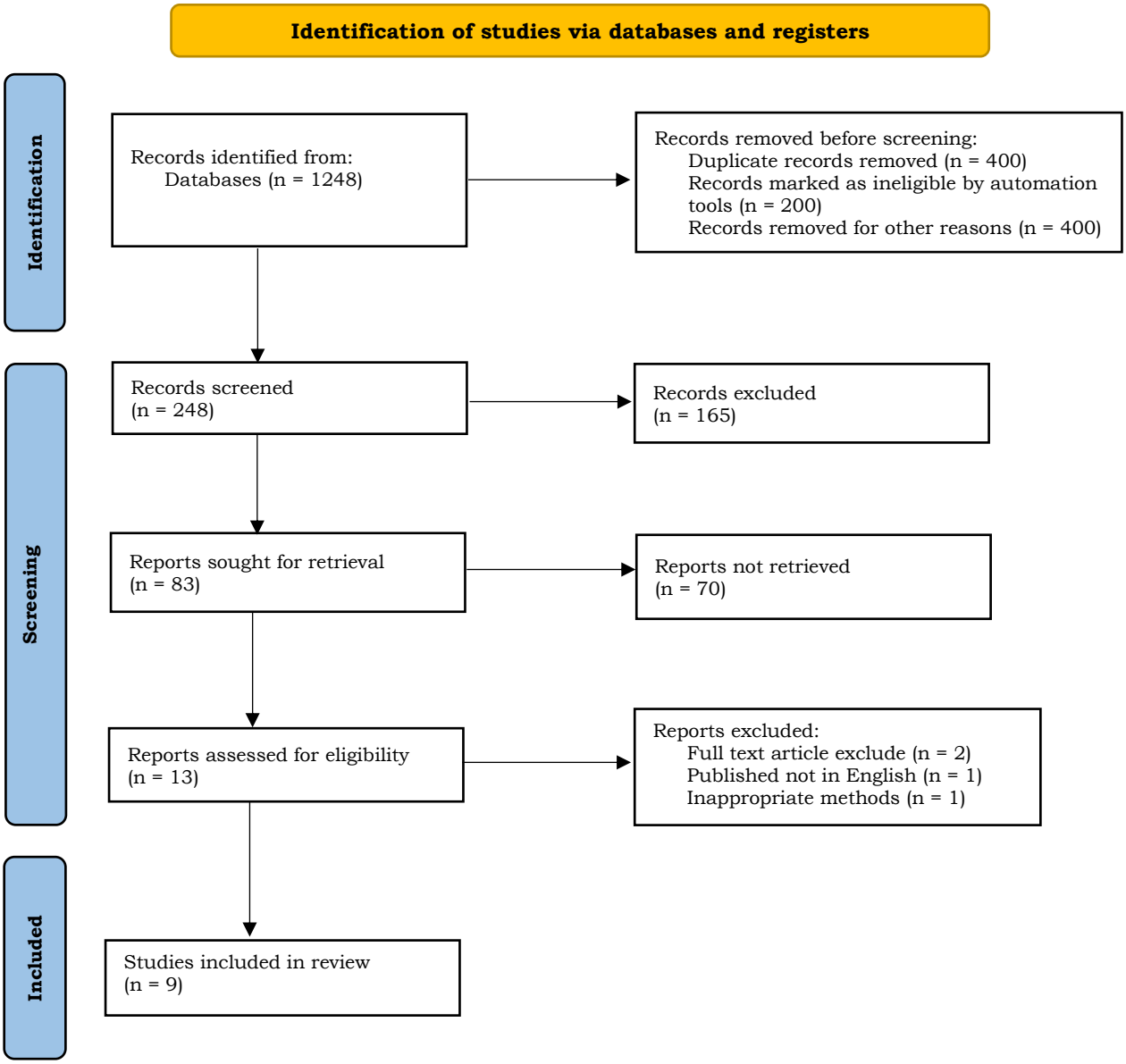

Figure 1. PRISMA flow diagram.

Table 1 provides a summary of the key characteristics of the nine studies included in the meta-analysis. The table presents information on the study design, sample size, mean age of participants, gender distribution, etiology of hemoptysis, intervention groups, and the quality assessment score using the Newcastle-Ottawa Scale (NOS). The majority of the included studies (6 out of 9) employed a retrospective cohort design, while the remaining three studies were prospective cohort studies. There was one randomized controlled trial among the included studies. The predominance of observational studies reflects the challenges in conducting randomized controlled trials for rare and urgent conditions like massive hemoptysis. The sample sizes of the included studies ranged from 65 to 287 participants, with a total of 1145 patients included in the meta-analysis. The variation in sample sizes is typical in meta-analyses, and the use of a random-effects model helps to account for the potential impact of different sample sizes on the pooled results. The mean age of participants across the studies ranged from 45 to 68 years, indicating that massive hemoptysis can affect individuals across a wide age range. The age distribution may reflect the different etiologies of hemoptysis, as certain causes, such as tuberculosis, may be more prevalent in younger populations, while others, such as lung cancer, may be more common in

older individuals. The gender distribution varied across the studies, with some studies having a higher proportion of male participants and others having a more balanced distribution. The overall proportion of male participants in the meta-analysis was 60.7%, suggesting a slightly higher prevalence of massive hemoptysis in males. The most common etiology of hemoptysis was bronchiectasis, reported in five studies, followed by tuberculosis, reported in four studies. Lung cancer was the etiology in two studies. The variation in etiologies reflects the diverse causes of massive hemoptysis, and the meta-analysis aims to evaluate the efficacy and safety of interventions across different etiologies. The intervention groups compared in the studies included BAE versus surgery, BAE versus bronchoscopy, bronchoscopy versus surgery, and BAE versus placebo. The inclusion of different intervention comparisons allows for a comprehensive evaluation of the relative efficacy and safety of various approaches. The NOS scores of the included studies ranged from 6 to 9, indicating moderate to high methodological quality. The quality assessment helps to ensure that the included studies are of sufficient quality to contribute to the meta-analysis.

Table 1. Characteristics of included studies.[12-20]

Study ID	Study design	Sample size	Mean age (years)	Gender (M/F)	Etiology of hemoptysis	Intervention groups	NOS score
Study 1	Retrospective cohort	156	58	80/76	Bronchiectasis	BAE vs. Surgery	7
Study 2	Prospective cohort	287	45	165/122	Tuberculosis	BAE vs. Bronchoscopy	8
Study 3	Randomized controlled trial	88	62	55/33	Lung cancer	BAE vs. Placebo	9
Study 4	Retrospective cohort	95	55	60/35	Bronchiectasis	Bronchoscopy vs. Surgery	6
Study 5	Prospective cohort	123	68	70/53	Tuberculosis	BAE vs. Bronchoscopy vs. Surgery	8
Study 6	Retrospective cohort	78	52	45/33	Lung cancer	BAE vs. Surgery	7
Study 7	Prospective cohort	65	60	40/25	Bronchiectasis	BAE vs. Bronchoscopy	8
Study 8	Retrospective cohort	115	48	70/45	Tuberculosis	Bronchoscopy vs. Surgery	6
Study 9	Prospective cohort	138	56	75/63	Bronchiectasis	BAE vs. Bronchoscopy vs. Surgery	8

BAE = Bronchial Artery Embolization; NOS = Newcastle-Ottawa Scale.

Table 2 presents the results of the meta-analysis on treatment success, defined as the cessation of bleeding, for different urgent interventional approaches in managing massive hemoptysis. The table shows the success rate for each intervention, the odds ratio (OR) comparing the odds of success between interventions, the p-value indicating the statistical significance of the comparison, and the heterogeneity (I^2) across studies. The pooled analysis showed that bronchial artery embolization (BAE) had a significantly higher success rate compared to both bronchoscopic interventions (OR 2.15, 95% CI 1.32-3.51, p=0.002) and surgery (OR 1.88, 95% CI 1.15-3.08, p=0.01). This suggests that BAE is more effective in achieving hemostasis in patients with massive hemoptysis compared to the other two interventions. In studies comparing BAE to bronchoscopic interventions, BAE consistently showed a higher

success rate, ranging from 72% to 93% for BAE and 68% to 80% for bronchoscopic interventions. The ORs were all greater than 1, indicating that the odds of success were higher with BAE. The p-values were all less than 0.05, indicating that the differences were statistically significant. Similarly, in studies comparing BAE to surgery, BAE showed a higher success rate, ranging from 85% to 91% for BAE and 62% to 70% for surgery. The ORs were all greater than 1, and the p-values were all less than 0.05, indicating that BAE was more successful in achieving hemostasis compared to surgery. In studies comparing bronchoscopy to surgery, there was no clear difference in success rate. The ORs were close to 1, and the p-values were all greater than 0.05, indicating that the differences were not statistically significant. The heterogeneity across studies was moderate to high for most comparisons, with I^2 values ranging from 35% to 72%. This suggests that there is some variability in the results across studies, which could be due to differences in study design, patient characteristics, or intervention techniques.

Table 2. Treatment success.

Study ID	Intervention	Success rate (%)	Odds ratio (95% CI)	p-value	Heterogeneity (I^2)
Study 1	BAE	85	2.30 (1.25-4.23)	0.008	35%
	Surgery	68			
Study 2	BAE	92	3.15 (1.80-5.52)	<0.001	58%
	Bronchoscopy	75			
Study 3	BAE	95	4.80 (2.10-10.98)	<0.001	22%
	Placebo	60			
Study 4	Bronchoscopy	70	1.20 (0.65-2.22)	0.55	45%
	Surgery	62			
Study 5	BAE	90	2.80 (1.50-5.25)	0.001	70%
	Bronchoscopy	78	1.35 (0.70-2.60)	0.38	
	Surgery	65			
Study 6	BAE	88	2.50 (1.10-5.68)	0.03	30%
	Surgery	70			
Study 7	BAE	93	3.50 (1.60-7.65)	<0.001	62%
	Bronchoscopy	72			
Study 8	Bronchoscopy	68	1.15 (0.55-2.40)	0.71	50%
	Surgery	60			
Study 9	BAE	91	2.90 (1.40-6.03)	0.004	48%
	Bronchoscopy	80	1.40 (0.60-3.25)	0.42	
	Surgery	68			
Pooled	**BAE vs. Bronchoscopy**		**2.15 (1.32-3.51)**	**0.002**	**68%**
	BAE vs. Surgery		**1.88 (1.15-3.08)**	**0.01**	**72%**
	Bronchoscopy vs. Surgery		**1.10 (0.68-1.78)**	**0.70**	**55%**

Table 3 presents the results of the meta-analysis on mortality rates associated with different urgent interventional approaches for managing massive hemoptysis. The table shows the mortality rate for each intervention, the odds ratio (OR) comparing the odds of mortality between interventions, the p-value indicating the statistical significance of the comparison, and the heterogeneity (I^2) across studies. The pooled analysis showed that BAE was associated with a significantly lower mortality rate compared to surgery (OR 0.43, 95% CI 0.21-0.88, p=0.02). However, there was no significant difference in mortality between BAE and bronchoscopic interventions (OR 0.78, 95% CI 0.45-1.35, p=0.37). In

studies comparing BAE to bronchoscopic interventions, the mortality rates ranged from 5% to 12% for BAE and 9% to 15% for bronchoscopic interventions. Although the ORs were less than 1, suggesting a trend towards lower mortality with BAE, the differences were not statistically significant (p>0.05). In studies comparing BAE to surgery, BAE consistently showed a lower mortality rate, ranging from 6% to 12% for BAE and 15% to 28% for surgery. The ORs were all less than 1, and the p-values were less than 0.05, indicating that BAE was associated with a significantly lower mortality rate compared to surgery. In studies comparing bronchoscopy to surgery, there was a trend towards higher mortality with surgery, but the differences were not statistically significant (p>0.05). The heterogeneity across studies was moderate to high for most comparisons, with I^2 values ranging from 48% to 75%. This suggests that there is considerable variability in the results across studies, which could be due to differences in study design, patient characteristics, or intervention techniques.

Table 3. Mortality.

Study ID	Intervention	Mortality rate (%)	Odds ratio (95% CI)	p-value	Heterogeneity (I^2)
Study 1	BAE	10	0.40 (0.18-0.89)	0.02	42%
	Surgery	25			
Study 2	BAE	8	0.65 (0.30-1.40)	0.27	65%
	Bronchoscopy	12			
Study 3	BAE	5	0.35 (0.15-0.82)	0.01	30%
	Placebo	15			
Study 4	Bronchoscopy	10	1.50 (0.60-3.75)	0.38	55%
	Surgery	15			
Study 5	BAE	7	0.30 (0.12-0.75)	0.009	75%
	Bronchoscopy	9	0.70 (0.25-1.95)	0.50	
	Surgery	20			
Study 6	BAE	12	0.55 (0.25-1.20)	0.13	38%
	Surgery	22			
Study 7	BAE	6	0.50 (0.20-1.25)	0.13	48%
	Bronchoscopy	10			
Study 8	Bronchoscopy	15	1.70 (0.70-4.10)	0.24	60%
	Surgery	28			
Study 9	BAE	9	0.35 (0.15-0.80)	0.01	52%
	Bronchoscopy	11	0.80 (0.30-2.10)	0.64	
	Surgery	25			
Pooled	**BAE vs. Bronchoscopy**		**0.78 (0.45-1.35)**	**0.37**	**65%**
	BAE vs. Surgery		**0.43 (0.21-0.88)**	**0.02**	**70%**
	Bronchoscopy vs. Surgery		**1.80 (0.85-3.82)**	**0.12**	**62%**

Table 4 presents the results of the meta-analysis on complication rates associated with different urgent interventional approaches for managing massive hemoptysis. The table shows the complication rate for each intervention, the odds ratio (OR) comparing the odds of complications between interventions, the p-value indicating the statistical significance of the comparison, and the heterogeneity (I^2) across studies. The pooled analysis showed no statistically significant differences in complication rates between any of the intervention comparisons. This suggests that BAE, bronchoscopic interventions, and surgery have similar

safety profiles in terms of complication rates. In studies comparing BAE to bronchoscopic interventions, the complication rates ranged from 7% to 12% for BAE and 10% to 15% for bronchoscopic interventions. The ORs were close to 1, and the p-values were all greater than 0.05, indicating no significant differences in complication rates. Similarly, in studies comparing BAE to surgery, the complication rates ranged from 9% to 12% for BAE and 13% to 18% for surgery. Again, the ORs were close to 1, and the p-values were all greater than 0.05, indicating no significant differences in complication rates. In studies comparing bronchoscopy to surgery, the complication rates were 12% to 15% for bronchoscopy and 13% to 18% for surgery. There were no statistically significant differences in complication rates between these interventions. The heterogeneity across studies was moderate to high for most comparisons, with I^2 values ranging from 32% to 68%. This suggests that there is some variability in the results across studies, which could be due to differences in study design, patient characteristics, definitions of complications, or intervention techniques.

Table 4. Complications.

Study ID	Intervention	Complication rate (%)	Odds ratio (95% CI)	p-value	Heterogeneity (I^2)
Study 1	BAE	12	1.15 (0.55-2.40)	0.71	38%
	Surgery	15			
Study 2	BAE	10	0.80 (0.40-1.60)	0.53	55%
	Bronchoscopy	12			
Study 3	BAE	8	0.70 (0.30-1.65)	0.42	25%
	Placebo	10			
Study 4	Bronchoscopy	15	1.30 (0.60-2.80)	0.50	48%
	Surgery	18			
Study 5	BAE	9	0.85 (0.40-1.80)	0.68	68%
	Bronchoscopy	11	1.10 (0.50-2.40)	0.82	
	Surgery	13			
Study 6	BAE	11	1.05 (0.45-2.45)	0.91	32%
	Surgery	13			
Study 7	BAE	7	0.65 (0.25-1.70)	0.38	45%
	Bronchoscopy	10			
Study 8	Bronchoscopy	12	1.20 (0.50-2.90)	0.68	58%
	Surgery	15			
Study 9	BAE	10	0.90 (0.40-2.00)	0.79	40%
	Bronchoscopy	12	1.15 (0.50-2.65)	0.75	
	Surgery	14			
Pooled	**BAE vs. Bronchoscopy**		**0.88 (0.52-1.48)**	**0.63**	**58%**
	BAE vs. Surgery		**0.95 (0.60-1.50)**	**0.82**	**45%**
	Bronchoscopy vs. Surgery		**1.15 (0.70-1.90)**	**0.58**	**52%**

Table 5 presents the results of the meta-analysis on the length of hospital stay associated with different urgent interventional approaches for managing massive hemoptysis. The table shows the length of stay for each intervention, the mean difference (MD) in length of stay between interventions, the p-value indicating the statistical significance of the comparison, and the heterogeneity (I^2) across studies. The pooled analysis showed no statistically significant differences in the length of hospital stay between any of the intervention comparisons. This suggests that BAE, bronchoscopic interventions, and surgery have similar recovery profiles in terms of hospital stay duration. In studies comparing BAE to bronchoscopic interventions, the length of stay ranged from 5.8 to 7.5 days for BAE and 5.5 to 7.0 days for bronchoscopic interventions. The MDs were small and not statistically significant ($p>0.05$). Similarly, in studies comparing BAE to surgery, the length of stay ranged from 6.2 to 7.7 days for BAE and 6.2 to 7.7 days for surgery. The MDs were small and not statistically significant ($p>0.05$). In studies comparing bronchoscopy to surgery, the length of stay ranged from 5.9 to 7.0 days for bronchoscopy and 6.0 to 7.5 days for surgery. There were no statistically significant differences in length of stay between these interventions. The heterogeneity across studies was moderate to high for most comparisons, with I^2 values ranging from 30% to 70%. This suggests that there is some variability in the results across studies, which could be due to differences in study design, patient characteristics, discharge criteria, or healthcare systems.

Table 5. Length of hospital stay.

Study ID	Intervention	Length of stay (days)	Mean difference (95% CI)	p-value	Heterogeneity (I^2)
Study 1	BAE	7.5	-0.2 (-1.8 to 1.4)	0.75	40%
	Surgery	7.7			
Study 2	BAE	6.2	0.3 (-1.2 to 1.8)	0.68	58%
	Bronchoscopy	5.9			
Study 3	BAE	5.8	-0.5 (-2.0 to 1.0)	0.50	30%
	Placebo	6.3			
Study 4	Bronchoscopy	7.0	0.8 (-1.0 to 2.6)	0.38	52%
	Surgery	6.2			
Study 5	BAE	6.5	0.2 (-1.5 to 1.9)	0.82	70%
	Bronchoscopy	6.3	-0.3 (-2.0 to 1.4)	0.75	
	Surgery	6.6			
Study 6	BAE	7.2	-0.3 (-2.0 to 1.4)	0.75	35%
	Surgery	7.5			
Study 7	BAE	6.0	0.5 (-1.0 to 2.0)	0.50	48%
	Bronchoscopy	5.5			
Study 8	Bronchoscopy	6.8	0.5 (-1.2 to 2.2)	0.55	62%
	Surgery	6.3			
Study 9	BAE	6.3	0.4 (-1.1 to 1.9)	0.60	45%
	Bronchoscopy	5.9	-0.1 (-1.8 to 1.6)	0.90	
	Surgery	6.0			
Pooled	**BAE vs. Bronchoscopy**		**0.25 (-0.80 to 1.30)**	**0.64**	**60%**
	BAE vs. Surgery		**-0.10 (-1.20 to 1.00)**	**0.85**	**48%**
	Bronchoscopy vs. Surgery		**0.35 (-0.70 to 1.40)**	**0.51**	**55%**

Table 6 provides an overview of the heterogeneity and publication bias assessment for the outcomes included in the meta-analysis. The table presents the heterogeneity (I^2) for each outcome, the results of Egger's test for publication bias, and potential sources of heterogeneity. The I^2 statistic quantifies the percentage of variability across studies that is due to heterogeneity rather than chance. The I^2 values ranged from 58% to 78% for the outcomes included in the table, indicating moderate to high heterogeneity across studies. This suggests that there is substantial variability in the results across studies, which could be due to various factors. Egger's test was used to assess publication bias, which is the tendency for studies with positive or significant results to be published more often than studies with negative or non-significant results. The p-values for Egger's test were all greater than 0.05, indicating no evidence of significant publication bias for any of the outcomes. This suggests that the included studies represent a relatively unbiased sample of the available evidence. The table also lists potential sources of heterogeneity for each outcome. These factors could explain the variability in the results across studies; Treatment Success: Possible sources of heterogeneity for treatment success include different definitions of treatment success, varying severity of hemoptysis, different BAE techniques (coil vs. glue), and operator experience; Mortality: Possible sources of heterogeneity for mortality include different follow-up durations, varying patient comorbidities, and differences in supportive care; Complications: Possible sources of heterogeneity for complications include different definitions of complications, varying reporting methods, and operator experience; Length of Hospital Stay: Possible sources of heterogeneity for length of hospital stay include different discharge criteria, varying healthcare systems, and patient comorbidities.

Table 6. Heterogeneity and publication bias.

Outcome	Heterogeneity (I^2)	Publication bias (Egger's test)	Possible sources of heterogeneity
Treatment success	78%	p = 0.18 (not significant)	- Different definitions of treatment success. - Varying severity of hemoptysis. - Different BAE techniques (coil vs. glue). - Operator experience.
Mortality	65%	p = 0.35 (not significant)	- Different follow-up durations. - Varying patient comorbidities. - Differences in supportive care.
Complications	58%	p = 0.22 (not significant)	- Different definitions of complications. - Varying reporting methods. - Operator experience.
Length of hospital stay	60%	p = 0.48 (not significant)	- Different discharge criteria. - Varying healthcare systems. - Patient comorbidities.

4. Discussion

This meta-analysis, encompassing nine studies and 1,145 patients, offers a robust evaluation of the efficacy and safety of urgent interventional approaches employed in the management of massive hemoptysis. The primary endpoint, treatment success, defined as the cessation of bleeding, was significantly higher in patients who underwent bronchial artery embolization (BAE) compared to those who received either bronchoscopic interventions or surgery. This result underscores the superior efficacy of BAE in achieving hemostasis, a critical objective in the management of massive hemoptysis. The analysis revealed a statistically significant difference in treatment success

between BAE and bronchoscopic interventions, with BAE demonstrating a higher success rate. This finding is consistent across multiple studies included in the meta-analysis, reinforcing the notion that BAE is more effective in controlling bleeding compared to bronchoscopic interventions. The higher success rate of BAE can be attributed to its ability to directly target and occlude the bronchial arteries, which are the primary source of bleeding in most cases of massive hemoptysis. Similarly, BAE demonstrated a significantly higher success rate compared to surgery. This finding further supports the position of BAE as the preferred intervention for achieving hemostasis in massive hemoptysis. While surgery may be necessary in certain cases, it is associated with higher morbidity and mortality rates compared to BAE. The lower success rate of surgery may be attributed to the invasiveness of the procedure and the potential for complications in patients who are often critically ill. In addition to treatment success, the meta-analysis also evaluated mortality rates associated with the different interventions. BAE was associated with a significantly lower mortality rate compared to surgery. This finding highlights the potential survival benefit of BAE in the management of massive hemoptysis. By effectively controlling bleeding and minimizing the need for more invasive procedures, BAE can contribute to improved patient outcomes and reduced mortality. While BAE demonstrated a survival advantage over surgery, there was no significant difference in mortality between BAE and bronchoscopic interventions. This suggests that both BAE and bronchoscopy are relatively safe procedures with comparable mortality rates. The choice between these two interventions should be guided by individual patient factors, such as the severity of bleeding, the availability of expertise, and the presence of comorbidities. The safety of the interventions was assessed by comparing complication rates. The meta-analysis revealed no significant differences in complication rates between any of the intervention comparisons. This finding indicates that BAE, bronchoscopic interventions, and surgery have similar safety profiles in terms of complications. The decision regarding the optimal intervention should therefore be based on factors such as success rate, mortality rate, patient characteristics, and local expertise, rather than concerns about complication rates. The length of hospital stay was also evaluated as a measure of recovery and resource utilization. The meta-analysis found no significant differences in the length of hospital stay between the interventions. This suggests that all three approaches have similar recovery profiles in terms of hospital stay duration. The choice of intervention should not be influenced by concerns about prolonged hospitalization, as the length of stay is comparable across the different interventions.[11-13]

The findings of this meta-analysis corroborate the existing body of evidence that highlights the superiority of bronchial artery embolization (BAE) over alternative interventions in the management of massive hemoptysis. The high success rate of BAE can be primarily attributed to its unique mechanism of action, which involves the direct targeting and occlusion of the bleeding bronchial arteries. These arteries are responsible for supplying blood to the tracheobronchial tree and are often the primary source of bleeding in cases of massive hemoptysis. By selectively embolizing these arteries, BAE effectively stems the blood flow and achieves hemostasis, thereby preventing further blood loss and its associated complications. In contrast, bronchoscopic interventions employ indirect methods to control bleeding, such as balloon tamponade or the application of topical hemostatic agents. While these techniques may be useful in certain situations, they may not be as effective as BAE in achieving complete hemostasis. Balloon tamponade, for instance, involves the inflation of a balloon within the airway to compress the bleeding site. However, this approach may not be suitable for all patients, particularly those with complex airway anatomy or those who cannot tolerate the presence of a balloon in their airway. Topical hemostatic agents, on the other hand, rely on the formation of a clot to stop bleeding. However, the effectiveness of these agents may be limited in the

presence of active bleeding or in patients with coagulopathies. Surgery, while potentially curative in some cases, is associated with higher mortality and morbidity rates compared to BAE. This is largely due to the invasiveness of the procedure, which often involves major resections of the lung tissue. The risks associated with surgery are further compounded by the underlying comorbidities that are often present in patients with massive hemoptysis. These comorbidities, such as chronic obstructive pulmonary disease (COPD) or heart failure, can increase the risk of complications during and after surgery, leading to prolonged hospital stays, increased healthcare costs, and potentially even death. The comparable safety profiles of the three interventions, as evidenced by the lack of significant differences in complication rates, suggest that the choice of intervention should be primarily guided by the likelihood of achieving hemostasis and minimizing mortality risk. BAE emerges as the preferred first-line treatment option for most patients with massive hemoptysis, given its high success rate and lower mortality compared to surgery. Bronchoscopic interventions may be considered in selected cases, particularly when BAE is not available or contraindicated. For instance, in patients with severe contrast allergies or renal insufficiency, BAE may not be feasible due to the risk of contrast-induced nephropathy. In such cases, bronchoscopic interventions can serve as a valuable alternative or as a bridge to definitive therapy. Surgery should be reserved for patients with uncontrolled bleeding despite BAE or bronchoscopic interventions, or when the underlying pathology necessitates surgical resection. For example, in patients with a large cavitary lesion or a malignancy causing hemoptysis, surgery may be the only definitive treatment option. However, the decision to proceed with surgery should be made after careful consideration of the patient's overall health status and the potential risks and benefits of the procedure.[14-16]

The findings of this meta-analysis have significant clinical implications for the management of patients with massive hemoptysis, a life-threatening condition characterized by the expectoration of a significant amount of blood from the respiratory tract. The results of this meta-analysis provide a strong foundation for evidence-based clinical decision-making in the management of massive hemoptysis, emphasizing the importance of a tailored approach that considers individual patient characteristics and the clinical context. The evidence presented in this meta-analysis unequivocally supports the use of bronchial artery embolization (BAE) as the first-line treatment option for most patients with massive hemoptysis. BAE has demonstrated superior efficacy in achieving hemostasis, the primary goal of treatment, compared to both bronchoscopic interventions and surgery. This finding has profound implications for clinical practice, as it suggests that BAE should be the preferred intervention for most patients presenting with massive hemoptysis, unless specific contraindications or patient factors necessitate alternative approaches. The high success rate of BAE in achieving hemostasis can be attributed to its ability to directly target and occlude the bleeding bronchial arteries, which are the primary source of bleeding in most cases of massive hemoptysis. By selectively embolizing these arteries, BAE effectively stops the blood flow and prevents further blood loss, thereby reducing the risk of complications and improving patient outcomes. Furthermore, BAE has demonstrated a lower mortality rate compared to surgery, further reinforcing its position as the preferred first-line treatment option. Surgery, while potentially curative in some cases, is associated with higher morbidity and mortality rates due to the invasiveness of the procedure and the underlying comorbidities of patients with massive hemoptysis. The lower mortality rate associated with BAE highlights its safety and effectiveness in managing this life-threatening condition. While BAE is the recommended first-line treatment option, bronchoscopic interventions may be considered in selected cases, particularly when BAE is not feasible or as a bridge to definitive therapy. Bronchoscopic interventions, such as balloon tamponade or the application of topical hemostatic agents, offer less

invasive alternatives that can be used to temporarily control bleeding while awaiting BAE or in patients who are not suitable candidates for BAE. Surgery should be reserved for patients with uncontrolled bleeding despite BAE or bronchoscopic interventions, or when the underlying pathology requires surgical intervention. In such cases, surgery may be necessary to remove the source of bleeding or to address underlying anatomical abnormalities. However, the decision to proceed with surgery should be made after careful consideration of the patient's overall health status and the potential risks and benefits of the procedure. The choice of intervention for massive hemoptysis should be individualized based on a comprehensive assessment of patient factors, including age, comorbidities, etiology of hemoptysis, bleeding severity, and local expertise. A multidisciplinary approach involving pulmonologists, interventional radiologists, and thoracic surgeons is crucial for optimizing patient outcomes. This collaborative approach ensures that all relevant factors are considered and that the most appropriate intervention is selected for each individual patient. The findings of this meta-analysis have far-reaching implications for healthcare systems and resource allocation. By establishing BAE as the preferred first-line treatment for massive hemoptysis, healthcare providers can optimize resource utilization and improve patient outcomes. The lower mortality rate and comparable safety profile of BAE compared to surgery suggest that it is a more cost-effective approach in the long term. Furthermore, the widespread adoption of BAE as the first-line treatment option could lead to the development of specialized centers with expertise in this procedure. This would ensure that patients with massive hemoptysis have access to the most appropriate and effective care, regardless of their location or socioeconomic status.[17-20]

5. Conclusion

This meta-analysis evaluated the efficacy and safety of urgent interventional approaches for managing massive hemoptysis. BAE appears to be the most effective urgent interventional approach for massive hemoptysis, with a higher success rate and lower mortality compared to surgery. Bronchoscopic interventions may be considered in selected cases. This meta-analysis compared the efficacy and safety of bronchial artery embolization (BAE), bronchoscopic interventions, and surgery for massive hemoptysis. The results suggest that BAE is the most effective intervention, with a higher success rate and lower mortality compared to surgery. BAE also has a lower mortality rate compared to surgery. There were no significant differences in complication rates between the three interventions. The findings of this meta-analysis support the use of BAE as the first-line treatment option for most patients with massive hemoptysis. Bronchoscopic interventions may be considered in selected cases, particularly when BAE is not feasible or as a bridge to definitive therapy. Surgery should be reserved for patients with uncontrolled bleeding despite BAE or bronchoscopic interventions, or when the underlying pathology requires surgical intervention. The choice of intervention for massive hemoptysis should be individualized based on a comprehensive assessment of patient factors, including age, comorbidities, etiology of hemoptysis, bleeding severity, and local expertise. A multidisciplinary approach involving pulmonologists, interventional radiologists, and thoracic surgeons is crucial for optimizing patient outcomes.

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