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Review

Bronchoscopy-related outbreaks and pseudo-outbreaks: A systematic review

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Abstract

Objective: To identify and report the pathogens and sources of contamination associated with bronchoscopy-related outbreaks and pseudo-outbreaks.

Design: Systematic review.

Setting: Inpatient and outpatient outbreaks and pseudo-outbreaks after bronchoscopy.

Methods: PubMed/Medline databases were searched according to Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines, using the search terms "bronchoscopy," "outbreak," and "pseudo-outbreak" from inception until December 31, 2022. From eligible publications, data were extracted regarding the type of event, pathogen involved, and source of contamination. Pearson correlation was used to identify correlations between variables.

Results: In total, 74 studies describing 23 outbreaks and 52 pseudo-outbreaks were included in this review. The major pathogens identified in these studies were *Pseudomonas aeruginosa*, *Mycobacterium tuberculosis*, nontuberculous mycobacteria (NTM), *Klebsiella pneumoniae*, *Serratia marcescens*, *Stenotrophomonas maltophilia*, *Legionella pneumophila*, and fungi. The primary sources of contamination were the use of contaminated water or contaminated topical anesthetics, dysfunction and contamination of bronchoscopes or automatic endoscope reprocessors, and inadequate disinfection of the bronchoscopes following procedures. Correlations were identified between primary bronchoscope defects and the identification of *P. aeruginosa* ($r = 0.351$; $P = .002$) and *K. pneumoniae* ($r = 0.346$; $P = .002$), and between the presence of a contaminated water source and NTM ($r = 0.331$; $P = .004$) or *L. pneumophila* ($r = 0.280$; $P = .015$).

Conclusions: Continued vigilance in bronchoscopy disinfection practices remains essential because outbreaks and pseudo-outbreaks continue to pose a significant risk to patient care, emphasizing the importance of stringent disinfection and quality control measures.

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Flexible bronchoscopy is a minimally invasive procedure that has become an integral part of pulmonology.[1] With the ability to perform bronchoscopy in settings ranging from dedicated endoscopy suites to the bedside, hundreds of thousands of procedures are carried out globally each year.[2,3]

Due to the risk of infection transmission, a dedicated disinfection protocol is essential for a successful bronchoscopy service. The protocol should incorporate a structured approach that includes specific hardware, such as automatic endoscope reprocessors (AERs), specific reprocessing and turnaround times, strict adherence to the manufacturer's instructions, and dedicated personnel.[4] Despite adherence to rigorous protocols, there is a risk of encountering various flaws that can result in bronchoscopy-related complications, including outbreaks and pseudo-outbreaks.[5]

An outbreak is defined as the increase in identified infections above the baseline rate, whereas a pseudo-outbreak refers to the isolation of microorganisms in specimens without any indication of infection.[6] They occur as a result of contamination or colonization of the bronchoscope and not an actual infection. Although pseudo-outbreaks are not genuine infections, they can

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still have adverse effects because patients may receive unnecessary antimicrobial therapy.[7]

Given the burden of these complications, we conducted a systematic review to identify and elucidate all published reports of bronchoscopy-related outbreaks and pseudo-outbreaks. We also sought to uncover any correlations between specific pathogens and sources of contamination and to determine whether they are linked to the categorization of a study event as an outbreak or a pseudo-outbreak.

Materials and methods

This systematic review was conducted according to the international Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.[8] The study protocol has been published in the international prospective register of systematic reviews PROSPERO (https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=375610, registration no. CRD42022375610).

Data sources and searches

A systematic literature review of articles published in PubMed was conducted from inception to December 31, 2022, using the following search terms: bronchoscopy [title/abstract] AND outbreak[title/abstract]; bronchoscope [title/abstract] AND outbreak[title/abstract]; bronchoscopy [title/abstract] AND pseudo-outbreak[title/abstract]; bronchoscope [title/abstract] AND pseudo-outbreak[title/abstract]. No restrictions were applied regarding the date of publication or language. Article titles and abstracts were screened based on the selection criteria presented in Table 1. References from the articles extracted were reviewed to identify further relevant publications.

Study selection

The study selection process was conducted by 2 reviewers (L.K. and S.E.) who applied the selection criteria summarized in Table 1 to determine whether a study was eligible for inclusion in the review. Studies that met the following 4 inclusion criteria were then further evaluated for their relevance and quality:

(1) Study design: Case-control studies, case series, and cohort studies describing outbreaks or pseudo-outbreaks following bronchoscopy.
(2) Type of participants: Adult patients having positive cultures from samples obtained during bronchoscopy.
(3) Type of exposure: Bronchoscopy regardless of indication.
(4) Type of outcome: Primary outcomes were the source(s) of contamination and the organisms involved in bronchoscopy-associated outbreaks and pseudo-outbreaks, as well as any correlations between them. Secondary outcomes of interest included whether individual pathogens were more likely to be associated with outbreaks or pseudo-outbreaks, whether contamination sources were associated with specific organisms, and the use of antibiotics among patients involved in outbreaks and pseudo-outbreaks.

Data extraction and quality assessment

The following data were extracted from full-text articles included in this review: eligibility criteria, study design, study event (whether the study event represented an outbreak or a pseudo-outbreak), pathogens involved, the duration of the study event and the source of the contamination.

Table 1. Inclusion and Exclusion Criteria of Study Selection

The inclusion criteria for study selection
1. Original articles describing outbreaks or pseudo-outbreaks following bronchoscopy.
2. Case series, case-control studies, cross-sectional studies, and prospective and retrospective cohort studies were eligible for inclusion.
The exclusion criteria for study selection
1. Presence of infection prior to bronchoscopy.
2. Hospital or community outbreaks that involved patients other than those undergoing bronchoscopy.
3. Outbreaks in intensive care units that included patients evaluated by bronchoscopy.
4. Studies pertaining to pediatric populations.

The risk of bias was assessed independently by 3 authors (L.K., S.E., and F.S.) using the Murad scale, a modified version of the Newcastle-Ottawa Scale (NOS) evaluating nonrandomized tirals,[9] using 6 evidence-based criteria evaluating for selection, representativeness of cases, ascertainment of outcomes and exposure, and adequate reporting.[10] The questions utilized for the assessment of each study are presented in Supplementary Table S1 (online). In cases of disagreement between the reviewers, studies were discussed among the group until an agreement was reached. A study was considered to have low risk of bias if all 6 criteria were met, moderate risk of bias when 4 or 5 criteria and met and high risk of bias when 3 or fewer criteria were met.[11] The scores of each study are presented in Supplementary Table S2 (online).

Data synthesis and analysis

Data pertaining to the primary and secondary end points were extracted; they have been presented using a narrative and analytical synthesis. SPSS for Windows version 28 (IBM, Armonk, NY) was used for statistical analysis. For continuous variables, means were reported for parametric variables and medians were used for nonparametric variables.

Statistical analyses were also conducted to evaluate whether the presence of a specific pathogen affected the possibility that the study event would be considered an outbreak or a pseudo-outbreak and whether the source of contamination was associated with a specific type of pathogen. This determination was achieved by extracting data as binary variables and using Pearson correlation to identify correlations between variables. *P* values were calculated using the Fisher exact test (2-sided). Only *P* values $<.05$ were considered significant.

Results

The initial PubMed search yielded 206 articles, and an additional 64 articles were identified through citation searching. Following the screening process depicted in Figure 1, a total of 74 studies were deemed to meet the inclusion criteria and were included in this review. Data extracted are summarized in Table 2, and the quality assessments of all studies are presented in Supplementary Table S2 (online).

Population characteristics

Overall, 74 studies describing 23 outbreaks and 52 pseudo-outbreaks were included; one study described 2 separate

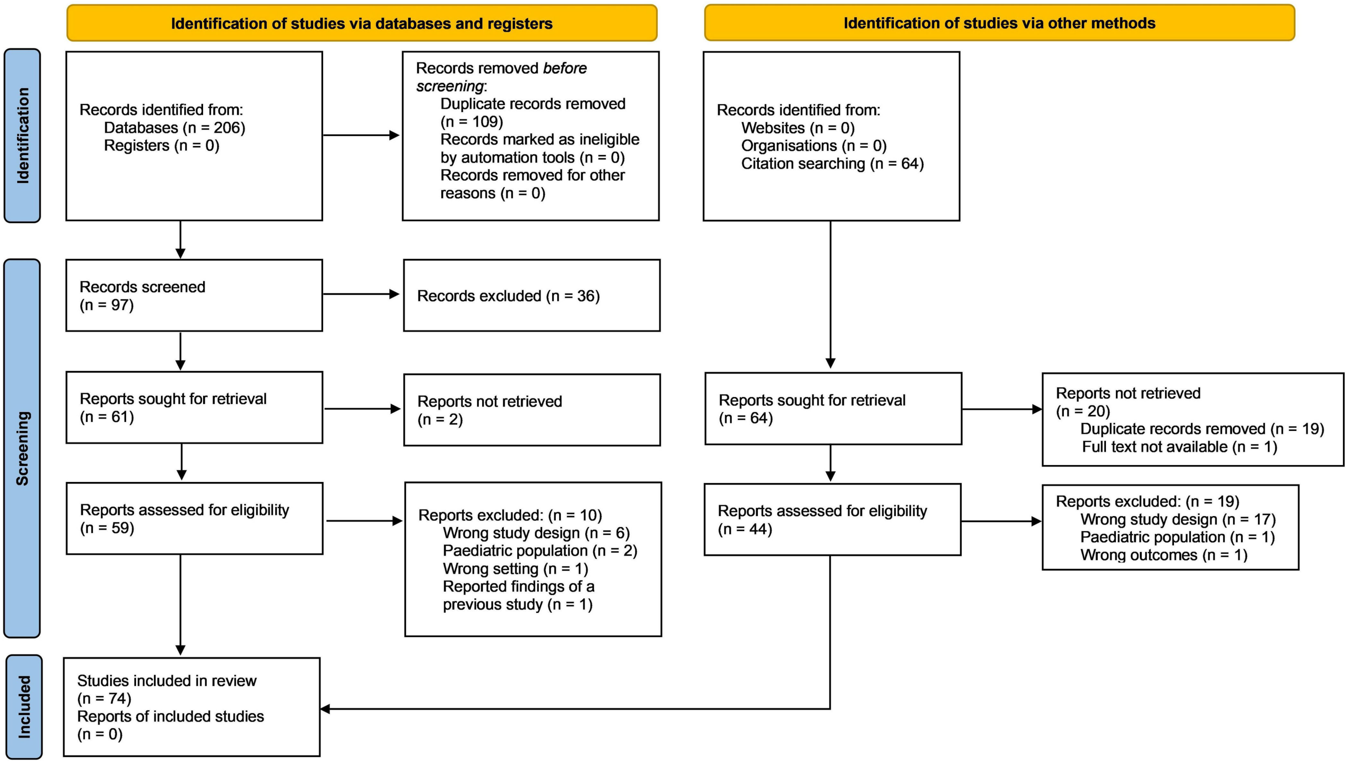

Figure 1. A diagram representing the assessed studies in accordance with the globally recognized Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.[8]

pseudo-outbreaks within their institution from different pathogens, which were counted as separate entries.[12] Study characteristics are presented in Table 3. During the defined event period, 7,105 patients had undergone bronchoscopy. Among them, 1,521 (20.3%) were part of an outbreak or a pseudo-outbreak and were classified as having been affected by the study event. The median number of patients described in studies of outbreaks was 15, with a median 10 being affected. The corresponding medians for pseudo-outbreaks were 21 and 14, respectively (Table 3). The median duration of was 91.3 days for outbreaks and 94.1 for pseudo-outbreaks.

Sources of contamination

We identified 5 major categories of contamination sources during the review: (1) use of contaminated water or ice (34.7% of studies), (2) defect in the bronchoscope itself or one of its parts (32%), (3) defect or contamination of the AER (28%), (4) inadequate disinfection due to deviation from disinfection protocol (18.7%), and (5) use of contaminated aerosolized topical anesthetics in preparation for the procedure (5.4%).

Water contamination was the most commonly identified source of contamination; it was reported in 26 of 74 studies,[13–39] 24 (92.3%) of which were pseudo-outbreaks.[13–15,17–20,22–39] In 13 (50%) of these studies, the pathogens were nontuberculous mycobacteria (NTM).[16,23,25,27–29,31–39] Notably, 4 pseudo-outbreaks were attributed to the use of contaminated ice. The ice was utilized in the preparation of cold saline solutions, which were used to control bleeding during interventional bronchoscopy procedures.[13,14,19,32] In all 4 cases, contaminated ice (obtained from a nonsterile, common-use ice machines) came in contact with sterile normal saline, while in all 4 cases, the pseudo-outbreaks were terminated by changing this practice.[13,14,19,32] The identification of a contaminated water as the source of contamination was significantly correlated with the characterization of the study as a pseudo-outbreak (r = 0.363; P = .001), and by the identification of *Legionella pneumophila* (r = 0.280; P = .015) or NTM (r = 0.331; P = .004) as the pathogens of interest (Table 4).

AER contamination was identified in 21 studies.[22–25,28,33,34,36–38,40–50] Among them, 10 pertained to a combination of AER and water source contamination.[22–25,28,33,34,36–38] In the majority of these, the contaminated water source led to the contamination of the AER itself. Presence of AER contamination was significantly correlated with pseudo-outbreaks (r = 0.286; P = .013) and with the presence of NTM (r = 0.446; P < .001).

In 24 studies, the source of contamination was attributed to a defect in the bronchoscope itself.[7,12,16,43,46,49–66] Bronchoscope segments identified as being defective or damaged included the lumen, the suction valve and channel, the biopsy port and its cap, as well as the biopsy channel itself. Notably, in 1 study the defect at the entry port of the biopsy channel was so significant that it led to a recall of the specific model by the manufacturer.[12] The identification of *Pseudomonas aeruginosa* (r = 0.351; P = .002) or *Klebsiella pneumoniae* (r = 0.346; P = .002) as the causative agents were correlated with the presence of a bronchoscope defect.

Another source of contamination identified was the inadequate disinfection of the bronchoscope. This was reported in 14 studies,[15,16,19,21,42,44,59,67–73] 50% of which pertained to outbreaks.[16,21,44,67,68,72,73] In 6 studies, an epidemiologic review identified deviations from the appropriate disinfection protocol[15,44,68,73–75] that led to the contamination. Examples included deviation from the disinfection protocol by the team maintaining

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Table 2. Parameters Extracted From Each Study, Outlining the Patient Population, Type of Outbreak and Duration, Pathogen Identified and Source of Contamination[a]

First Author, Year	Country	Patients Affected/ Undergoing Bronchoscopy, n/N (%)	Type of Outbreak	Patients Receiving Antibiotics, No. (%)	Outbreak Duration	Pathogen	Source of Contamination
Weinstein et al, 1977[70]	USA	8/21 (38.1)	Pseudo-outbreak	4 (50)	30	*Proteus* spp	Bronchoscope suction channel malfunction, inadequate disinfection
Steere et al, 1979[76]	USA	52/52 (100)	Pseudo-outbreak	0 (0)	912	*Mycobacterium gordonae*	Contaminated green dye used for topical anesthesia
Schleupner et al, 1980[77]	USA	8/8 (100)	Pseudo-outbreak	0 (0)	21	*Trichosporon cutaneum, Penicillium* spp	Bottles containing cocaine solution used as topical anesthetic were not sterilized between uses
Sammartino et al, 1982[63]	USA	11/19 (57.9)	Outbreak	1 (9)	90	*Pseudomonas aeruginosa*	Contamination of the inner channel of the bronchoscope
Nelson et al, 1983[82]	USA	2/17 (11.8)	Outbreak	1 (50)	30	*M. tuberculosis*	Bronchoscope channel contamination
Goldstein et al, 1985[59]	USA	15/57 (26.3)	Pseudo-outbreak	0 (0)	49	Bacillus spp	Inadequate disinfection of automatic suction valves
Siegman-Igra et al, 1985[30]	Israel	4/4 (100)	Pseudo-outbreak	0 (0)	8	*Serratia macerscens*	Containers of sterile water that had been opened and kept for repeated use
Richardson et al, 1986[20]	UK	14/14 (100)	Pseudo-outbreak	0 (0)	122	Bacillus spp	Environmental contamination of the cupboard used to store bronchoscopes, water supply
Stine et al, 1987[31]	USA	8/311 (2.6)	Pseudo-outbreak		242	Mycobacterium spp	Contaminated tap water used to rinse disinfected bronchoscopes
Prigogine et al, 1988[47]	Belgium	8/8 (100)	Pseudo-outbreak		517	*M. tuberculosis*	Automatic aspiration adaptor contamination
Wheeler et al, 1989[60]	USA	6/1200 (0.5)	Outbreak	2 (33)	150	*M. avium*, 2, and *M. tuberculosis*, 4	Bronchoscope valve malfunction
Hoffmann et al, 1989[26]	USA	30/56 (53.6)	Pseudo-outbreak		120	*Rhodotorula rubra*	Contamination of brushes used to clean the bronchoscope channels, contaminated water supply
Nye et al, 1990[29]	UK	7/7 (100)	Pseudo-outbreak	0 (0)	180	*M. chelonae*	Contaminated water supply
Gubler er al, 1992[25]	USA	16/41 (39)	Pseudo-outbreak	4 (25)	91	*M. chelonae*, *M. gordonae*, *MAC*, *M. tuberculosis*, and *M. scorfulaceum*	AER contamination
Flournoy et al, 1992[18]	USA	7/7 (100)	Pseudo-outbreak	0 (0)	91	*Methylobacterium mesophilicum*	Main water supply
Fraser et al, 1992[37]	USA	14/14 (100)	Pseudo-outbreak	0 (0)	639	*M. chelonae*	AER contamination
Whitlock et al, 1992[87]	USA	15/15 (100)	Pseudo-outbreak	0 (0)	180	*Rhodotorula rubra*	Retention of moisture between the suction valve and rubber biopsy valve on the biopsy channel after disinfection, eliminated after bronchoscope was allowed to dry
Vandenbroucke-Grauls et al, 1993[72]	Netherlands	7/7 (100)	Outbreak	7 (100)	91	*S. macerscens*	Bronchoscope contamination, unable to determine further
Jereb et al, 1993[67]	USA	10/10 (100)	Outbreak	10 (100)	395	*M. tuberculosis*	Bronchoscopy generated aerosols contaminated the air of renal transplant unit
Brown et al, 1993[50]	UK	15/15 (100)	Pseudo-outbreak	8 (53.3)	415	*Mycobacterium* spp	Bronchoscope channel contamination and debris found inside the water inlet and drainage tubes of AER
Kolmos, 1994[69]	Denmark	8/8 (100)	Pseudo-outbreak	0 (0)	15	*P. aeruginosa*	Inadequate disinfection, deviation from protocol
Campagnaro et al, 1994[46]	Australia	12/65 (18.5)	Pseudo-outbreak	0 (0)	180	*M. chelonae*	Bronchoscope channel and AER contamination

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Table 2. (*Continued*)

First Author, Year	Country	Patients Affected/ Undergoing Bronchoscopy, n/N (%)	Type of Outbreak	Patients Receiving Antibiotics, No. (%)	Outbreak Duration	Pathogen	Source of Contamination
Maloney et al, 1994[48]	USA	16/47 (34)	Pseudo-outbreak	0 (0)	97	*M. abscesus*	Contamination of bronchoscope, AER and inlet feeding water into the AER
Bennett et al, 1994[27]	USA	21/21 (100)	Pseudo-outbreak		1125	*M. xenopi*	Contaminated tap water used to rinse disinfected bronchoscopes
Wang et al, 1995[80]	Taiwan	18/123 (14.6)	Pseudo-outbreak	0 (0)	3	*M. chelonae*	Bronchoscope suction channel malfunction
Kiely et al, 1995[23]	Ireland	7/100 (7)	Pseudo-outbreak	0 (0)	150	*M. chelonae*	Contaminated water supply leading to AER contamination, resolved after introduction of bacterial water filter
Takigawa et al, 1995[28]	Japan	15/19 (78.9)	Pseudo-outbreak	4 (26.6)	150	*M. chelonae*	Contamination of bronchoscope, AER, water source, detergent and disinfectant
Hagan et al, 1995[62]	USA	11/11 (100)	Pseudo-outbreak	0 (0)	48	*R. rubra*	Contamination of bronchoscope suction channel, inadequate drying
Agerton et al, 1997[81]	USA	8/8 (100)	Outbreak	8 (100)	548	*M. tuberculosis*	Inadequate disinfection
Cox et al, 1997[78]	USA	34/91 (37.4)	Pseudo-outbreak	0 (0)	90	*M. chelonae*, 28; *M. avium-intracellulare*, 3; *M. gordonae*, 2; *M. fortuitum*, 1	3 reusable lidocaine sprayers grew *M. chelonae*. Sprayers were cleaned with tap water, which had rapidly growing AFB in the past (not speciated)
Blanc et al, 1997[49]	France	35/410 (8.5)	Pseudo-outbreak		210	*P. aeruginosa*	AER contamination
Mitchell et al, 1997[24]	Australia	3/3 (100)	Pseudo-outbreak	0 (0)	90	*Legionella* spp	Contaminated tap water used to rinse disinfected bronchoscopes, failure of 70% ethanol flush
Wilson et al, 2000[88]	USA	0/9 (0)	Pseudo-outbreak	0 (0)	69	*Aureobasidium* spp	Reuse of single use disposable stopcocks
Schelenz et al, 2000[44]	UK	8/11 (72.7)	Outbreak		61	*P. aeruginosa*	Inadequate maintenance of AER
Southwick et al, 2001[79]	USA	3/3 (100)	Outbreak	3 (100)	1	*M. tuberculosis*	Likely contaminated atomizer used to spray lidocaine in preparation for bronchoscopy
Sorin et al, 2001[85]	USA	18/18 (100)	Outbreak	3 (16.7)	91	Imipenem-resistant *P. aeruginosa*	Use of incorrect connectors joining the bronchoscope suction channel to the AER
Kressel et al, 2001[42]	USA	20/22 (90.9)	Pseudo-outbreak	3 (13.6)	73	*M. chelonae* and *Methylobacterium mesophilicum*	Inadequate disinfection, deviation from protocol, biofilm formation within the AER that made it resistant to decontamination
Ramsey et al, 2002[54]	USA	4/10 (40)	Outbreak	10 (100)	17	*M. tuberculosis*	Defects in the external sheath of the bronchoscope tip
Kirschke et al, 2003[84]	USA	20/60 (33.3)	Outbreak	5 (25)	122	*P. aeruginosa*	Defect in biopsy port caps in 3 bronchoscopes
Srinivasan et al, 2003[56]	USA	97/414 (23.4)	Outbreak	39 (40.2)	243	*P. aeruginosa*	Bronchoscope lumen and biopsy port cap
Larson et al. 2003[73]	USA	3/13 (23.1)	Outbreak	3 (100)	10	*M. tuberculosis*	Inadequate disinfection, deviation from protocol
Silva et al, 2003[71]	Brazil	41/324 (12.7)	Pseudo-outbreak		669	*P. aeruginosa* and *S. marcescens*	Contaminated water filter
Cetre et al, 2003[61]	France	117/418 (28)	Outbreak		240	Enterobacteriaceae	Loose cap on the port of the biopsy channel of the bronchoscope
Severino et al, 2004[53]	Brazil	13/13 (100)	Outbreak		183	*P. aeruginosa* and *S. marcescens*	Inadequate disinfection, deviation from protocol

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Table 2. (*Continued*)

First Author, Year	Country	Patients Affected/ Undergoing Bronchoscopy, n/N (%)	Type of Outbreak	Patients Receiving Antibiotics, No. (%)	Outbreak Duration	Pathogen	Source of Contamination
Cetre et al, 2005[12]	France	89/342 (26)	Pseudo-outbreak		91	*Klebsiella pneumoniae*, *P. vulgaris*, *Morganella morganii* and *P. mirabilis*	Defect at the entry port of the biopsy channel - led to a recall of the specific model
		28/111 (25.2)	Pseudo-outbreak		61	*Enterobacter cloacae*, *P. aeruginosa*, and *S. marcescens*	
Bou et al, 2006[68]	Spain	10/11 (90.9)	Outbreak		91	*P. aeruginosa*	Inadequate disinfection, deviation from protocol during the weekends
Young et al, 2007[21]	USA	21/25 (84)	Outbreak	21 (100)	304	*Acinetobacter baumani*	Environmental contamination of multiple surfaces
Schaffer et al, 2008[17]	Ireland	4/6 (66.7)	Pseudo-outbreak	0 (0)	183	*Fusarium solani*	Main water supply
Chroneou et al, 2008[36]	USA	9/57 (15.8)	Pseudo-outbreak	0 (0)	61	*M. chelonae*	Contaminated water supply and AER, inadequate change of water filters for AER
Schuetz et al, 2009[13]	USA	13/13 (100)	Pseudo-outbreak		243	*L. pneumophila* serogroup, 8	Ice machine producing nonsterile ice used for control of bleeding
Kioski et al, 2009[14]	USA	4/4 (100)	Pseudo-outbreak	2 (50)	42	*L. pneumophila* serogroup, 8	Ice machine producing nonsterile ice used for control of bleeding
DiazGranados et al, 2009[57]	USA	12/12 (100)	Outbreak	11 (91.7)	91	*P. aeruginosa*	Internal damage to the bronchoscope channels
Rosengarten et al, 2010[22]	Israel	3/3 (100)	Pseudo-outbreak	0 (0)	30	*Burkholderia cepacia*	AER was missing a necessary water filter
Cosgrove et al, 2012[66]	USA	16/77 (20.8)	Pseudo-outbreak	7 (43.8)	3	*P. putida*, *P. aeruginosa*, and *Stenotrophomonas maltophilia*	Bronchoscope biopsy port
Zweigner et al, 2014[55]	Germany	3/6 (50)	Outbreak	3 (100)	40	Carbapenem-resistant *K. pneumoniae*	Defects in the internal channel of 2 bronchoscopes
Blake et al, 2014[19]	Canada	31/62 (50)	Pseudo-outbreak	0 (0)	322	*Phaeoacremonium parasiticum*	Ice machine producing nonsterile ice used for control of bleeding
Ece et al, 2014[41]	Turkey	4/4 (100)	Pseudo-outbreak	4 (100)	7	*S. maltophilia*	Bronchoscope contamination, unable to determine further
Peaper et al, 2015[92]	USA	18/18 (100)	Pseudo-outbreak	2 (11.1)	730	*Actinomyces graevenitzii*	No identified source, attributed to changes in laboratory practices
Guy et al, 2016[16]	France	10/157 (6.4)	Outbreak	10 (100)	213	*P. aeruginosa*	Bronchoscope suction valve malfunction, contaminated water source, inadequate disinfection
Botana-Rial et al, 2016[40]	Spain	39/154 (25.3)	Pseudo-outbreak	21 (53.9)	26	*P. putida* and *S. maltophilia*	AER contamination
Scorzolini et al, 2016[34]	Italy	7/497 (1.4)	Pseudo-outbreak	1 (14.3)	122	*M. gordonae*	AER and water supply
Waite et al, 2016[51]	UK	18/47 (38.3)	Pseudo-outbreak	2 (11.1)	31	*S. maltophilia*	Bronchoscope design issue leading to difficulties in decontamination of the internal aspect of one of the ports
Ardoino et al, 2016[98]	Italy	68/68 (100)	Outbreak		365	*A. baumannii*	Case-control study identifying bronchoscopy as a risk factor for infection with an OR, 29.9 (95% CI, 11.07–80.75). No further information regarding source provided.

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Table 2. (*Continued*)

First Author, Year	Country	Patients Affected/ Undergoing Bronchoscopy, n/N (%)	Type of Outbreak	Patients Receiving Antibiotics, No. (%)	Outbreak Duration	Pathogen	Source of Contamination
Guimaraes et al, 2016[43]	Brazil	5/5 (100)	Pseudo-outbreak	2 (40)	7	*M. abscessus*	Bronchoscopes and AER, unable to determine further
Alipour et al, 2017[83]	Turkey	15/15 (100)	Outbreak	10 (66.7)	50	*P. aeruginosa*	Biofilm formation on the external channel of the bronchoscope
Carvalho et al, 2018[38]	Brazil	28/28 (100)	Pseudo-outbreak		365	*M. abscessus* and *M. fortuitum*	Inadequate disinfection and water contamination
Hellinger et al, 2019[64]	USA	1/8 (12.5)	Pseudo-outbreak		19	Adenovirus	Nonviable adenovirus DNA remaining on bronchoscopes after index patient bronchoscopy
Seidelman et al, 2019[33]	USA	173/1133 (15.3)	Pseudo-outbreak	0 (0)	243	*Mycobacterium avium* complex	AER water rinse filter
Galdys et al, 2019[7]	USA	23/33 (69.7)	Outbreak	22 (95.7)	183	*P. aeruginosa* and *K. pneumoniae*	Defect in bronchoscope lumen leading to debris accumulation
Bringhurst et al, 2020[32]	USA	15/15 (100)	Pseudo-outbreak	0 (0)	29	*M. mucogenicum*	Ice machine producing nonsterile ice used for control of bleeding
Campos-Gutiérrez et al, 2020[35]	Spain	9/9 (100)	Pseudo-outbreak	1 (11.1)	91	*M. fortuitum*	Contaminated water supply used in AER
Zhang et al, 2020[15]	China	37/37 (100)	Pseudo-outbreak		152	*P. aeruginosa*	Inadequate disinfection, deviation from protocol
Abdolrasouli et al, 2021[58]	UK	9/9 (100)	Pseudo-outbreak	0 (0)	243	*Rhinocladiella similis*	Damage to the internal lumen of the bronchoscope
Seidelman et al, 2021[65]	USA	10/35 (28.6)	Pseudo-outbreak		122	Adenovirus	Bronchoscope defects causing leaks

Note. AER, automated endoscope reprocessor; OR, odds ratio; CI, confidence interval.
[a]Numbers presented here include the index case as part of the affected patients.

the bronchoscopes on the weekends,[68] inadequate maintenance of the AER,[44] lack of a dedicated technician for bronchoscope disinfection, and workarounds utilized by staff when the suite's AER had broken down.[74]

Finally, in 4 studies, the source of contamination was related to the use of topical anesthetics.[76–79] Mechanisms of contamination included contamination of the anesthetic solution itself,[76] cleaning of anesthetic sprayers with contaminated tap water,[78] not sterilizing the bottles containing the anesthetic,[77] or contamination of the atomizer used to apply the anesthetic.[79] Although 3 of the studies reported pseudo-outbreaks caused by NTM[76,78] and fungi,[77] 1 study described an outbreak where 3 patients were infected with *Mycobacterium tuberculosis*.[79] This organism was traced back to a contaminated atomizer that had been used to spray lidocaine in preparation for bronchoscopy.[79]

Pathogens

Pathogens identified as causing outbreaks or pseudo-outbreaks included bacteria in 54.6% of studies, mycobacteria in 41.3%, fungi in 10.6%, and viruses in 2.7%. Bacteria included *P. aeruginosa* (identified in 24% of studies), *Stenotrophomonas maltophilia* (5.3%), *K. pneumoniae* (5.3%), *Serratia marcescens* (6.7%), *L. pneumophila* (4%), and *Acinetobacter* spp (4%). Notably, 2 studies reported outbreaks with carbapenem-resistant strains of *K. pneumoniae*[55] and *P. aeruginosa*.[85] Mycobacteria consisted of *M. tuberculosis,* identified in 12% of studies and NTM, identified in 29.3%.

The most common type of pathogen identified overall were NTM (22 studies, 29.3%).[23,25,27–29,31–39,42,43,46,48,50,60,76,80] The most commonly isolated species was *M. chelonae*,[23,25,28,29,36,37,42,46,78,80] (10 studies, 13.5%) followed by *M. abscessus*,[38,43,48] *M. fortuitum*,[35,38,78] and *M. gordonae*[25,34,78] (3 studies each, 4%). With the exception of a single study by Wheeler et al,[60] which involved isolation of both *M. avium* and *M. tuberculosis*, all other studies involving NTMs were classified as pseudo-outbreaks by their investigators.[23,25,27–29,31–39,42,43,46,48,50,76,80] Also, in the vast majority of studies that NTM were identified, they were associated with either use of contaminated water (5 studies),[27,29,31,35,78] deficiencies in the AER (5 studies),[42,43,46,48,50] or both (8 studies).[23,25,28,33,34,36–38] The presence of NTM was significantly associated with pseudo-outbreaks ($r = 0.365$; $P = .001$), water contamination ($r = 0.331$; $P = .004$), and AER dysfunction ($r = 0.446$; $P < .001$).

In contrast, *M. tuberculosis* was a considerably more significant pathogen. Among the 9 studies[25,47,54,60,67,73,79,81,82] in which *M. tuberculosis* was detected, 7 were considered outbreaks.[54,60,67,73,79,81,82] Regarding sources of contamination, inadequate disinfection was identified as the cause in 2 cases,[67,73] the presence of a bronchoscope defect was identified in another 2 cases,[54,60] water contamination in 1 case,[25] AER dysfunction in 2 cases,[25,47] and the use of a contaminated atomizer in 1 case.[79] In 2 cases, a source was not identified.[81,82] The only significant correlation regarding *M. tuberculosis* was with the study event being identified as an outbreak ($r = 0.377$; $P = .001$).

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Table 3. Study Characteristics and Findings, Divided Based on Study Event

Variable	Total, %[a]	Outbreak, %[a]	Pseudo-outbreak, %[a]
Total patients, N[b]	7,105	2,548	4,557
Affected patients, N[c]	1,521	489	1,032
Patients treated with antibiotics, N (%)	234 (15.4)	169 (34.6)	65 (6.3)
Outbreak duration, median, days	91.25	91.3	94.1
Bacteria	53.2	65.0	47.6
P. aeruginosa	24.0	52.2	11.5
K. pneumoniae	5.3	13.0	1.9
S. marcescens	6.7	13.0	3.8
S. maltophilia	5.3	0.0	7.7
L. pneumophila	4.0	0.0	5.8
Other bacteria	21.0	5.0	28.6
Mycobacteria	33.9	25.0	38.1
M. tuberculosis	12.0	30.4	3.8
NTM	29.3	4.3	40.4
Fungi	10.7	0.0	15.4
Viruses	2.7	0.0	3.8
Multiple pathogens	19.7	15.0	22.0
Bronchoscope dysfunction	32.0	47.8	25.0
Water contamination	34.7	8.7	46.2
AER contamination	28.0	8.7	36.5
Inadequate disinfection	18.7	30.4	13.5

Note. NTM, nontuberculous mycobacteria; AER, automated endoscope reprocessor.
[a]Units unless otherwise specified.
[b]Total patients: Number of patients described by the studies, which include both patients affected by outbreaks or pseudo-outbreaks, as well as control patients that had undergone bronchoscopy during the same period but remained unaffected by the study event.
[c]Affected patients: patients that were part of an outbreak or a pseudo-outbreak following bronchoscopy.

Table 4. Results of Pearson Correlation Analysis

Correlation	Variable	Pearson r	*P* Value
Outbreak	*P. aeruginosa*	0.439	<.001
	K. pneumoniae	0.228	.049
	M. tuberculosis	0.377	.001
	Antibiotic administration	0.617	<.001
Pseudo-outbreak	Water contamination	0.363	.001
	AER contamination	0.286	.013
	NTM	0.365	.001
	Fungi	0.23	.047
Antibiotic administration	*M. tuberculosis*	0.479	<.001
Bronchoscope defect	*P. aeruginosa*	0.351	.002
	K. pneumoniae	0.346	.002
Water contamination	*L. pneumophila*	0.28	.015
	NTM	0.331	.004
AER contamination	NTM	0.446	<.001

Note. NTM, nontuberculous mycobacteria; AER, automated endoscope reprocessor.

Among bacteria, the most commonly isolated was *P. aeruginosa*, which was reported in 18 studies.[7,12,15,16,44,45,49,52,53,56,57,63,66,68,69,71,83] It was not uncommon for *P. aeruginosa* to be isolated along with other bacteria, such as *K. pneumoniae*,[7,61] *S. marcescens*,[53,71,84] or *S. maltophilia*.[66] *P. aeruginosa* caused outbreaks in 66.6% of studies,[7,16,44,53,56,57,61,63,68,83–85] and its presence was associated with bronchoscope defects[7,12,16,49,53,56,57,61,63,66,84] or inadequate disinfection of the bronchoscope.[15,44,68,71,74] Significant correlations were identified between the presence of *P. aeruginosa* and the study event being an outbreak (r = 0.439; *P* < .001) and with a bronchoscope defect being identified as the source of contamination (r = 0.351; *P* = .002).

Other bacteria identified included *L. pneumophila*[13,14,24] in 3 cases, *K. pneumoniae*[7,12,55,61] in 4 cases, *S. marcescens*[30,52,53,71,86] in 5 cases, *S. maltophilia*[40,41,51,66] in 4 cases and *A. baumannii* in 1 case.[98] Significant correlations were identified between the identification of *K. pneumoniae* and the presence of a bronchoscope defect (r = 0.346; *P* = .002) or the study event being an outbreak (r = 0.228; *P* = .049) and between *L. pneumophila* and water contamination (r = 0.280; *P* = .015).

In addition, 8 studies have reported pseudo-outbreaks related to fungi. Among the isolated organisms, *Rhodotorula rubra* was identified in 3 studies, whereas all other species were reported in only 1 study each.[26,62,87] These included *Fusarium solani*,[17] *Rhinocladiella similis*,[58] *Phaeoacremonium parasiticum*,[19] *Aureobasidium* spp.[88] In 1 study, both *Trichosporon cutaneum* and *Penicillium* spp were isolated.[77] The only significant correlation identified was between the presence of fungi and pseudo-outbreaks (r = 0.230; *P* = .047).

Lastly, 2 studies reported viral pseudo-outbreaks. Both pseudo-outbreaks involved adenovirus and were attributed to a bronchoscope defect.[64,65]

Use of antibiotics

Information regarding antibiotic administration was available from 56 studies. Among them, 18 pertained to outbreaks and 38 to pseudo-outbreaks. From a total of 489 patients that were involved in outbreak studies, data on antibiotic use were available for 273, of whom 169 (61.9%) received antibiotics. Among 1,032 patients described in pseudo-outbreak studies, information on antibiotic use was available for 194, of whom 65 (33.5%) received antibiotics. Notably, among the 18 outbreak studies with available antibiotic usage data, all reported at least 1 patient receiving antibiotics.[7,16,54,55,57,60,61,63,67,72,73,79,83,85,89–91] Among the 38 studies describing pseudo-outbreaks that reported data on antibiotic use, 14 described at least 1 patient being on antibiotics.[14,25,28,34,35,40,41,43,50,51,66,70,75,92] Among these studies, 7 pertained to pseudo-outbreaks by NTM.[25,28,34,35,43,50,75] Factors positively correlated with the percentage of patients receiving antibiotics were the characterization of the study event as an outbreak (r = 0.617; *P* < .001) and the identification of *M. tuberculosis* (r = 0.479; *P* < .001) as the causative agent.

Discussion

This review presents an analysis of studies describing outbreaks and pseudo-outbreaks following bronchoscopy. Based on the studies identified, pseudo-outbreaks were more than twice as prevalent as outbreaks. Distinct patterns of pathogens and sources of contamination appeared to be linked to either outbreaks or pseudo-outbreaks. The isolation of *P. aeruginosa, K. pneumoniae*, and *M. tuberculosis* was more prevalent in outbreaks, as was the recognition of bronchoscope dysfunction and inadequate

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disinfection as sources of contamination. Conversely, the isolation of NTM was significantly more common in pseudo-outbreaks, whereas *S. maltophilia*, *L. pneumophila*, viruses, and fungi were exclusively isolated from studies describing pseudo-outbreaks. Water contamination and AER dysfunction were the sources of contamination more commonly associated with pseudo-outbreaks.

Furthermore, we were able to identify correlations between pathogens and sources of contamination. Specifically, *P. aeruginosa* and *K. pneumoniae* were correlated with primary bronchoscope defects, whereas NTM and *L. pneumophila* were correlated with the presence of a contaminated water source. Although these correlations are by no means absolute, they can serve as an initial guide to clinicians, infection preventionists, and hospital epidemiologists tasked with identifying the source of an outbreak or pseudo-outbreak.

The findings of this study also have significant implications from an antimicrobial stewardship perspective. Firstly, among studies that reported data on antibiotic use, 33.5% of patients involved in pseudo-outbreaks had been prescribed antibiotics. This finding implies that several patients had received unnecessary antibiotics as a result of a pseudo-outbreak, exposing them to the adverse effects of these agents, as well as leading to the development of antibiotic-resistant bacteria.[7,93] Secondly, 2 studies described outbreaks involving highly resistant bacteria, such as carbapenem-resistant strains of *K. pneumoniae*[55] and *P. aeruginosa*,[85] which pose a substantial threat to public health.

In addition, in 14 (18.9%) of studies, the source of contamination was identified as being inadequate disinfection, highlighting the importance of proper bronchoscope reprocessing. This process necessitates the use of high-level disinfection techniques, defined as procedures that lead to the complete elimination of all microorganisms with the exception of a few bacterial spores.[94] Device-specific instructions should always be followed, and staff should be regularly trained on device-specific instructions and should have access to cleaning and disinfection protocol manuals.[95,96] The recommendations for bronchoscope reprocessing comprise of several steps to ensure that the instrument is properly cleaned and disinfected between uses.[96] These include regular inspection and cleaning of the instrument after each procedure, cleaning external surfaces and thoroughly brushing all internal channels to reduce bioburden, using approved disinfectants and regularly testing their concentrations, ensuring compatibility between the bronchoscope and AER, rinsing and subsequently thoroughly drying the bronchoscope before storage, and maintaining a log of use and maintenance.[95–97]

This study had several limitations. The studies evaluated exhibited a high degree of heterogeneity in terms of their reported outcomes, making it impossible to conduct a random-effects–based meta-analysis. We did not record the mortality rates of the patients included in each outbreak because it was not part of the original study protocol. Most studies identified a contamination source, suggesting a potential publication bias, as studies that did not identify a source may have been less likely to be published. Finally, the reported correlations were based on binary variables regarding the presence or absence of the evaluated factors, which may not consider possible confounders.

In conclusion, this review provides valuable insights into the sources of contamination and pathogens associated with outbreaks and pseudo-outbreaks in the bronchoscopy suite. These findings highlight the importance of strict adherence to disinfection and maintenance guidelines specific to each device involved in these procedures and not limited to bronchoscopes alone. Furthermore, the identification of correlations between specific pathogens and sources of contamination can provide valuable guidance to clinicians, public health investigators, infection preventionists and hospital epidemiologists in identifying the source of an outbreak or pseudo-outbreak. Ongoing vigilance and attention to infection control practices both inside and outside the bronchoscopy suite are critical to ensure patient safety and prevent future outbreaks.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/ice.2023.250

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