Heliyon 9 (2023) e20580

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Review article

A 20-year bibliometric analysis of postoperative pulmonary complications: 2003–2022

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ARTICLE INFO

Keywords:
Postoperative complications
Bibliometric
Publication
Ventilation
Neuromuscular blockade

ABSTRACT

Background: Postoperative pulmonary complications (PPCs) are known to adversely affect surgical outcomes and patient prognoses, yet no published study provides a qualitative and quantitative analysis of the latest trends and developments in the field of PPCs. Therefore, we conducted a bibliometric analysis of 20 years of publications related to PPCs.

Methods: We examined publications on PPCs published between 2003 and 2022 in the Web of Science Core Collection database to assess trends in the field in four dimensions: trends in publications, major research power, keywords, and co-cited publications.

Results: A total of 1881 articles were analyzed using CiteSpace and VOSviewer. Overall, the number of publications on PPCs has increased in the last two decades, with 42.72% of the publications being produced in the last five years. The United States of America had the highest number of articles, accounting for 21.91% of the total. The institution with the highest number of publications was the University of Genoa, which published 54 articles and showed a general lack of inter-institutional collaboration. The most productive author was Paolo Pelosi, with no core group of authors identified in the field of PPCs. The keyword co-occurrence analysis indicated that the focus of research has shifted over the past 20 years in terms of risk factors, type of surgery, and so on, while "enhanced recovery", "prehabilitation", "driving pressure" and "sugammadex" have received the most recent attention. In the analysis of co-cited literature, the most recent clusters that received attention were driving pressure, lung cancer patient, enhanced recovery, and neuromuscular blockade.

Conclusion: This bibliometric study suggests that pulmonary protective ventilation strategies, neuromuscular blockade reversal, and pulmonary prehabilitation strategy will be the focus of attention in the coming period. More large-scale studies and strengthened institutional collaboration are necessary to generate robust evidence for guiding individualized prevention of PPCs.

1. Introduction

Postoperative pulmonary complications (PPCs) include most postoperative complications affecting the respiratory system, with postoperative respiratory failure being the most common [1,2]. PPCs are known to severely affect surgical outcomes and patient

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https://doi.org/10.1016/j.heliyon.2023.e20580
Received 24 July 2023; Received in revised form 23 September 2023; Accepted 29 September 2023
Available online 30 September 2023

prognoses. Surgical patients who develop PPCs have a mortality rate of up to 20% at 30 days postoperatively and approximately 24% at 90 days postoperatively [3]. Patients at an increased risk of PPCs have an intraoperative event rate of 35.3% [4] and an additional length of stay [5].

The standardized scope of PPCs was first proposed in the European Perioperative Clinical Outcome definitions only in 2015 [6]; however, no consensus on the PPCs diagnostic criteria exists to date. Many research groups have presented risk prediction models [3, 7], implying that the focus should be on high-risk patients. Therefore, prevention strategies with high consensus for high-risk patients are a pressing requirement.

With new technologies, drugs and scientific breakthroughs, risk identification, prevention, and management of PPCs have considerably progressed. For example, the generalization of minimally invasive surgery has become a transformative tool for reducing postoperative complications. However, optimizing the anesthetic process is more feasible for improving postoperative respiratory function than upgrading the procedure. Goal-oriented fluid management, lung-protective ventilation strategy, residual neuromuscular blockade avoidance, and postoperative analgesia are key factors in the anesthetic process. The aging global population and the coronavirus disease 2019 epidemic are increasing the need for exploring PPCs.

Providing comprehensive, dynamic and quantitative research analysis is a unique advantage of the bibliometric method. Compared with other research methods, bibliometrics analyzes a large amount of data, covers a wide range of areas and provides more representative results. The method can be continuously applied to the same field to observe the research progress and dynamic changes. Analyzing the research power and exploring the cutting-edge hotspots can help researchers easily identify the pressing issues and future direction of PPCs and have a macroscopic grasp of the whole research field. For clinical doctors, it can help guide clinical practice, allowing them to pay more attention to currently important prevention and treatment strategies, identify possible strategies for individualized treatment, and ensure optimal patient care and recovery. It can also reveal knowledge gaps and research hotspots in the research field, provide direction for future clinical research, and promote interdisciplinary collaboration. Therefore, this study aimed to present a bibliometric analysis of 20 years of PPCs-related publications retrieved from the Web of Science Core Collection database.

2. Material and methods

2.1. Search strategies and data collection

The Web of Science Core Collection database covers a wide spectrum of disciplines and has more comprehensive citation records than other databases [8]. Therefore, the following search strategy was chosen to collect the target literature:

Topic: [(postoperative or postsurgical) NEAR/2 (pulmonary or lung) NEAR/2 complication?]

Document Type: Article OR Review.

Year Published: 2003–2022.

Language: English.

Since PPCs are not clearly defined, the search terms included only the composite outcome of postoperative pulmonary complications, and the search formula was restricted by using “NEAR” to increase the accuracy rate based on completeness. Using the above search strategy, we obtained 1881 publications that met our search criteria. All literature searches and downloads were completed within one day on January 2, 2023 to avoid time-related data bias.

After completing the literature selection, we downloaded the full text and cited references of the final 1881 articles in.TXT format. The final extracted literature was then visualized and analyzed using CiteSpace v.6.1.R6, 64-bit (Drexel University, Philadelphia, PA, US) and VOSviewer 1.6.18 (Leiden University, Leiden, The Netherlands).

2.2. Bibliometric analysis

VOSviewer was developed by Van Eck and Waltman in 2009 to build a web map of parameters based onco-occurrence matrices, including authors, journals, and keywords. It can display the maps in different ways, including network, overlay, and density views [9]. We used VOSviewer for keyword co-occurrence analysis to show the evolution of keywords over time and the degree of attention they receive.

CiteSpace provides an analytical overview of the underlying knowledge domain based on set theory [10]. It is unique in showing trends and hotspots in scientific development using concepts such as burst detection and mediated centrality. The value of burst detection is the relative variation of the node value over the same period with reference to other variables in the overall data [11]. The exploration of bursts makes it easier for researchers to focus on milestones or turning point events under the theme. The magnitude of betweenness centrality reflects a node’s importance in connecting any two nodes in the network [8]. The literature on nodes with high betweenness centrality often represents transformative discoveries [10]. In the analysis of PPCs, institutional publications and collaborative networks between institutions were represented using a tree-ring diagram. We also used the software for keyword burst detection and analyzed the clustering of co-cited documents as a timeline graph. In the analysis, “Year Per Slice” was set to 1, “g index” was selected in the “selection criteria” and “k = 20” was set. In addition, “pathfinder” and “pruning sliced networks” were selected as the crop method.

We also used specific indicators to evaluate the results of our research. The Local Citation Scores (LCS) referred to the number of times a publication is cited by another article in the same field. The Global Citation Scores (GCS) represents the extent to which articles received attention across all fields. We used GCS per document (GCS_pd) and LCS per document (LCS_pd) to evaluate the overall

interest in articles published in each country. Single country publications (SCP) represented the number of publications in which all authors were from the same country. A multiple-country publications (MCP) indicated the presence of inter-country collaboration in the articles. The proportion of articles with collaboration was represented by the MCP_ratio, with greater values indicating that the country was prone to collaboration. The specific values of these parameters were calculated using the R Programming Language.

3. Results

3.1. An overview of publications

A total of 1881 publications from the Web of Science Core Collection database met our search criteria. Overall fluctuating growth was noted in the number of publications per year (Fig. 1). The quadratic polynomial fits the literature growth curve well (R = 0.993), indicating that the number of publications in the field will continue to grow rapidly. In the 20-year cumulative publication curve, the growth rate of the publication volume accelerated after 2018 compared with that in the previous years. Between 2018 and 2022, the number of publications grew by 804 articles, accounting for 42.74% of the total number of publications.

We analyzed the top 10 locally cited articles using LCS as an indicator (Table 1). Based on their primary research orientations, these publications could be categorized into three domains that elucidate risk factors for PPCs, prevention strategies, and a comprehensive overview of the field. Of the four publications providing insight into the potential risk factors for PPCs [3,5,12,13], Canet et al. (2010) has attracted the most academic attention (LCS = 278) and is the most cited of the ten publications. This research developed the Assess Respiratory Risk in Surgical Patients in Catalonia prediction model, which provides an important basis for risk assessment in medical practice [3]. In comparison, the five articles on prevention strategies focused more on exploring of ventilation strategies [14–18]. This sequence of studies systematically analyzed the effects of variable ventilation parameters and how the risk of PPCs can be reduced by optimizing ventilation strategies [16–18].

3.2. Analysis of research forces

3.2.1. Publications and cooperation of countries/regions

Countries were ranked according to the number of articles published, and the top 10 countries were extracted for analysis (Table 2). The top three countries ranked by the number of articles published were the United States of America (410, 21.91%), China (376, 20.10%), and Japan (147, 7.86%). These three countries accounted for 49.87% of the total number of publications. The Netherlands (MCP_ratio = 0.40), Germany (MCP_ratio = 0.35), and the UK (MCP_ratio = 0.27) preferred to conduct cooperative research with other countries. High values of GCS_pd and LCS_pd were found in the UK (GCS_pd = 35.87, LCS_pd = 8.27), the Netherlands (GCS_pd = 49.31, LCS_pd = 11.66), and France (GCS_pd = 41.80, LCS_pd = 7.23), indicating these three countries published high-quality literature thatgreatly influences this field and in other areas as well. In contrast, China and Japan, the top countries in terms of the total number of publications, received less attention.

The country cooperation chord diagram illustrates the collaboration between countries in detail (Fig. 2A). The strength of the linkage between countries was reflected in the thickness and color of the lines. The strongest cooperation was between the Netherlands and Germany (link weight = 50), followed by Germany and Italy (link weight = 46), and Germany and the United States of America (link weight = 43).

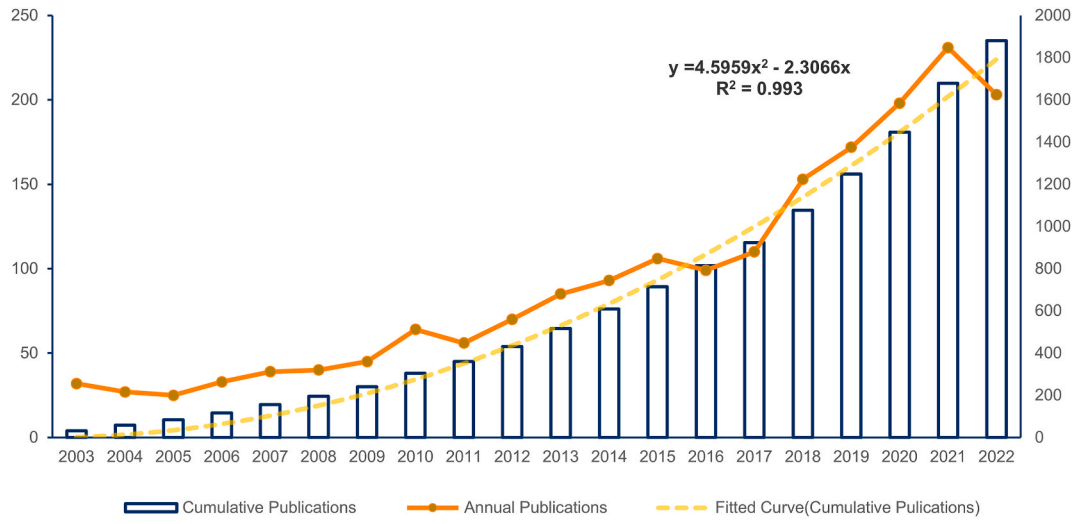


Fig. 1. The publication number and growth trends in postoperative pulmonary complications (PPCs) research from 2003 to 2022.

Table 1
The top 10 articles with the highest local citation scores in postoperative pulmonary complications research.

Rank	Document	LCS
1	Canet (2010)	278
2	Futier (2013)	173
3	Smetana (2006)	150
4	Hulzebos (2006)	145
5	Hemmes (2014)	133
6	Miskovic (2017)	126
7	Fernandez-Bustamante (2017)	123
8	Agostini (2010)	111
9	Severgnini (2013)	108
10	Lawrence (2006)	101

Abbreviations: LCS, local citation scores.

Table 2
Top 10 most productive countries in postoperative pulmonary complications research.

Country	Articles	SCP	MCP	MCP_ratio	LCS	GCS	LCS_pd	GCS_pd
USA	410	350	60	0.15	1759	14651	4.29	35.73
CHINA	376	353	23	0.06	530	3075	1.41	8.18
JAPAN	147	144	3	0.02	259	2183	1.76	14.85
ITALY	105	82	23	0.22	412	2523	3.92	24.03
KOREA	92	88	4	0.04	232	1462	2.52	15.89
GERMANY	82	53	29	0.35	452	2663	5.51	32.48
UK	77	56	21	0.27	637	2762	8.27	35.87
BRAZIL	77	58	19	0.25	529	1859	6.87	24.14
NETHERLANDS	58	35	23	0.40	676	2802	11.66	49.31
FRANCE	56	45	11	0.20	405	2341	7.23	41.80

Abbreviations: GCS, global citation scores; GCS_pd, global citation scores per document; LCS, local citation scores; LCS_pd, local citation scores per document; MCP, multiple country publications; MCP_ratio, multiple country publications ratio; SCP, single country publications.

3.2.2. *Publications and cooperation of institutions*

The collaboration network of institutions was created by CiteSpace (Fig. 2B). The node size indicated the total number of citations of the institution, and the ring's color matched the time of corresponding citations, showing a change from cool to warm colors in chronological order. The width of the ring was citations in a single time slice [10]. The final number of nodes was 486, and the number of connections was 793. The inter-institutional cooperation network was of low density (density = 0.0067), suggesting that cooperation between institutions should be strengthened. University of Genoa (54 documents; 2746 citations) was the most active institution, followed by Sichuan University (49; 594), the Mayo Clinic (40; 2736), and Dresden University of Technology (39; 2114). The top 10 institutions were dispersed regionally. As shown in the heat map of the top 10 institutions (Fig. 2C), the University of Genoa published the most literature in 2018, while Sichuan University published the most in the last two years. For temporal distribution, the Mayo Clinic focused on the PPCs field the earliest and for the longest duration.

3.2.3. *Publications of journals*

Table 3 show the publications of the journals, with the number of publications (NP) and citations per document (Cit_pd) of the journals as ranking indicators, respectively. From the main focus of the journals, it was revealed that the cardiothoracic surgery and anesthesiology disciplines were most concerned with PPCs. Among the journals, the highest number of publications were in the *Journal of Thoracic Disease* (NP = 40), followed by *Anesthesia and Analgesia* (NP = 39), and *Annals of Thoracic Surgery* (NP = 39). The articles published by the *Annals of Surgery* received the most attention (Cit_pd = 97.47).

3.2.4. *Publications of authors*

A group of highly productive authors authored half of the papers on this topic, and; this set of authors was numerically equal to the square root of the total number of authors [19]. According to Price's law, $m = 0.749 \times \sqrt{n_{max}}$, where n_{max} denotes the number of articles by the most productive authors and m is the minimum number of articles by the core authors [20]. The VOSviewer showed that $n_{max} = 54$, and $m \approx 5.5$, which meant that the core authors in this field were those with six or more publications. From the results, the total number of authors whose publications met the criteria was 77. These authors published 570 articles, accounting for 46.62% of the total publications, which did not meet the criteria of Lotka's law (50%). Thus, no core group of authors was formed for PPCs. In the analysis of the 10 most prolific authors (Fig. 2D), the node size represented the annual publication number of the authors and the node color shade represented the total citations per year. Pelosi P, Schultz MJ, and De Abreu MG were consistently productive and followed. The author with the most publications was Paolo Pelosi, who has focused more on the direction of pulmonary protective ventilation [21].

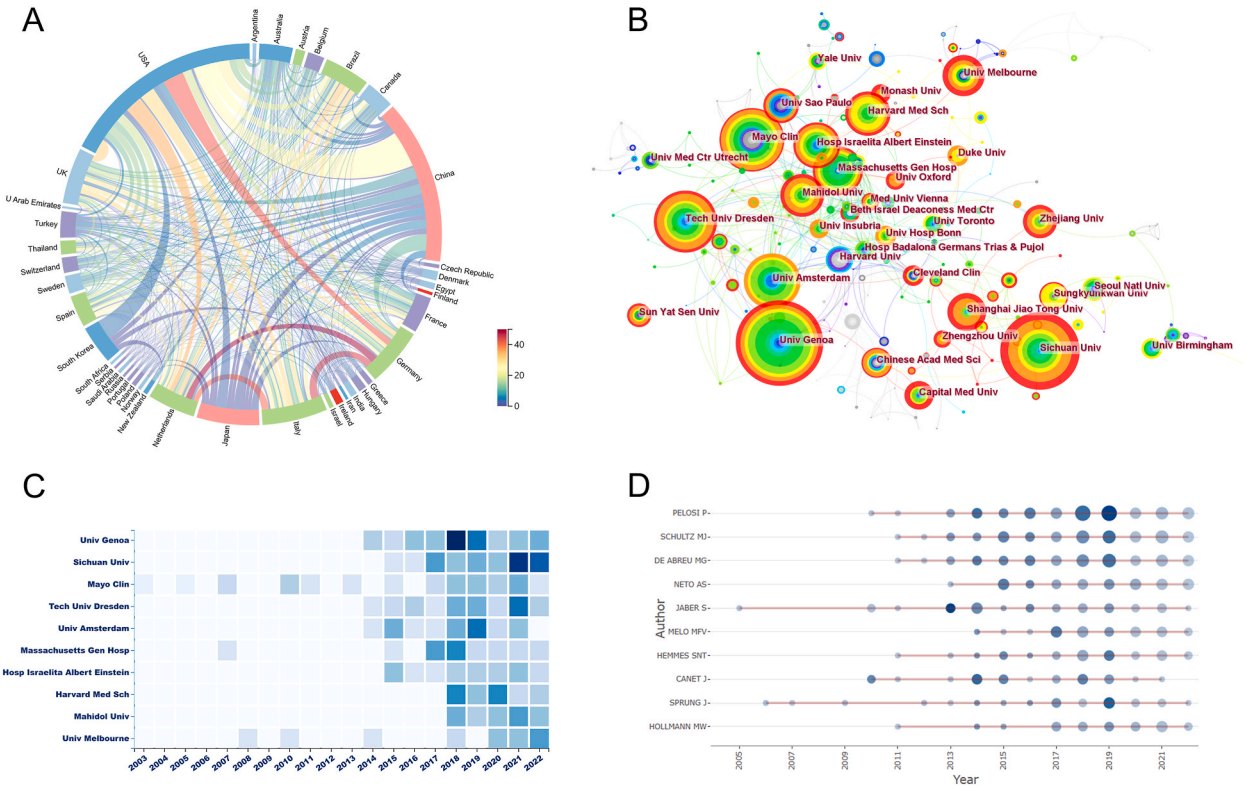


Fig. 2. Analysis of research forces. Collaboration between countries/regions (A) and the network map of institutions (B) in postoperative pulmonary complications (PPCs) research. The heat map of the top 10 most published institutions in PPCs research over 20 years (C). Production of the top 10 authors in PPCs research over 20 years (D).

Table 3
Top 5 most active journals and top 5 journals with the highest average number of citations per document in postoperative pulmonary complications research.

Journals	TC	NP	Cit_pd	Journals	TC	NP	Cit_pd
J Thorac Dis	489	40	12.23	Ann Surg	1657	17	97.47
Anesth Analg	1998	39	51.23	Anesthesiology	3066	33	92.91
Ann Thorac Surg	1358	39	34.82	Chest	1067	13	82.08
Br J Anaesth	1524	36	42.33	Int J Radiat Oncol Biol Phys	799	13	61.46
Eur J Cardio-Thorac	1536	34	45.18	Cochrane Db Syst Rev	891	16	55.69

Abbreviations: Cit_pd, citations per document; NP, the number of publications; TC, total citations.

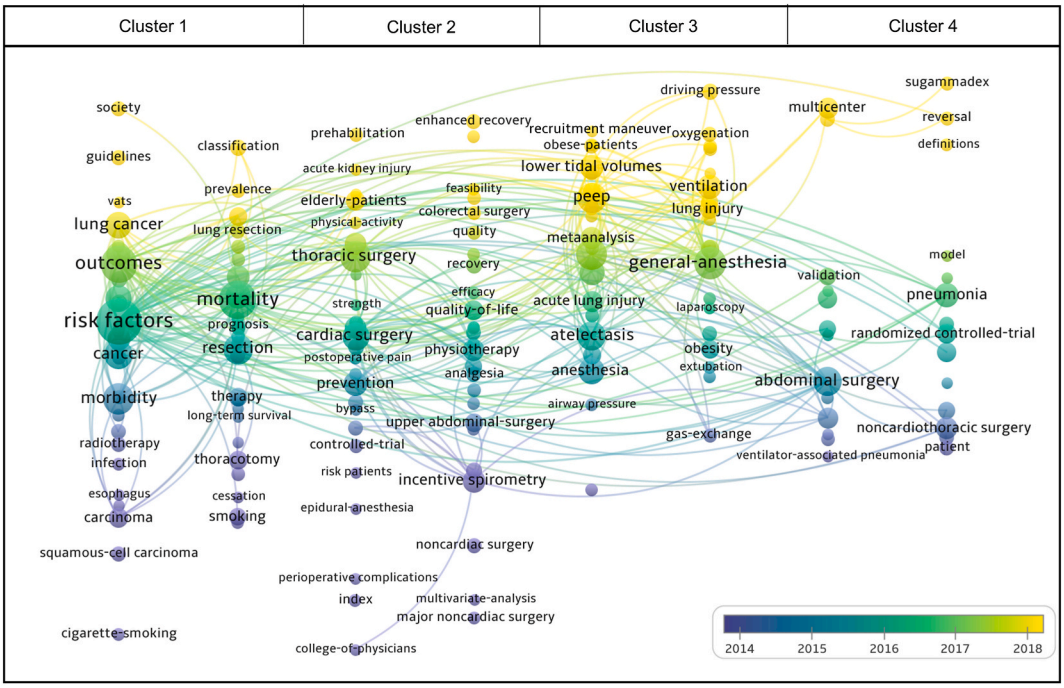
3.3. Co-occurrence of keywords

First, the keywords were cleaned and merged. "Postoperative pulmonary complications" and "postoperative pulmonary complication" were deleted, and synonyms such as "positive end-expiratory pressure" were merged with "peep". The threshold of keyword occurrences was set to 15, and 179 keywords were obtained for co-occurrence analysis (Fig. 3A). The colors and the vertical position in the graph represented the average time of keyword occurrences. Correspondingly, the horizontal axis order matched the clustering results.

Overall, "risk factors" (occurrences = 452) were widely focused as the most co-occurring keyword. "Smoking" was the first element to be studied. The "obese-patients" and "elderly-patients" were the risk groups that received the most attention. In subcluster 2, for the type of surgery, there was a shift in focus from "noncardiac surgery" to cardiothoracic surgery. In addition, the keywords "enhanced recovery" and "prehabilitation" also received close interest after 2019. In the anesthesia management segment, which was reflected in cluster 3, the attention to protective lung ventilation strategies shifted from "peep" and "lower tidal volumes" to "recruitment maneuver". Up to now, "driving pressure" has become the most emergent focus. On the reversal of neuromuscular blockade, "sugammadex" was the latest drug that had attracted the notice of researchers.

Burst detection analysis was performed by CiteSpace (Fig. 3B), with blue lines indicating when keywords appeared and red lines indicating when keywords exploded. "Incentive spirometry" (Strength = 10.31) ranked highest in burst detections. Its burst strength

A



B

Top 15 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2003 - 2022
incentive spirometry	2003	10.31	**2003**	2014	
carcinoma	2003	6.34	**2003**	2012	
chest physiotherapy	2003	5.32	**2003**	2014	
college of physician	2006	5.79	**2006**	2014	
noncardiothoracic surgery	2007	7.73	**2007**	2016	
squamous cell carcinoma	2007	5.5	**2007**	2014	
physiotherapy	2008	7.44	**2008**	2015	
abdominal surgery	2003	6.08	**2010**	2014	
respiratory failure	2003	6.12	**2012**	2015	
randomized controlled trial	2012	8.38	**2014**	2018	
protective ventilation	2013	4.88	**2016**	2019	
low tidal volume	2017	5.33	**2017**	2019	
enhanced recovery	2017	4.61	**2017**	2022	
lung resection	2014	4.75	**2020**	2022	
perioperative care	2017	4.72	**2020**	2022	

Fig. 3. Co-occurrence network for all 179 keywords (A). The top 15 keywords with the strongest citation bursts (B).

may be related to its widespread use in clinics and the continuing controversy over its effectiveness in preventing PPCs. Enhanced recovery, lung resection, and perioperative care were the focus of the current discussion.

3.4. Analysis of Co-cited publications

The timeline graph of the collaborative network of co-cited literature was derived from CiteSpace analysis (Fig. 4), after title-based clustering. It was named after the noun term extracted from the title of the corresponding citing literature; this name could be

considered an emerging frontier topic. A total of 22 clusters were classified, and we selected 10 clusters containing the highest amount of publications for the timeline analysis. The clusters were numbered starting from 0; the smaller the number, the larger the cluster. The node size represents the number of literature citations— the lighter the color, the more recent its attention time. In recent years, the largest and most popular cluster was driving pressure (0), which contained 111 co-cited publications. In addition to the driving pressure (0), the most updated clusters included lung cancer patient (3), enhanced recovery (4), and neuromuscular blockade (6). The results were consistent with the keyword co-occurrence analysis mentioned above, reinforcing that these directions will be hotspots in the coming period.

A total of 13 articles with high betweenness centrality (centrality >0.1) are listed in Table 4. Four articles were related to identifying risk factors and risk assessment for PPCs. A case-control study conducted by Gupta et al., in 2001 identified obstructive sleep apnea as a single risk factor for PPCs [22]. In 2006, Smetana et al. performed the first systematic stratification of risk factors for patients, procedures, and laboratory indicators [12]. However, this study was conducted only on patients undergoing non-cardiothoracic surgery. Subsequently, investigators attempted to develop systematic predictive models. Canet et al. (2010) developed the Assess Respiratory Risk in Surgical Patients in Catalonia, a predictive model for PPCs in a broad population [3]. In 2013, Brueckmann et al. developed the Score for Prediction of Postoperative Respiratory Complications model to assess severe postoperative respiratory complications [7]. Thus, the development of risk assessment studies for PPCs shifted from single to composite factors and from specific groups to broad populations.

In a study by Agostini et al. (2011), the authors conducted a comparative analysis of three outcome assessment criteria for PPCs: the Brooks-Brunn score, the Gosselink score, and the Melbourne Group Scale. They concluded that the Melbourne Group Scale was the optimal tool for identifying PPCs [23].

The remaining eight articles were related to interventions for PPCs. As observed, of the five papers published in 2013 and after, Bradley et al. (2013), Cassidy et al. (2013), and Boden et al. (2018) all focused on preoperative rehabilitation strategies for pulmonary function [20,24,25].

4. Discussion

This study presents a comprehensive bibliometric analysis of the status and trends in the field of PPCs. Over two decades, from 2003 to 2022, a pronounced escalation occurred in the quantity of literature pertaining to PPCs, particularly within the past five years. In the quantitative assessment of the major research contributors, the United States of America, China, and Japan have emerged as prolific producers of literature in this field; however, the latter two were relatively low for international collaborations and literature impact. By quantitatively analyzing the academic output of institutions, journals, authors, and collaborations, we found that the PPCs field has not yet formed a clear core group of researchers. The results of the cluster analysis of keywords and co-cited publications were highly consistent, highlighting that neuromuscular blockade reversal, lung-protective ventilation strategies, and prehabilitation strategies are current topics of high interest. This investigation also analyzed the publications that received the most attention, further accentuating the changing characteristics of the field of PPCs, where the focus of research is gradually shifting from identifying risk factors to the corresponding preventive measures and postoperative care.

4.1. Residual neuromuscular blockade

In the 1950s, evidence indicated that the residual neuromuscular blockade caused by non-depolarizing muscle relaxants is an important risk factor for PPCs [26]. Subsequently, the cholinesterase inhibitor neostigmine, gained attention for preventing PPCsand

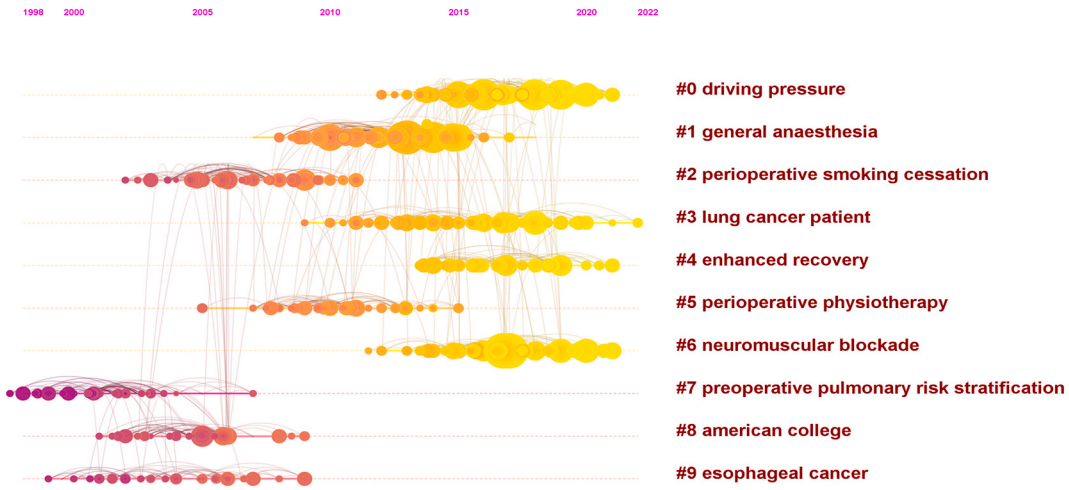


Fig. 4. The timeline view of the top 10 co-citation clusters.

Table 4
Total of 13 co-cited articles with the highest centrality in postoperative pulmonary complications research.

Rank	Ref.	Centrality
1	Smetana (2006)	0.32
2	Canet (2010)	0.30
3	Lawrence (2006)	0.26
4	Cassidy (2013)	0.21
5	Agostini (2011)	0.19
6	Moller (2002)	0.15
7	Neto (2012)	0.13
8	Boden (2018)	0.12
9	Bradley (2013)	0.12
10	Ferreyra (2008)	0.12
11	Brueckmann (2013)	0.11
12	Agostini (2013)	0.11
13	Gupta (2001)	0.11

Abbreviations: Ref., reference.

has been well validated [27,28]. Neostigmine administered (dose: ≤60 μg/kg) after recovery from the second train-of-four (TOF) twitch is appropriate for reducing PPCs [28]. In 2015, the United States Food and Drug Administration officially approved sugammadex for reversal of neuromuscular blockade,.Since then, the perspective has gradually shifted to sugammadex instead of neostigmine for preventing PPCs. While evidence suggests no significant difference between sugammadex and neostigmine in reducing PPCs incidence [29], compared with neostigmine, which has a ceiling effect, sugammadex reverses neuromuscular blockade rapidly [30].

Quantitative monitoring of the degree of residual neuromuscular blockade is key to ensuring full recovery. A 2020 re-analysis of the prospective observational European multicenter cohort study found that TOF ratio (TOFR) > 0.9 is ineffective for avoiding respiratory muscle injury caused by residual neuromuscular blockade with non-depolarizing muscle relaxants and recommended increasing the optimal TOFR to 0.95 [31]. Because of factors such as limited data samples, no studies have substantiated this threshold. The keywords "sugammadex" and "neuromuscular blockade" clustering may prompt clinicians to focus more on residual neuromuscular blockades and utilize quantitative methods to monitor the neuromuscular blockade. In the context of future multidisciplinary collaboration, advancing neuromuscular monitoring equipment and developing more efficacious neuromuscular reversal agents will become inevitable.

4.2. Pulmonary protective ventilation

Ventilation-associated lung injury causes PPCs [32]; therefore, pulmonary protective ventilation strategies received strong attention in the analysis. Traditional strategies for pulmonary protective ventilation include low tidal volume (VT), PEEP, and recruitment maneuvers. However, in 2015, Amato et al. introduced driving pressure in pulmonary protection strategies for acute respiratory distress, arguing that driving pressure is the strongest mediator associated with the survival of acute respiratory distress; VT and PEEP indirectly cause changes in driving pressure on lung function [33]. A 2016 meta-analysis of parameters such as individual patient information similarly concluded that driving pressure is the only significant mediator in PPCs development [34]. An optimal driving pressure-oriented ventilation strategy in clinical practice depends on determining individualized optimal PEEP. However, no mature ventilation technology exists. In 2022, Stenqvist proposed a simple method to achieve the best PEEP with the lowest driving pressure [35]. The validity of this method remains to be proven, but the development of optimal lung-protective ventilation strategies and economical individualized PEEP titration techniques will certainly be hot topics.

At the same time, more research is needed to discover the best ventilation strategies geared to achieve the optimal balance for different surgical requirements. Regarding thoracic surgery, a 2017 meta-analysis concluded that lung-protective ventilation strategies with low VT during one-lung ventilation may impair gas exchange [36]. Concerning cardiac surgery, cardiopulmonary bypass usually suspends pulmonary ventilation. Some studies have concluded that maintaining pulmonary ventilation during cardiopulmonary bypass reduces the inflammatory response and tissue damage [37]; however, these benefits are not well documented, and more research is needed for optimal ventilation strategies accommodating different surgeries.

4.3. Pulmonary prehabilitation

In the era of "patient-centeredness," pulmonary prehabilitation, which enhances patient participation in PPCs prevention, is another hot topic. Respiratory physical training is routine after thoracic surgery. Among the burst detection methods, incentive spirometry has the highest burst strength value. It helps patients breathe deeply, provides visual feedback [38], and is commonly used in clinical practice. Evidence supports that incentive spirometry is not associated with reduced PPCs incidence [12,39]. In recent years, preoperative inspiratory muscle training methods, with mechanical threshold load training as the primary modality, have been well supported by clinical evidence [15,40]. Unfortunately, the optimal intensity of inspiratory muscle training is unclear.

A high-centrality article is considered while analyzing co-cited publications. Unlike in other trials, the authors concluded that preoperative training's effectiveness is based on its educational effect in helping patients perform respiratory exercises immediately

after regaining consciousness postoperatively [25].

In addition to respiratory muscle physiotherapy, the nursing team is important for patient prehabilitation. The "ICOUGH" care strategies proposed by Cassidy effectively reduced the incidence of postoperative pneumonia (1.6% versus 2.6%) and unplanned intubation (1.2% versus 2.0%) [20]. Pulmonary function prehabilitation strategies are individualized, and determining the best comprehensive rehabilitation program for different populations is the goal. More research should be conducted to evaluate the effectiveness of different prehabilitation modalities. Exploring collaboration models between surgical and nursing teams is also necessary to determine the most effective approach for enhancing patient prognoses.

4.4. Overall trends in PPCs

Regarding publications, a quadratic polynomial fits the cumulative publication curve well. Based on the logistic growth curve, it can be initially determined that the field is in the early developmental stages. This preliminary conclusion's credibility is reinforced by analyzing the main research forces and changes in the hotspots of PPCs research development through keywords and co-cited literature. At present, relevant theories and research in the field of PPCs are rapidly developing; however, forming a well-established system requires further research.

4.5. Strengths and limitations

This comprehensive quantitative analysis is the first undertaken for PPCs. Drawing from a variety of data and visual presentations, we firmly believe that this bibliometric analysis holds the potential to objectively identify trends and research hotspots in the field of PPCs. The study is anticipated to facilitate academic discourse, guiding researchers toward underexplored areas.

At the same time, this study has some limitations. First, although the Web of Science Core Collection database has wide coverage with comprehensive citation information, some literature unique to PubMed, Scopus, and other databases were not searched. In addition, some international databases were not considered because of language barriers. Second, although we set the search scope from 2003 to 2022, because of the possible delay in including papers in the Web of Science Core Collection database, the papers published in 2022 may not be fully included in the analysis. Despite the clear labeling of the retrieval date, this uncertainty in the review's timeframe may influence the study results. Special attention should focus on bibliometrics as a repeatable and dynamic analytical methodology that can be continuously applied to update the latest advances in the PPCs field. Thirdly, the software's parameters, including slicing parameters in CiteSpace, selection criteria, and the chosen cropping method may affect the final analysis results. However, based on multiple data and visual representations, we believe that this bibliometric analysis can objectively and quantitatively help identify the trends and research hotspots in the field of PPCs.

5. Conclusion

This bibliometric analysis reveals that the PPCs field is in the early stages of rapid research development. During the last two decades, theory and clinical practice concerning the prevention strategies for PPCs have improved. Among these strategies, pulmonary protective ventilation strategies, neuromuscular blockade reversal, and pulmonary prehabilitation strategies are the current hotspots. Cooperation among research forces should be enhanced to improve theoretical research and build individualized prevention strategies to reduce the incidence and adverse outcomes of PPCs and improve patient satisfaction. This research lays the foundation for future studies, contributing to the evolving narrative of PPCs research. These insights can guide subsequent investigations into preventive interventions, shaping the landscape of PPCs prevention and management.

Data availability statement

Data will be made available on request.

Funding

This work was supported by the National Natural Science Foundation of China [grant number 82171187].

CRediT authorship contribution statement

Qi Sun: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Visualization. **Tianhao Zhang:** Data curation, Investigation, Resources, Software, Writing – original draft, Visualization. **Jiayun Liu:** Methodology, Resources, Software, Writing – original draft, Visualization. **Yong Cui:** Data curation, Investigation, Supervision, Writing – review & editing, Project administration. **Wenfei Tan:** Conceptualization, Project administration, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to

influence the work reported in this paper.

Acknowledgements

The authors thank the National Natural Science Foundation of China [grant number 82171187].

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