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Original Article

Research Trends and Hotspots in Childhood Interstitial Lung Disease Over 40 Years: A Bibliometric Analysis

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Abstract
This study examines the research trends and hotspots in the field of Childhood Interstitial Lung Disease (chILD) over the past four decades. The research was based on 1,123 articles published between 1984 and 2023, with the United States ranking first with 351 publications (31.3%). The study also identified three main research trends: classification, diagnosis, and management of chILD, genetic studies of chILD, and primary diseases associated with chILD. Keywords such as 'polymyositis', 'management', 'features', 'efficacy', and 'mutations' reflected recent research hotspots. Johns Hopkins University was the leader in overall impact, with 44 scholarly works and a cumulative citation count of 2,732. The American Journal of Respiratory and Critical Care Medicine ranked sixth in publication volume but second in total citation counts and average citations per paper. Future research may focus on clinical features, disease management, gene mutations, and polymyositis accompanied by chILD.

Keywords: *Childhood Interstitial Lung Disease, Bibliometric Analysis, Research Trends, Hotspots, Visualization.*

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1 Introduction

Childhood interstitial lung disease (chILD) is a group of rare diseases characterized by abnormal gas exchange due to inflammatory responses and lung fibrosis. Because these conditions can involve the lung interstitial, alveolar structures, and distal airways, it may be more appropriate to refer to them as diffuse parenchymal lung diseases (DPLD) (Kurland et al., 2013, Nathan et al., 2018a, Clement et al., 2010). The causes of childhood ILD are complex and diverse, encompassing more than 200 different disease entities (Griese et al., 2015). Based on limited reports, the estimated overall prevalence ranges from 0.15 to 4.65 per 100,000 (Nathan et al., 2023, Dinwiddie et al., 2002, Kornum et al., 2008, Griese et al., 2009, Nathan et al., 2012, Saddi et al., 2017, Torrent-Vernetta et al., 2022, Nevel et al., 2024, Griese et al., 2018). Due to its complexity and rarity, current research on chILD predominantly consists of case reports and small case series.

In recent decades, an increasing body of literature has been dedicated to enhancing our understanding of chILD. These efforts have improved diagnostic approaches and management strategies (Kurland et al., 2013, Nathan et al., 2018a, Bush et al., 2015, Cassibba et al., 2024). However, fragmented research output and the lack of a unified classification system hinder comprehensive progress assessments in this field. Given the complexity and diversity of chILD, systematic analysis of collective research outcomes is essential for

identifying key trends, knowledge gaps, and areas requiring further investigation.

Bibliometric analysis is a quantitative method using statistical tools to examine the structure and content of academic publications (Donthu et al., 2021). It enables researchers to map a particular field by evaluating citation patterns, collaboration networks, and thematic trends. By providing an extensive overview of research activities, bibliometric analysis can highlight influential research, leading institutions, and collaborative networks, thus facilitating the identification of research priorities and emerging trends.

To date, there appears to be a lack of dedicated bibliometric analysis specifically focused on chILD. This study aims to fill this gap by performing a comprehensive bibliometric analysis of chILD literature. Specifically, our objectives are to identify the most prolific authors, institutions, and countries, evaluate citation metrics to determine the research impact, and map thematic trends and research hotspots. Understanding these aspects will help researchers and clinicians navigate the vast amount of available information, guide future research directions, and foster collaborations within the chILD research community.

2 Materials and methods

2.1 Data Collection

This bibliometric analysis evaluated global research trends and contributions regarding childhood interstitial lung disease. A comprehensive search was conducted in the Web of Science Core Collection (WoSCC) database on 4 July 2024 to identify relevant articles published from the inception of the database until December 31, 2023. The search strategy is as follows: TS= (“interstitial lung disease” OR “ILD” OR “interstitial pneum*” OR “pulmonary interstitial disease” OR “diffuse parenchymal lung disease” OR “diffuse lung disease”) AND TS= (“pediatric*” OR “child*” OR “kid” OR “kids” OR “baby” OR “babies” OR “infant*” OR “infanc*” OR “toddler*”). The document types were set to "article" and "review article". The language was set to "English".

We first screened the titles and abstracts to determine their relevance to the research field. If the relevance could not be ascertained from the title and abstract, a full-text review was performed to confirm eligibility. Initially, 1,159 articles were identified. Historical analysis showed that significant research began in 1985, with only 36 papers published from 1904 to 1984. Therefore, the focus was narrowed to 1,123 articles published between 1984 and 2023.

Studies meeting the following criteria were included: (a) focused on childhood interstitial lung disease, (b) reviews or original articles, (c) published in English, and (d) published after 1984, as shown in Fig. 1, it presents the flow diagram outlining the study design.

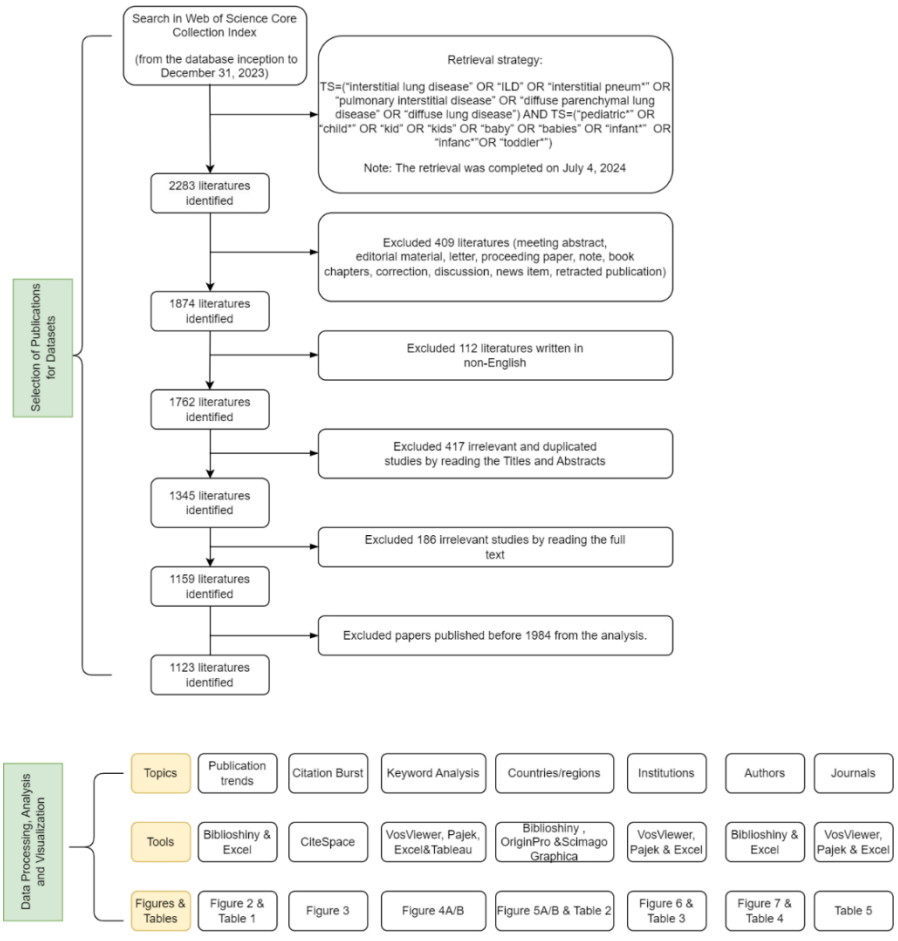

Fig. 1. *Flow diagram outlining the study design*

2.2 Data Processing

Data extraction was performed using the export function of WoSCC, which downloads citation records. Extracted data included article titles, authors, affiliations, publication year, journal names, abstracts, keywords, citations, and references. All extracted data were imported into VOSviewer software (version 1.6.19) and Pajek64 (version 5.19) for bibliometric mapping and analysis. Using VOSviewer, a multidimensional analysis of trend keywords was conducted based on both author-selected keywords and Keywords Plus. Data processing and statistical analysis were performed using RStudio software (version 2023.12.0 build 369) and biblioshiny with the "bibliometrix" package. Citation bursts were analyzed using CiteSpace (version 5.7r5) (Chen, 2006).

Terms merging and exclusion: Terms related to "child" or "interstitial lung disease" and their synonyms were excluded. Keywords with the same meaning or differing only by hyphenation were merged, and the term with the highest frequency was used for the merged result.

2.3 Analysis Tools and Software

Analysis and visualization were performed using the following software: VOSviewer, Pajek, Biblioshiny, Cite Space, Microsoft Excel, Origin Pro, Tableau and Scimago Graphica (Hassan-Montero et al., 2022).

Settings and parameters: The minimum number of publications for institutions was set at 20. The minimum number of publications for authors and journals was set at 15. In the topic cluster analysis, the minimum number of occurrences for each keyword was set to 12. In the trend topic analysis, the minimum frequency for each keyword was set to 15.

3 Results

3.1 Publication trends

The publication trend shows a significant increase in annual publication rates, with an average annual growth rate of 9.41% ($R^2 = 0.906$), as illustrated in Fig. 2. Over 80% of the documents were published after 2005, and over half were published after 2015. Collectively, they have been cited 16,107 times, with an average of 22.06 citations per article, highlighting the growing academic interest and impact of chILD research.

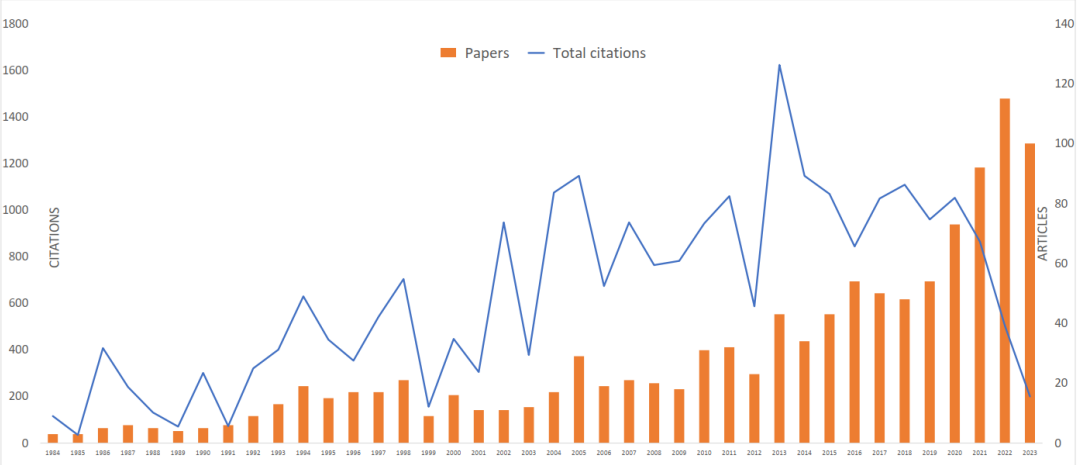

Fig. 2. *Global publications and citations of research results on chILD*

By using Biblioshiny, the top 10 most cited papers were identified, as presented in Table 1. The papers cover 2002 to 2020, with citations ranging from 170 to 468. The highest-cited paper, "Heterozygosity for a Surfactant Protein C Gene Mutation Associated with Usual Interstitial Pneumonitis and Cellular Nonspecific Interstitial Pneumonitis in One Kindred," by THOMAS AQ (2002), has 468 citations, averaging 20.35 citations per year. Four top high-cited papers are published in the American Journal of Respiratory and Critical Care Medicine. Other journals represented include American Journal of Diseases of Children, Nature Reviews Rheumatology, JAMA - Journal of the American Medical Association, Journal of the American Academy of Dermatology, and The Journal of Biological Chemistry. Topics include HIV infection, myositis autoantibodies, HTLV-III RNA detection, ABCA3 as a lipid transporter, and protocols or guidelines for childhood interstitial lung disease.

Table 1. *Top 10 high-cited articles on childhood interstitial lung disease research.*

Author	Year	Journal	Title	Total Citations	TC per Year
THOMAS AQ	2002	American Journal of Respiratory and Critical Care Medicine	Heterozygosity for a Surfactant Protein C Gene Mutation Associated with Usual Interstitial Pneumonitis and Cellular Nonspecific Interstitial Pneumonitis in One Kindred	468	20.35
DEUTSCH GH	2007	American Journal of Respiratory and Critical Care Medicine	Diffuse Lung Disease in Young Children Application of a Novel Classification Scheme	323	17.94
KURLAND G	2013	American Journal of Respiratory and Critical Care Medicine	An Official American Thoracic Society Clinical Practice Guideline: Classification, Evaluation, and Management of Childhood Interstitial Lung Disease in Infancy	293	24.42
BLANCHE S	1990	American Journal of Diseases of Children	Longitudinal Study of 94 Symptomatic Infants With Perinatally Acquired Human Immunodeficiency Virus Infection: Evidence for a Bimodal Expression of Clinical and Biological Symptoms	246	7.03
MCHUGH NJ	2018	Nature Reviews Rheumatology	Autoantibodies in myositis	238	34
BULLARD JE	2005	American Journal of Respiratory and Critical Care Medicine	ABCA3 Mutations Associated with Pediatric Interstitial Lung Disease	229	11.45
CHAYT KJ	1986	JAMA - Journal of the American Medical Association	Detection of HTLV-III RNA in Lungs of Patients With AIDS and Pulmonary Involvement	208	5.33
DEWANE ME	2020	Journal of the American Academy of Dermatology	Dermatomyositis: Clinical features and pathogenesis	189	37.8
BAN N	2007	The Journal of Biological Chemistry	ABCA3 as a Lipid Transporter in Pulmonary Surfactant Biogenesis	171	9.5
BUSH A	2015	Thorax	European protocols for the diagnosis and initial treatment of interstitial lung disease in children	170	17

3.2 Review of Research Trends and Hotspots

3.2.1 Citation Burst

A citation burst refers to a sudden surge in the number of citations received by a particular document within a short period. This phenomenon usually indicates that the research findings are groundbreaking or have garnered significant attention from the academic community at a given time (Chen et al., 2010). CiteSpace provides citation burst analysis to help researchers identify emerging trends or hot topics (Chen, 2006). To explore the temporal dynamics of highly influential references within childhood ILDs, we performed citation burst analysis using the CiteSpace software. This approach allows us to identify key articles that experienced a sharp increase in citations over a short period, which may indicate significant shifts or developments within the research domain.

We preprocessed the raw data using the data preparation tools provided by CiteSpace to ensure compliance with the software requirements. We enabled citation burst detection to identify articles with a sudden increase in citations. Default settings detected bursts, with the minimum burst duration set to 2. Ultimately, 173 citations exhibited citation bursts. We selected the top 25 articles with the strongest citation, as shown in Fig. 3, intensity and analyzed their characteristics, such as publication year, authors, journals, and themes, to interpret their significance in chILD's research.

Among these 25 papers, 14 articles focused on specific gene mutations associated with interstitial lung diseases, particularly the *Surfactant Protein C (SP-C)* gene and the *ABCA3* gene. Seven papers discussed *SP-C* gene mutations (e.g., Nogee LM, 2001; Thomas AQ, 2002; Nogee LM, 2002; Hamvas A, 2004; Cameron HS, 2005; Thouvenin G, 2010; Avital A, 2014) (Nogee et al., 2001, Nogee et al., 2002, Hamvas et al., 2004, Cameron et al., 2005, Thouvenin et al., 2010, Avital et al., 2014). Six studies addressed the impact of *ABCA3* gene mutations (e.g., Schulenberg S, 2004; Bullard JE, 2005; Doan ML, 2008; Young LR, 2008; Wambach JA, 2014; Kröner C, 2017) (Shulenin et al., 2004, Bullard et al., 2005, Doan et al., 2008, Young et al., 2008, Wambach et al., 2014, Kröner et al., 2017), and one paper by Wert SE et al. in 2009 examined the effects of both types of gene mutations together (Wert et al., 2009). Many studies described the clinical presentations, radiological characteristics and pathological features of patients carrying these gene mutations. Collectively, these findings offer crucial insights into the genetic underpinnings of childhood ILDs.

Top 25 References with the Strongest Citation Bursts

References	Year	Strength	Begin	End	1984 - 2023
Nogee LM, 2001, NEW ENGL J MED, V344, P573, DOI 10.1056/NEJM200102223440805, DOI	2001	15.74	2002	2006	
Thomas AQ, 2002, AM J RESP CRIT CARE, V165, P1322, DOI 10.1164/rccm.200112-123OC, DOI	2002	13.58	2003	2006	
Nogee LM, 2002, CHEST, V121, P0, DOI 10.1378/chest.121.3_suppl.20S, DOI	2002	9.04	2003	2007	
Shulenin S, 2004, NEW ENGL J MED, V350, P1296, DOI 10.1056/NEJMoa032178, DOI	2004	15.44	2004	2009	
Fan LL, 2004, PEDIATR PULM, V38, P369, DOI 10.1002/ppul.20114, DOI	2004	12.5	2005	2009	
Hamvas A, 2004, AM J RESP CELL MOL, V30, P771, DOI 10.1165/rcmb.2003-0323OC, DOI	2004	9.08	2005	2009	
Bullard JE, 2005, AM J RESP CRIT CARE, V172, P1026, DOI 10.1164/rccm.200503-504OC, DOI	2005	13.97	2006	2010	
Cameron HS, 2005, J PEDIATR-US, V146, P370, DOI 10.1016/j.jpeds.2004.10.028, DOI	2005	10.19	2006	2010	
Deterding RR, 2005, PEDIATR PULM, V40, P157, DOI 10.1002/ppul.20243, DOI	2005	9.67	2007	2010	
Deutsch GH, 2007, AM J RESP CRIT CARE, V176, P1120, DOI 10.1164/rccm.200703-393OC, DOI	2007	21.83	2008	2012	
Doan ML, 2008, THORAX, V63, P366, DOI 10.1136/thx.2007.083766, DOI	2008	15.46	2009	2013	
Brody AS, 2010, AM J ROENTGENOL, V194, P238, DOI 10.2214/AJR.09.2743, DOI	2010	10.14	2010	2015	
Young LR, 2008, CHEST, V134, P192, DOI 10.1378/chest.07-2652, DOI	2008	9.41	2010	2013	
Wert SE, 2009, PEDIATR DEVEL PATHOL, V12, P253, DOI 10.2350/09-01-0586.1, DOI	2009	9.9	2011	2014	
Young LR, 2011, CHEST, V139, P1060, DOI 10.1378/chest.10-1304, DOI	2011	9.61	2011	2016	
Thouvenin G, 2010, ARCH DIS CHILD, V95, P449, DOI 10.1136/adc.2009.171553, DOI	2010	9.28	2012	2015	
Kurland G, 2013, AM J RESP CRIT CARE, V188, P376, DOI 10.1164/rccm.201305-0923ST, DOI	2013	31.57	2014	2018	
Wambach JA, 2014, AM J RESP CRIT CARE, V189, P1538, DOI 10.1164/rccm.201402-0342OC, DOI	2014	15.15	2015	2019	
Avital A, 2014, PEDIATR PULM, V49, P1097, DOI 10.1002/ppul.22971, DOI	2014	10.99	2015	2019	
Soares JJ, 2013, PEDIATRICS, V132, P684, DOI 10.1542/peds.2013-1780, DOI	2013	9.72	2015	2018	
Bush A, 2015, THORAX, V70, P1078, DOI 10.1136/thoraxjnl-2015-207349, DOI	2015	21.76	2016	2020	
Rauch D, 2016, AM J RESP CRIT CARE, V193, P438, DOI 10.1164/rccm.201508-1655OC, DOI	2016	10.07	2017	2021	
Griese M, 2018, THORAX, V73, P231, DOI 10.1136/thoraxjnl-2017-210519, DOI	2018	13.69	2018	2023	
Kr?ner C, 2017, THORAX, V72, P213, DOI 10.1136/thoraxjnl-2016-208649, DOI	2017	12.88	2018	2023	
Sanchez GAM, 2018, J CLIN INVEST, V128, P3041, DOI 10.1172/JCI98814, DOI	2018	10.9	2020	2023	

Fig. 3. *The top 25 references with the strongest citation bursts*

3.2.2 Keyword Analysis

3.2.2.1 Topic cluster analysis

VOSviewer was utilized to conduct keyword analysis on published papers. To ensure enough keywords for our analysis, we opted for "all keywords," which includes both the author-selected keywords and Keywords Plus. To limit the visualization to within 100 keywords, we conFig. d the software to filter out keywords that appeared fewer than 12 times. After merging synonyms and excluding search terms and their synonyms, we identified 92 keywords that met our criteria. VOSviewer grouped these 92 keywords into three clusters.

To enhance the visualization, we processed the cluster data generated by VOSviewer in two ways: first, by rearranging the time-ordered cluster data using Pajek software to align the keywords into three columns; subsequently, by sorting the keywords according to their publication year using Excel, and then regenerating the VOSviewer map and network files. Finally, we re-imported the processed data files from Excel and Pajek into VOSviewer to produce the following image, as depicted in Fig. 4(A).

From left to right in Fig. 4(A), the three columns of points in the image represent three distinct clusters; from top to bottom, they indicate the chronological order of keyword appearance. The color of the points denotes the average publication year, while the size reflects the frequency of keyword occurrence.

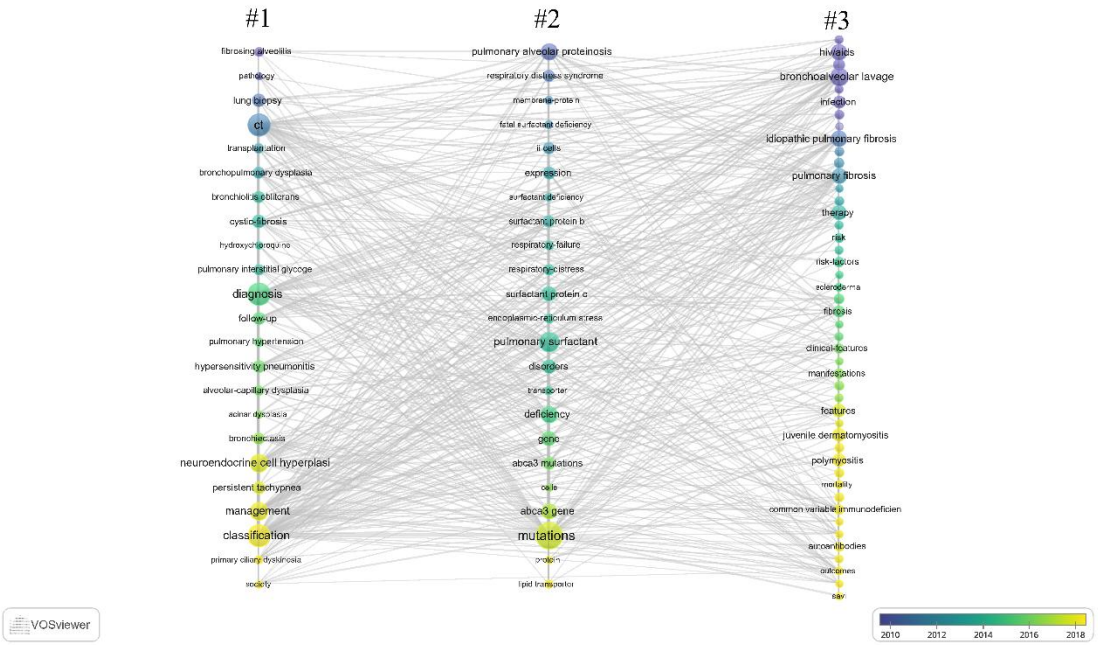

Fig. 4(A). *Cooccurrence network visualization of keywords*

The first cluster is associated with the classification, diagnosis, and management of childhood interstitial lung disease. Key terms include 'CT', 'diagnosis', 'classification', 'neuroendocrine cell hyperplasia of infancy', 'management', 'lung biopsy', 'cystic fibrosis', 'follow-up', 'hypersensitivity pneumonitis', and

'persistent tachypnea'. When reviewing these terms chronologically from earliest to most recent, 'CT', 'diagnosis' and 'classification' emerge as the most prominent keywords in this cluster. Due to the complexity and heterogeneity of chILD, research into classification systems and diagnostic strategies has been a focal point for decades. Advancements in CT imaging pattern recognition have also facilitated progress in diagnostic and classification studies. Additionally, disease management has become a research emphasis in recent years.

The second cluster revolves around gene mutations, with 'mutations' being the most frequently occurring keyword and a hot topic in recent years. In descending order, we see 'pulmonary alveolar proteinosis', 'Surfactant Protein B', 'Surfactant Protein C', 'Pulmonary Surfactant', '*ABCA3* Gene' and '*ABCA3* Mutations'. This indicates that early studies focused more on genes related to pulmonary alveolar proteinosis. At the same time, recent years have seen increased attention on surfactant-related genes such as *SFTPB*, *SFTPC*, and *ABCA3*. Genetic mutations associated with surfactant-related genes have been a major research focus over the past decade.

The third cluster addresses primary diseases associated with childhood interstitial lung disease. Keywords, progressing from earlier to more recent times, include 'HIV/AIDS', 'stem-cell transplantation', 'scleroderma', 'rheumatoid arthritis', 'arthritis', 'systemic lupus erythematosus', 'juvenile dermatomyositis', 'polymyositis', 'idiopathic inflammatory myopathies', 'common variable immunodeficiency', 'systemic sclerosis', and 'SAVI'. Overall, the frequency of keywords in this cluster is lower than in the previous two clusters, with some earlier high-frequency terms appearing. Early research was primarily concentrated on chILD associated with HIV/AIDS, but interest has waned over the past decade. In recent years, growing attention has been given to the relationship between childhood interstitial lung diseases and connective tissue disease and/or inborn errors of immunity.

3.2.2.2 Trend topic analysis

When conducting trend topic analysis using Biblioshiny, the source of keywords was set to Keywords Plus, with the minimum frequency for each keyword set to 15, and the number of words per year set to 3. After merging synonyms and filtering the search keywords, we obtained 37 keywords related to pediatric interstitial lung disease (PILD). Subsequently, these data were imported into Tableau software for visualization analysis, as shown in Fig. 4(B). In the Fig. , the x-axis represents the years, the y-axis represents the keywords, and the circles indicate the frequency of keyword occurrences.

In the recent five years, the keywords 'polymyositis', 'management', 'features', 'efficacy' and 'mutations' have appeared frequently, as shown in Fig. 4(B). This suggests that the clinical features and disease management of chILD, gene mutations related to chILD, and polymyositis (a connective tissue disease) accompanied with chILD may be recent research hotspots.

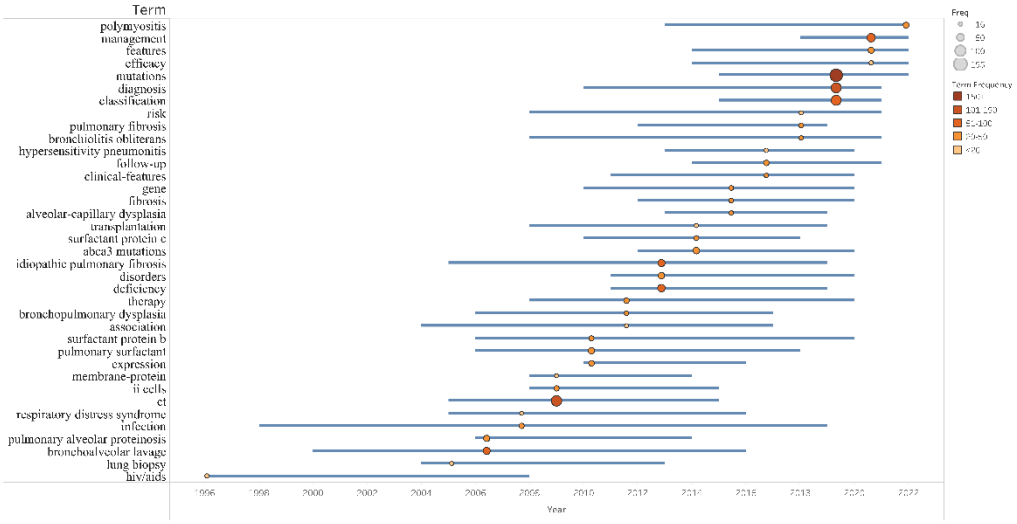

Fig. 4(B). *Trend topic analysis*

3.3 Countries/regions

A total of 5,474 researchers from 84 countries or regions have contributed to the 1,123 original articles on childhood interstitial lung disease (chILD).

Table 2 illustrates the top ten contributing countries or regions. Researchers from the United States lead in publication output with 351 articles, accounting for 31.1% of all publications, and achieving an average citation of 30.70, underscoring its significant contribution to the field.

Germany and the United Kingdom follow closely, with substantial contributions in both quantity and quality of articles, notably having higher percentages of multi country publications (MCP) compared to other

countries. France, despite publishing fewer papers (n=68), has the highest average citation count per paper at 36.1, with a total of 2,454 citations. While China has a similar number of articles as France, it has significantly fewer citations and MCP, indicating a disparity in the impact of research output. Italy stands out for having a smaller number of articles but a relatively high percentage of MCP, suggesting a focus on impactful research rather than volume. Additionally, the data reveal that countries like India and Turkey, despite publishing fewer articles, still contribute meaningfully to the major works in the field, reflecting a global distribution of research efforts.

Table 2. *Top 10 countries with the most articles.*

Rank	Country	No. of articles	Articles %	Total citation	Average Citation	SCP	MCP	MCP %
1	USA	351	31.3	10784	30.70	304	47	13.4
2	GERMANY	90	8	1854	20.60	54	36	40
3	UNITED KINGDOM	73	6.5	2322	31.80	52	21	28.8
4	CHINA	68	6.1	451	6.60	66	2	2.9
5	FRANCE	68	6.1	2454	36.10	54	14	20.6
6	ITALY	52	4.6	818	15.70	36	16	30.8
7	JAPAN	47	4.2	749	15.90	43	4	8.5
8	INDIA	33	2.9	214	6.50	31	2	6.1
9	TURKEY	30	2.7	265	8.80	25	5	16.7
10	AUSTRALIA	24	2.1	308	12.80	17	7	29.2

Corresponding author's country (the data was generated by Biblioshiny). SCP = Single Country Publications, MCP = Multi Country publications.

A chord diagram and a global map of collaborative networks, Fig. 5(A) and Fig. 5(B) provide insights into international cooperation patterns. These visualizations underscore the United States' prominence in fostering extensive and diverse international collaborations in this research area.

Most of the analyzed papers were conducted by authors from single-country institutions. International collaboration was more prevalent among researchers from North America and Europe compared to their Asian counterparts.

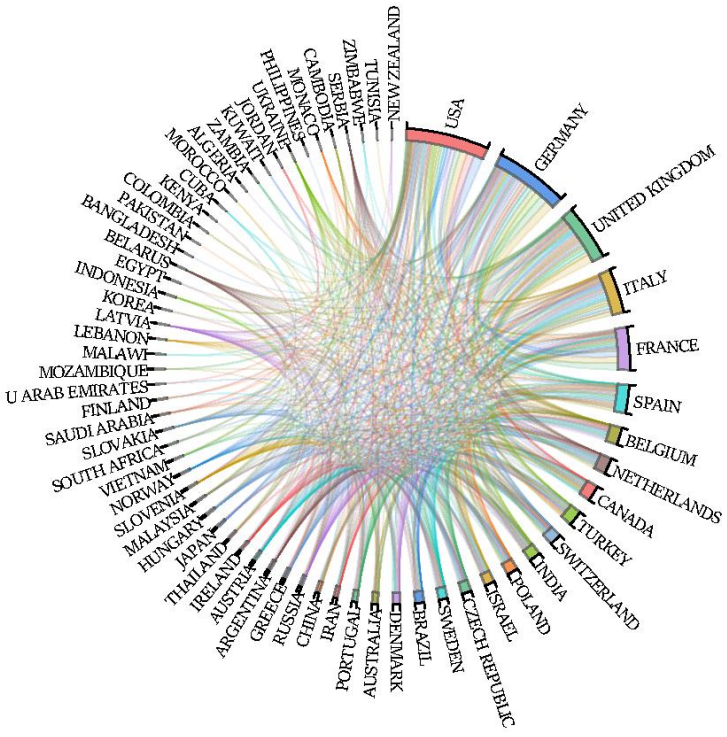

Fig. 5(A). *A chord diagram of collaborative*

Fig. 5(B). *Global map of collaborative networks*

3.4 Institutions

The 1,123 scholarly articles examined involve authors affiliated with 1,712 distinct institutions. Thirteen institutions stand out, each contributing at least 20 papers to the field of childhood interstitial lung disease (chILD). Table 3 details these institutions, assessing their contributions in terms of the number of publications, total citation counts, and average citations per paper, along with their rankings in each category. Two additional metrics, "Sum of Ranks" and "Overall Ranking", are included to better evaluate institutional impact. "Sum of Ranks" aggregates the rankings across the three primary metrics, while "Overall Ranking" determines the position based on the "Sum of Ranks", with lower values indicating higher overall standing.

Table *3.* *Top 12 institutions with the most publications in the field of childhood interstitial lung disease*

Organization	Country	Papers	Citations	Average Citation Count Per Paper	Publication Rank	Citations Rank	Average Citation Rank	Sum Of Ranks	Overall Ranking
Johns Hopkins University	USA	44	2732	62.1	2	1	1	4	1
University of Munich	Germany	66	1921	52.1	1	2	3	6	2
University of Cincinnati	USA	29	1584	54.6	7	4	2	13	3
University of Colorado	USA	44	1674	38	3	3	7	13	4
Texas Children's Hospital	USA	32	1505	47	5	5	5	15	5
Hôpital Necker - Enfants Malades	France	27	1301	48.2	9	6	4	19	6
Washington University	USA	29	1229	42.4	8	7	6	21	7
Baylor College of Medicine	USA	30	1079	36	6	8	8	22	8
Hannover Medical School	Germany	34	856	25.2	4	9	10	23	9
University of Pennsylvania	USA	24	769	32	10	10	9	29	10
Royal Brompton Hospital	United Kingdom	22	513	23.3	12	11	11	34	11
Hacettepe University	Turkey	24	444	18.5	11	12	12	35	12

The Table 3 reveals that institutions in the United States dominate the field of childhood interstitial lung disease (chILD) research, with multiple institutions ranking highly across all metrics. Johns Hopkins University stands out as the leader with the highest overall ranking, boasting the highest average citation count per paper and the highest number of citations overall. The University of Munich in Germany is a strong contender, leading in the number of papers published while maintaining a high citation count and average citation per paper. Institutions

such as the University of Cincinnati and the University of Colorado also show significant contributions, particularly in terms of average citation counts and total citations, reflecting a strong presence in impactful research.

Institutions from outside the U.S., such as those in Germany and France, also make notable contributions, demonstrating that international research is vital to advancing knowledge in the field of chILD. However, the dominance of U.S.-based institutions is clear, highlighting the country's leadership role in this area of medical research.

Notably, while some institutions like Texas Children's Hospital and Hôpital Necker - Enfants Malades have fewer publications, they maintain a high average citation count per paper, indicating that their contributions are highly valued within the academic community. This suggests that the quality of research, as measured by citation impact, is as crucial as the quantity of publications when assessing institutional contributions to chILD research.

A collaboration network and cluster analysis in Fig. 6, reveals the dynamics of institutional interactions. Each node in the diagram represents an institution, and connecting lines indicate collaborative ties. Institutions are grouped into three clusters based on collaboration intensity, with colors distinguishing different groups. Notably, the four green nodes represent non-U.S. institutions.

This visualization demonstrates that despite geographical distances, leading healthcare organizations actively share knowledge. International cooperation is more frequent among institutions known for strong research within their countries, and a clustering effect is observed within specific regions, with U.S. institutions forming denser networks than others.

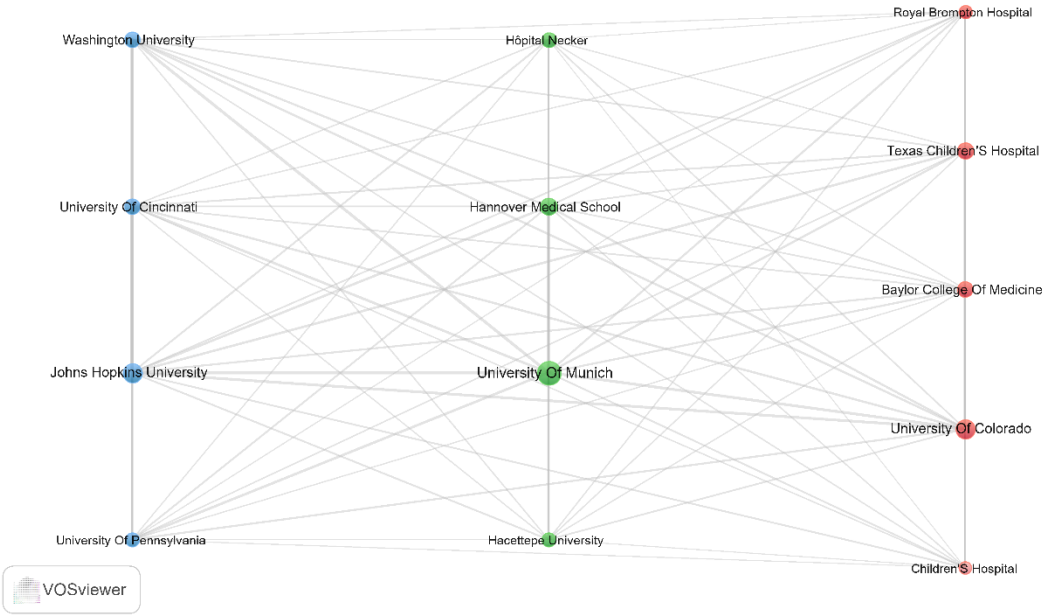

Fig. 6. *Collaboration network and cluster diagram of the top 13 institutions by publication volume*

3.5 Authors

In the specialized domain of childhood interstitial lung disease (chILD), the efforts of 5,451 scholars have produced the existing body of literature. Through a rigorous screening process focused on publication quantity, a select group of 13 researchers was identified, each contributing at least 15 papers. These top 13 authors have collectively published 317 papers, constituting 28.23% of the total scholarly output in this field, averaging 24 papers per author. Their works have garnered a total of 11,241 citations, averaging 35.46 citations per paper. The number of papers published, total citations, and average citations per author for the top 13 authors are shown in Fig. 7.

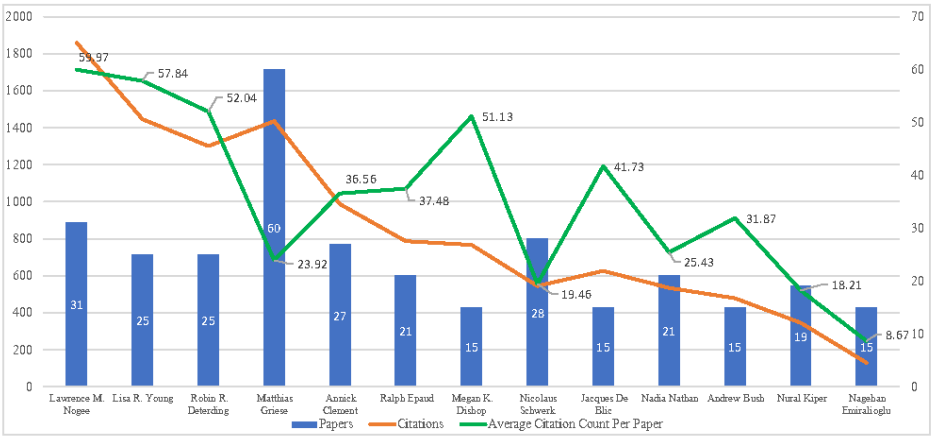

Fig. 7. *Number of papers published and citations by author*

A detailed overview of the academic achievements of these 13 high-yield authors is then given, focusing on three key metrics: the number of papers published, the total citation count, and the average citation frequency per paper, alongside their rankings in each category. Consistent with the analytical framework used for research institutions, two new metrics are included in the final columns of the table to provide a comprehensive evaluation of each author's influence. The primary metric, "Sum of Ranks", combines the ranks achieved across the three metrics, while the secondary metric, "Overall Ranking", is derived from the "Sum of Ranks", with a lower score indicating a higher overall standing.

Table 4 highlights that a select group of researchers has significantly impacted the field of childhood interstitial lung disease (chILD). Lawrence M. Nogee leads the group with 31 papers and the highest average citation count per paper at 59.97, securing him the top spot in both publication and citation metrics. Lisa R. Young and Robin R. Deterding follow closely behind, contributing 25 papers each and maintaining high average citation counts, positioning them second and third, respectively. Although leading in the number of publications with 60 papers, Matthias Griese has a lower average citation count per paper. On the other hand, researchers like Megan K. Dishop and Jacques De Blic, who have published fewer papers but achieved higher average citation counts, demonstrate the importance of impactful research regardless of the number of publications.

The predominance of U.S.-based researchers is evident, with seven out of the top 13 authors affiliated with American institutions. European institutions, particularly from Germany, France, and the UK, also feature prominently, suggesting a strong international collaboration in the field. This distribution underscores the global nature of chILD research and the significant contributions made by a small group of highly productive authors.

Table 4. *Publication count, citation frequency, and ranking of the top 13 authors by publication volume*

Author	Papers	Citations	Average Citation Count Per Paper	Publication Rank	Citations Rank	Average Citation Rank	Sum Of Ranks	Overall Ranking
Lawrence M. Nogee	31	1859	59.97	2	1	1	4	1
Lisa R. Young	25	1446	57.84	6	2	2	10	2
Robin R. Deterding	25	1301	52.04	5	4	3	12	3
Matthias Griese	60	1435	23.92	1	3	10	14	4
Annick Clement	27	987	36.56	4	5	7	16	5
Ralph Epaud	21	787	37.48	7	6	6	19	6
Megan K. Dishop	15	767	51.13	12	7	4	23	7
Nicolaus Schwerk	28	545	19.46	3	9	11	23	8
Jacques De Blic	15	626	41.73	11	8	5	24	9
Nadia Nathan	21	534	25.43	8	10	9	27	10
Andrew Bush	15	478	31.87	10	11	8	29	11
Nural Kiper	19	346	18.21	9	12	12	33	12
Nagehan Emiralioglu	15	130	8.67	13	13	13	39	13

3.6 Journals

Table 5 reveals high citation rates and significant contributions to the research landscape characterize the top journals in childhood interstitial lung disease (chILD). There are 13 journals with at least 15 publications in the chILD field. These journals

collectively published 357 papers, accounting for approximately 31.79% of all chILD-related articles, averaging 29.75 papers per journal with an average impact factor of 6.84.

The "American Journal of Respiratory and Critical Care Medicine" takes the lead with a high average citation count of 131.59 per paper and ranks first in citation metrics, despite having fewer papers than other journals. "Chest" follows closely, demonstrating a strong balance between the number of publications and citation impact. "Pediatric Pulmonology" stands out due to its high volume of publications (156 papers) and significant citation count, placing it third overall despite having a lower impact factor. This indicates that while impact factors are important, the sheer volume of research can also be critical in determining a journal's influence in the field.

Other notable journals include "Journal of Pediatrics" and "Orphanet Journal of Rare Diseases," which rank well in terms of the number of papers and citation impact, showing a balanced contribution to the field. "European Respiratory Journal," despite its high impact factor, ranks sixth overall due to its relatively lower number of publications, illustrating that the quantity of research can sometimes outweigh the prestige of the journal's impact factor.

While not leading in impact factors, journals such as "Pediatric Radiology" and “Thorax” have performed well regarding citation counts, indicating a solid readership and relevance within the chILD community. "Pediatrics" and "Pediatric Respiratory Reviews" also perform reasonably well, highlighting their consistent performance in both quality and citation metrics.

On the other hand, journals like "Pediatric Allergy Immunology and Pulmonology" and "Frontiers in Pediatrics," with lower impact factors and citation counts, rank lower, suggesting that they may need to increase their research output or impact to elevate their standing in the field.

Table 5. *Top 13 journals by publication volume*

Journal	IF	Papers	Citations	average citation	Paper Rank	Citations Rank	Average Citation Rank	Sum Of Ranks	Overall Ranking
American Journal of Respiratory And Critical Care Medicine	19.3	17	2237	131.59	6	2	1	9	1
Chest	9.5	18	872	48.44	5	3	3	11	2
Pediatric Pulmonology	2.7	156	2738	17.55	1	1	9	11	3
Journal Of Pediatrics	3.9	20	790	39.50	4	5	5	14	4
Orphanet Journal Of Rare Diseases	3.9	21	733	34.90	3	6	6	15	5
European Respiratory Journal	16.6	16	821	51.31	10	4	2	16	6
Pediatric Radiology	2.1	27	450	16.67	2	9	10	21	7
Thorax	10	15	626	41.73	12	7	4	23	8
Pediatrics	6.2	16	453	28.31	11	8	7	26	9
Paediatric Respiratory Reviews	4.7	17	326	19.18	8	10	8	26	10
Pediatric Allergy Immunology And Pulmonology	1.1	17	283	16.65	9	11	11	31	11
Frontiers In Pediatrics	2.1	17	225	13.24	7	12	12	31	12

4 Discussion

A bibliometric analysis of publications related to childhood interstitial lung disease (chILD) over the past 40 years was conducted to evaluate the current state of research, progress made and identify new trends and hotspots.

4.1 Global Output on chILD

The Web of Science Core Collection has indexed articles related to chILD since 1904, totaling 1,159 publications over 120 years. Of these, 1,123 English-language documents were published in the last 40 years alone, showing an exponential increase in annual output. In the initial exploratory phase, publication numbers were relatively low, but there has been a steady rise since 2005. Notably, more than half of all articles published in the last 40 years appeared after 2015. Bibliometric analysis indicates a steady increase in publications related to pediatric interstitial lung diseases over the past four decades. This growth signifies increasing interest and recognition within the medical and research communities of the importance of chILD. The rising trend also underscores growing awareness of the importance of early detection, accurate diagnosis, and effective management of chILD.

4.2 Research Status, Trends, and Hotspots in chILD

We comprehensively evaluated the status, trends, and hotspots in chILD research through citation burst analysis of references, clustering analysis of keywords, and trend topic analysis. Our study summarizes three major clusters of research on chILD: (1) classification, diagnosis, and management of chILD; (2) genetic studies of chILD; and (3) primary diseases associated with chILD. Based on the trend topic analysis of keywords, we found that the clinical features and disease management of chILD, gene mutations related to chILD, and polymyositis accompanied with chILD may be recent research hotspots.

4.2.1 Classification, Diagnosis, and Management of chILD

Due to its rarity and wide clinical spectrum, significant research efforts have been devoted to the classification, diagnosis, and management of chILD. Accurate and rational disease classification guides optimal diagnostic, therapeutic, and preventive strategies. The classification of ILD is inherently complex, and chILD face additional challenges compared to adult ILD due to its unique clinical presentation, natural history, and prognosis.

In 2004, the European Respiratory Society introduced a chILD classification system (Clement, 2004), derived from adult classifications. In 2007, Deutsch et al. analyzed 187 lung biopsy cases and published a classification scheme for diffuse lung disease in children under two years old, primarily based on pathological findings (Deutsch et al., 2007). This classification system has been widely accepted, validated, and improved by many experts and teams in the chILD field (Griese et al., 2015, Griese et al., 2009, Bush et al., 2015, Langston and Dishop, 2009, Fan et al., 2015). It was subsequently incorporated into the American Thoracic Society's (ATS) official Clinical Practice Guidelines for Infants with chILD in 2013(1). In 2017, Matthias Griese reported the establishment of the International Management Platform for chILD (chILD-EU), which optimized and further refined the aforementioned classification system for case registry and management within the chILD-EU network (Griese et al., 2018). The chILD classification system has evolved over decades and continues to do so; however, it has yet to fully meet all clinical classification requirements. We anticipate that advancements in diagnostic technologies and establishing more chILD registries will significantly contribute to refining the classification system and advancing research in this field.

Accurate and rapid etiological diagnosis facilitates better management and personalized treatment. The complexity of chILD etiology poses significant challenges to etiological diagnosis. Both the ATS and the chILD-EU Working Group have proposed diagnostic approaches (Kurland et al., 2013, Bush et al., 2015). In 2013, the ATS released chILD Clinical Practice Guidelines recommending a detailed review of family history (which determines the necessity for early genetic testing) and exclusion of other common causes of diffuse lung disease. Subsequently, appropriate diagnostic tests (including controlled ventilation HRCT, genetic analysis, and lung biopsy) should be scheduled based on specific clinical factors (Kurland et al., 2013). In 2015, the chILD-EU collaboration group suggested initiating diagnosis with chest CT scans and then considering blood tests, bronchoscopy, and lung biopsy depending on the extent of bodily damage (Bush et al., 2015). A diagnostic algorithm for chILD has been established and optimized based on expert consensus. Griese et al. summarized the diagnostic algorithm for chILD, starting with assessing symptoms, signs, presence of hypoxia, and imaging abnormalities to determine suspicion of ILD. Typical entities are excluded. This is followed by identifying a precise entity through detailed history-taking and additional clinical investigations (such as serology, genetics, pulmonary function tests, bronchoscopy), leading to an accurate diagnosis and assignment to the correct disease category by a multidisciplinary panel (Griese, 2022). Nathan et al. proposed a systematic two-step approach to chILD (Nathan et al., 2023). The first step involves general pediatricians conducting a comprehensive clinical evaluation, family history, routine biological tests, and chest X-ray and echocardiography assessments. When chILD is suspected, patients are referred to specialist centers (second step) for detailed specialist evaluations (such as chest CT, bronchoscopy, and lung biopsy). With rapid developments in medical sciences, we expect the development and implementation of more effective and non-invasive diagnostic methods.

Consensus on the management and follow-up strategies for chILD has yet to be established, and treatment may vary depending on the experience of the treating institution. Generally, management strategies include supportive care (such as oxygen therapy, nutritional support, vaccination, and infection prevention), pharmacological interventions (mainly corticosteroids, hydroxychloroquine, immunosuppressants, and macrolides), lung transplantation, comprehensive home care, and genetic counseling (Kurland et al., 2013, Nathan et al., 2020, Nathan et al., 2018b). Our study suggests that the management of chILD has become a research hotspot in recent years. Teams in various countries have made efforts to improve disease management. In 2016, the Children's Interstitial Lung Disease Respiratory Network of Australia and New Zealand (chILDRANZ) established multidisciplinary team meetings (MDTm) (McKnight et al., 2024). In 2018, the French respiratory network initiated the chILD-specific MDTm (Cassibba et al., 2024). These developments provide more opportunities for etiological diagnosis and management of chILD.

Over the past few decades, establishing specialized disease registries and national/international databases has significantly enhanced the identification and understanding of chILD (Nathan et al., 2012, Nevel et al., 2024, Griese et al., 2018, Nayır-Büyükşahin et al., 2024). These clinical registries or databases collect detailed clinical information, considerably enhancing understanding of pediatric ILD and providing valuable insights into the natural history, molecular mechanisms, and disease diagnostic and management strategies.

4.2.2 Genetic Research in chILD

Recent studies increasingly indicate that genetic factors play a critical role in the etiology of ILD (Nathan et al., 2018b). Our study shows that chILD genetic research has become a focus over the past decade. Currently, the most prominent genetic variants associated with chILD involve mutations related to surfactant dysfunction (Nathan et al., 2018b, Nogee, 2006). Specifically, mutations in the *SFTPB* and *SFTPC* genes, encoding surfactant proteins B and C, the surfactant transporter *ABCA3* (ATP-binding cassette sub-family A member 3), and the transcription factor *NKX2-1* are most reported (Kröner et al., 2017, Gupta and Zheng, 2017, Nogee et al., 1994, Devriendt et al., 1998). Mutations in the *SFTPA1* and *SFTPA2* genes, encoding surfactant proteins A, and *FLNA* (filamin A) are mainly seen in

adults but can also occur in children (Legendre et al., 2020, Shelmerdine et al., 2017).Moreover, gene mutations causing alveolar proteinosis and certain autoinflammatory/autoimmune diseases can also be genetic causes of chILD (Nathan et al., 2018b). For instance, the former could include mutations in the genes encoding methionyl-tRNA synthetase (*MARS*) and the α and β chains of the granulocyte-macrophage colony-stimulating factor (GM-CSF) receptor (*CSF2RA* and *CSF2RB*) (Hildebrandt et al., 2014). The latter, for example, includes the *TMEM173* gene associated with SAVI syndrome, and the *COPA* gene associated with COPA syndrome (Tarantino et al., 2016, Melki et al., 2017, Picard et al., 2016, Vece et al., 2016).

In this cluster, recent research hotspots have focused more on interstitial lung diseases associated with mutations in the ATP-binding cassette sub-family A member 3 (*ABCA3*) gene (Li et al., 2023, Yang et al., 2023b, Yang et al., 2023a). *ABCA3* is a lipid transporter anchored in the outer membrane of lamellar bodies in alveolar type 2 cells. Multiple studies have shown that mutations in the *ABCA3* gene can cause lethal surfactant deficiency in newborns (Li et al., 2023, Yang et al., 2023a, Bullard et al., 2005, Doan et al., 2008). However, as research deepens, more researchers find that *ABCA3* mutations can present as chronic ILD in young children and survive into adulthood. Undeniably, *ABCA3* mutations are a genetic cause of chILD related to surfactant dysfunction. Simultaneously, *ABCA3* gene mutations exhibit strong genotype-phenotype correlations in chILD, with the age of onset and disease prognosis linked to the type of *ABCA3* mutation (Doan et al., 2008, Wambach et al., 2014, Kröner et al., 2017, Yang et al., 2023b, Hallik et al., 2014). Bi-allelic frameshift or nonsense variants in *ABCA3* are predictive of neonatal presentation and poor outcome, whereas the presentation and outcome for infants and children with other genotypes (missense, splice site, and in-frame mutations) were more variable and less predictable. Professor Matthias Griese's team attempted to quantify *ABCA3* function by assessing in vitro impairment of its intracellular trafficking and pumping activity, improving the phenotype prediction of genetic variants, thus providing more ideas and possibilities for future research.

Given the widespread view that many known gene mutations related to ILD can be identified in various forms of chILD, timely genetic testing of children with ILD is necessary. With advances in genetic testing technology, our understanding of the genetics of chILD will continue to deepen, contributing to a better understanding of underlying pathogenic mechanisms and paving the way for future personalized treatment strategies.

4.2.3 Primary diseases associated with childhood interstitial lung disease

This research cluster spans a considerable period, with early years seeing numerous studies on chILD associated with HIV/AIDS. However, interest in this area has diminished over the past decade. As research progressed, recent years have seen a focus on chILD associated with connective tissue disease (CTD) and ILD linked to inborn errors of immunity (IEI).

The lungs are common target organs for complications arising from connective tissue diseases. Interstitial lung disease is one of the most frequent and severe complications in children with CTD, which can result from progression of the primary disease, concurrent infections, or because of medication (Ramamurthy et al., 2015). While all types of CTD carry a risk for ILD, the prevalence varies depending on the specific type of CTD. For instance, studies indicate that over 50% of patients with systemic sclerosis (SSc) in North America suffer from SSc-associated ILD (SSc-ILD) (Bergamasco et al., 2019). A study involving 153 adolescents with SSc demonstrated that respiratory involvement in pediatric SSc cases is far less common than in adults (Martini et al., 2006). However, Cespedes-Cruz and colleagues reported a series of cases involving 15 children with SSc, where more than half (11 cases) had ILD (Céspedes-Cruz et al., 2021). Other types of CTD, such as polymyositis (PM), dermatomyositis (DM), systemic lupus erythematosus (SLE), juvenile idiopathic arthritis (JIA) and mixed connective tissue disease (MCTD), also carry a risk for ILD, often indicating a poor prognosis when ILD is present (Ramphul et al., 2020). Our study indicates a notable increase in research on polymyositis accompanied by chILD in recent years, suggesting that this area may become a research hotspot in the coming period. Early screening for pulmonary involvement in CTD is critical for managing disease progression. Research into CTD-ILD in children remains in its infancy, and there is currently a lack of consensus regarding diagnostic and treatment approaches. We anticipate greater efforts from researchers dedicated to CTD-ILD.

Our findings indicate that interest and significance in IEI-related ILD have increased in recent years. IEI refers to genetic defects that impair the development and function of immune cells, encompassing a wide range of conditions from immunodeficiencies to immune dysregulation (Gutierrez et al., 2022, Tangye et al., 2020). As of 2022, the International Union of Immunological Societies categorization lists approximately 430 different IEI diseases (Tangye et al., 2020). Common variable immunodeficiency disorders (CVIDs) represent a heterogeneous group of diseases collectively constituting the most common form of primary immunodeficiency (Chapel and Cunningham-Rundles, 2009, Cooper et al., 2003). Interstitial lung disease is a common non-infectious pulmonary complication in CVID patients. Multiple studies show that granulomatous-lymphocytic interstitial lung disease (GLILD) shortens the lifespan of CVID patients (Bates et al., 2004, Pérez, 2012, Gao et al., 2022). Xianfei Gao et al. reviewed 217 cases of immunodeficient children and found that 40% had ILD, with known ILD-related monogenic diseases identified through genetic testing in 76% of patients. With advancements in molecular diagnostics, an increasing number of genetic mutations associated with primary immunodeficiency phenotypes linked to ILD are better described.

4.3 Regional Differences and Collaborative Efforts

Among the top 10 countries ranked by publication volume, European and North American nations, particularly the United States, Germany, and the United

Kingdom, dominate. Most studies are independently conducted by researchers within their own countries, with scholars from North America and Europe collaborating more frequently than their Asian counterparts. Notably, the U.S. is the most diverse country in terms of collaboration within this field. While the U.S. and European countries continue to lead in chILD research output, there is evidence that contributions from the Asia region are emerging. However, significant regional disparities remain, highlighting the need for strengthened international cooperation to address research gaps and ensure equitable access to resources and expertise. Collaborative efforts between researchers from different regions and institutions can facilitate knowledge sharing, enhance research capabilities, and accelerate progress in understanding and managing chILD. Many leading institutions actively seek connections with peers and share knowledge and experience. Moreover, compared to other countries, U.S. institutions tend to form tighter collaborative networks.

4.4. Limitations

This study has several limitations that should be acknowledged. Firstly, there is a potential publication bias because non-English articles were excluded. Additionally, the quality of individual studies was not assessed, and citation counts do not necessarily reflect the quality or impact of the research. Moreover, more than bibliometric data is needed to provide a comprehensive understanding of research impact, as it does not account for qualitative factors such as clinical significance or patient outcomes. Furthermore, this study used the Web of Science Core Collection (WoSCC) as the data source. While WoSCC is a widely recognized and frequently used database, it may only capture some relevant publications, particularly those indexed in other databases such as Scopus, PubMed, or EMBASE. Therefore, relying on a single database could lead to the omission of specific studies, thereby affecting the comprehensiveness and representativeness of the analysis.

Despite these limitations, the bibliometric analysis provides a comprehensive overview of the research landscape in childhood interstitial lung disease (chILD). Future studies might consider integrating multiple databases for more comprehensive data coverage. Additionally, future research should explore innovative methodologies, such as text mining or machine learning algorithms, to overcome these limitations and provide a more nuanced understanding of the chILD research landscape.

5 Conclusion

In summary, the bibliometric analysis of publications on childhood interstitial lung disease (chILD) indicates a growing interest in this field of research and significant advancements. This study has highlighted the countries, institutions, and standard subtopics that contribute most to the research output in this area. The findings from this analysis provide valuable insights for researchers, clinicians, and policymakers to understand the current research in pediatric ILD, identify knowledge gaps, and identify potential areas for future research. It may assist researchers in identifying potential collaborators, institutions, and countries actively engaged in research within this field. The outcomes can also be utilized to develop evidence-based strategies to improve the diagnosis, management, and treatment of pediatric ILD. In conclusion, this study represents the first bibliometric analysis of chILD-related publications. Our study explores the status quo of chILD over nearly four decades and identifies frontiers and hotspots in the field. Future research may focus on the clinical features and disease management of chILD, gene mutations related to chILD, and polymyositis accompanied with chILD.

Author Contributions

Lu Chen: Responsible for literature search, data collection, study design, analysis of data, and manuscript preparation.

Lingxiao Wang: Responsible for literature search, data collection, and analysis of data.

Xiaobo Zhang: Responsible for study design, analysis of data, manuscript preparation, and review of manuscript.

Institutional Affiliation: The study was performed at Children's Hospital of Fudan University, Shanghai, China

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