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Global research trends and focus of Lung Ultrasound: A Bibliometric Analysis

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Abstract:	Object: The purpose of this study was to summarize the knowledge structure of pulmonary ultrasound through bibliometric analysis, and to discuss potential research trends and priorities. Methods: Publications related to pulmonary ultrasound were selected from the Science Core Collection website before March 2, 2023. Use VOSviewer(version 1.6.18), CiteSpace(version 6.1.3), and Rstudio's free online platforms (http://bibliometric.com) for co-write, co-cite, and co-occurrence analysis of countries, institutions, authors, references, and keywords in the field. And the visual analysis is carried out. Results: A total of 1057 papers were included. Since 2013, research papers based on lung ultrasound have increased. In terms of published articles, Italy has contributed the most in this area. The institutions and authors we think have been most productive are the University of Milan and Luna Gargani. The top three journals with the most published articles are the 《JOURNAL OF ULTRASOUND IN MEDICINE》, 《DIAGNOSTICS》 and 《PEDIATRIC PULMONOLOGY》. According to the results of literature and keyword analysis, "covid-19", "SARS-CoV-2", "PoCUS", "deep learning" and "lung ultrasound score" have been identified as the main research directions in the future. Conclusion: Pulmonary ultrasound is in the stage of vigorous development and has a broad prospect. The development of pulmonary ultrasound will be the focus of future research.

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【Abstract】

Object: The purpose of this study was to summarize the knowledge structure of pulmonary ultrasound through bibliometric analysis, and to discuss potential research trends and priorities. Methods: Publications related to pulmonary ultrasound were selected from the Science Core Collection website before March 2, 2023. Use VOSviewer(version 1.6.18), CiteSpace(version 6.1.3), and Rstudio's free online platforms (http://bibliometric.com) for co-write, co-cite, and co-occurrence analysis of countries, institutions, authors, references, and keywords in the field. And the visual analysis is carried out. Results: A total of 1057 papers were included. Since 2013, research papers based on lung ultrasound have increased. In terms of published articles, Italy has contributed the most in this area. The institutions and authors we think have been most productive are the University of Milan and Luna Gargani. The top three journals with the most published articles are the 《JOURNAL OF ULTRASOUND IN MEDICINE》, 《DIAGNOSTICS》 and 《PEDIATRIC PULMONOLOGY》. According to the results of literature and keyword analysis, "covid-19", "SARS-CoV-2", "PoCUS", "deep learning" and "lung ultrasound score" have been identified as the main research directions in the future. Conclusion: Pulmonary ultrasound is in the stage of vigorous development and has a broad prospect. The development of pulmonary ultrasound will be the focus of future research.

【Keywords】 Lung; Ultrasound; Bibliometric

Background

The application of ultrasound technology in clinical diagnosis began in the 1940s. Until the 1990s, lung ultrasound had been first proposed with pioneering applications in the critically ill in a range of clinical conditions[1]. Whether it was the early A-mode ultrasound or the later widely used B-mode ultrasound, the application of lung ultrasound was mainly to observe the presence of pleural effusion, whether the pleural effusion was encapsulated or not, and to adjunctive ultrasound-guided puncture[2, 3]. With the continuous development of ultrasound technology, the application of lung ultrasound has gradually expanded to many aspects, including atelectasis, pneumothorax, pneumonia, and pleural and peripheral lung lesions [4-7]. Due to various underlying architectures, the two separate and unique artifacts known as A-lines and B-lines may be visible during an ultrasound examination of the nonconsolidated lungs. A-lines are hyperechoic lines that resemble the pleural line on the ultrasound screen and run about horizontally across the image. They represent the normal pattern of the lung. B-lines are described as hyperechoic artifacts that move synchronously with lung respiration and originate at the pleura line and lay nearly perpendicular to the latter. They frequently have a narrow base and take the shape of a ray that expands from the transducer and moves toward the bottom of the screen. [3].Some researchers have discussed the meaning of A- and B-Lines in the diagnostic ultrasound imaging of the lung[8-10].

The development of lung ultrasound is significantly behind that of high-resolution imaging

methods like X-ray and CT. CT has been considered the "gold standard" for identifying many pulmonary illnesses because to its superior sensitivity. Yet, lung ultrasonography has the advantages of being bedside, instantaneous, having no transit danger, being less expensive, and being able to be repeated frequently. Lung ultrasonography is a common tool for the upcoming generation of internists and is known as the visual stethoscope for internists abroad[11].

Throughout the past several decades, the volume of research publications on LUS has expanded, and bibliometric analysis, as a technique that can statistically and qualitatively assess and visualize all the papers published in a certain study subject, has been widely employed in the medical sciences[12-14]. Based on the above, a bibliometric analysis was carried out to investigate the trends, frontiers, and hot spots in global scientific output in LUS research over the last decade. We retrieved the Science Citation Index Expanded (SCI-Expanded) of the Web of Science Core Collection (WoSCC) for publications and recorded information published from 2013 to 2024. The bibliometric analysis and visualization analysis of the overall distribution of annual outputs, leading countries, active institutions, journals, authors, references, and keywords were carried out with the VOSviewer and CiteSpace.

Materials and methods

The Science Citation Index Expanded of Clarivate Analytics'S Web of Science Core Collection (WoSCC), one of the largest and most significant databases in interdisciplinary domains, comprises a significant amount of scholarly literature and journals and is commonly used as the data source for bibliometric studies. To avoid offsets due to rapid data updates, the literature search was conducted in one day (01 September 2024).

The following were the search terms: (TS=("lung ultrasound") OR TS=("lung sonography") OR TS=("lung ultrasonography")OR TS=("pulmonary ultrasound") OR TS=("pulmonary sonography") OR TS=("pulmonary ultrasonography")).Only articles and reviews written in the English language were taken into account among the many kinds of publications. Overall, 1767 publications spanning 2013 to 2024 were identified.

Open the data for all identified articles in Excel, including authors, affiliations, countries/regions, journals, the number of papers and citations, publication year, keywords, and references. In this study, bibliometric analysis and visualization were performed using VOSviewer (version 1.6.18), CiteSpace (version 6.1.3) and RStudio's free online platforms (http://bibliometric.com).

Bibliometric Analysis

The bibliometric analysis was carried out using VOSviewer (version 1.6.10), CiteSpace (version 5.8.R3), and the web tool (https://www.bibliometrix.org). As a widely used bibliometric analysis program, VOSviewer offers three different types of visualization maps: network visualization, overlay visualization, and density visualization[15]. VOSviewer was primarily used in this research's cocitation and co-occurrence analyses. The thickness of the line indicated the intensity of the association, the size of the nodes indicated the number of papers published, and the colors of the nodes indicated different clusters or periods. Another citation visualization and analysis tool created by Chen et al. is Citespace, which places more emphasis on the links across knowledge disciplines than VOSviewer does[16]. It can visually perceive the research frontiers and hotspots in various domains by detecting and monitoring the growth and changes of

knowledge, and then anticipate the future development possibilities and prospective research orientations of these fields. The co-citation analysis of authors and references, the dual-map overlay of journals, and the citation burst of keywords or references were all accomplished in our study using Citespace.

Results

Publication year

According to WoSCC database search results, 1767 articles and reviews related to LUS were published between 2013 and 2024 (Irrelevant publications were manually excluded). The number of publications generally increased each year and exploded in the last three years due to the outbreak of Covid-19, peaking in 2021 with 270 publications (Figure 1(A)). It indicates that LUS research field gained attention gradually.

Leading countries/regions and institutions

A world map was drawn to intuitively understand the total number of publications from 75 countries/regions worldwide (Figure 1(B)). North America, East Asia, and Western Europe reached remarkable achievements. Italy ranked first in terms of the number of publications, followed by China and the United States（Table 1）. The ranking of countries/regions in terms of the number of publications cited changed, with Italy still in the first place, followed closely by the United States and France (Figure 1(C)). It indicates that Italy is a global leader in this field, and publications from the United States and France have higher academic quality. Furthermore, intensive cooperation was observed among these countries (Figure 2(A)).

Among the top 10 research institutions globally, seven were from Italy, the other three are from France, Spain, and the United States（Table 2）. The University of Milan was the world's most productive research institute regarding LUS research . The top 10 institutions published 35.8% of the papers.

Analysis of most active journals

According to data analysis, 317 journals published in LUS field. The top ten journals in terms of the number of publications are detailed in Table 3. From the results, the JOURNAL OF ULTRASOUND IN MEDICINE had the highest number of publications, with total citations of 1011 times, followed by DIAGNOSTICS and PEDIATRIC PULMONOLOGY. Although CHEST ranked 6th, its total citations were 2040 times, which was higher than that of any other journal. Also, CHEST (IF = 10.262) had the highest impact factor (IF). All these show that Chest is a high-quality journal, at the forefront of the LUS field. According to the Journal Citation Report (JCR), all the top 10 journals except JOURNAL OF CLINICAL ULTRASOUND were located in Q1/Q2, indicating the high quality of the article. Furthermore, We used VOSviewer to generate a journal network map for a clearer presentation (Figure 2(B)).

Most productive authors and co-cited authors

A total of 5817 authors participated in the publication of papers in the field of LUS. In the analysis of most productive authors, Luna Gargani contributed the most papers with 36 papers, followed by Jing Liu and Danilo Buonsenso with 33 and 30 papers respectively（Table 4）. When it comes to most co-cited authors, Luna Gargan is ranked 1st, followed by Giovanni Volpicelli and Jing Liu. Moreover, Figure 2(C) generated by VOSviewer showed more visually the leading scholars in the field.

Analysis of references and co-cited references

A total of 1767 papers were included in this study. The most cited article was published by Gino Soldati in 2020, with a total of 330 times, followed by two articles both published by Daniel A Lichtenstein (2015, 2014), with 302 and 275 times respectively（Table 5）. A network visualization map of co-cited references analysis generated by VOSviewer is shown in Figure 3(A). As shown, articles published by Giovanni Volpicelli and Daniel A Lichtenstein were the two most co-cited references, with a total of 513, and 420 citations respectively. Top 25 references with the strongest Citation bursts were summarized in Figure 3(B). The first burst in this study began in 2013, and the latest reference citation burst was detected in 2020 and last until now due to the outbreak of Covid-19. At present, most of the important references are still frequently cited, and it can be speculated that the study of LUS will remain a hot research topic in the coming years.

Keywords co-occurrence analysis

Keywords can reflect the current research hotspots in the field. A Network visualization map of keywords generated by VOSviewer was shown in Figure 4(A). The clusters are labeled using different colors according to publication time. Dots represent keywords and larger dots indicate hotter research trends. It was noticeable that “lung ultrasound” was in the central position of the visualization map, which was consistent with our study topic. Moreover, “covid-19”, “SARS-CoV-2”, “PoCUS”, “deep learning”, “lung ultrasound score” et al, are hot research topics in recent years.

The top 25 keywords with the strongest citation bursts were listed in Figure 4(B). The following were the initial research directions: “sign”, “alveolar interstitial syndrome, “ultrasound sign”, “natriuretic peptide”, “comet tail artifact”, “chest sonography”, “alveolar consolidation”, and “comet” (all began in 2013). However, in recent years, the research hotspots have transformed into the following directions: “intensive care unit” (began in 2016), “protocol” (began in 2017), “prognostic value” (began in 2017), “chest ultrasound” (began in 2017), “society” (began in 2018), “of care ultrasonography” (began in 2018), “consolidation” (began in 2018), “thoracic ultrasound” (began in 2018), suggesting that these research topics had received extensive attention in recent years.

Discussion

This study aimed to undertake a bibliometric analysis of trends and foci of LUS utilizing the SCI extended of the WoSCC database, VOSviewer, and Citespace. We retrieved 1767 articles and reviews published from 2013 to 2024. Although the number of papers published has a minor fluctuation during the decade, there has been an overall trend toward more articles being published, according to the polynomial fit curve. It also suggests that the research of LUS has a good research prospect.

Although publications are dispersed worldwide, production varies widely. Italy is the nation with the most publications, followed by China and the USA. Also, Italy ranked 1 in terms of citations among the top ten countries, followed by the US and France. It indicates that they are global leaders in this field. Comparatively, in China, Turkey, and Australia, there is a disparity in the amount and quality of publications. Among the top 10 research institutions globally, seven were from Italy. And the University of Milan was the world’s most productive research institute regarding LUS research. Thus it can be seen that Italy has the most exceptional institutions and specialist scholars in this field.

Scholars can discover an abundance of trustworthy reference data from the identification of

journal cocitation analysis, which helps them choose the best target journals for literature searches or study submissions. According to the analysis of most active journals, nine of the top ten most productive journals were in Q1/Q2, indicating that the academic research in the field of LUS is worthy of recognition. Regarding the number of publications, the JOURNAL OF ULTRASOUND IN MEDICINE, DIAGNOSTICS, and PEDIATRIC PULMONOLOGY made significant contributions, suggesting that scholars in this field should pay more attention to the research findings published in these journals to obtain the latest research progress.

Notably, regarding the number of citations, CHEST ranks 1st, although it does not have many publications. Also, CHEST had the highest impact factor (IF = 10.262). All of these demonstrate that CHEST is a high-quality journal, at the forefront of the LUS field. Scholars seeking a challenge should target journals for CHEST.

In the analysis of authors, Luna Gargani is ranked 1st in both the number of articles and citations, demonstrating his academic leadership[17-20]. It is also worth noting that although Giovanni Volpicelli is only 6th in the number of publications, his citations rank 2nd, showing he has a very high level of scholarship[21-24]. Meanwhile, we found that Daniele De Luca and Gino Soldati were also key in bridging several clusters, which would account for their high citation rates. Therefore, we believe that strengthening cooperation with the above authors can assist scholars in publishing high-quality articles in the field of LUS.

Analysis of references and co-cited references are crucial in bibliometric studies, which identify noteworthy literature, and forecast its future directions. High-quality research with substantial innovation and an important influence in a particular field typically constitutes highly cited publications. The top 10 cited papers, all of which have significant influence in this field. The paper of Gino Soldati “Proposal for International Standardization of the Use of Lung Ultrasound for Patients With COVID-19: A Simple, Quantitative, Reproducible Method” published in 2020 had been cited 330 times, which was the most cited article in this field, indicating that other scholars highly acknowledged his work. The paper share experience and propose a standardization with respect to the use of LUS in the management of COVID-19 patients[25]. Also, it emphasized the need for a shared database, necessary to foster further developments and to disseminate the results achieved. Meanwhile, we found that articles published by Giovanni Volpicelli and Daniel A Lichtenstein were the two most co-cited references, indicating their articles are of high academic value in the field. And it is beneficial for clinical and scientific researchers as well as patients to gain a better understanding of LUS.

Burst detection is an algorithm created to capture the sharp increase in references or keywords popularity over a period and it can be used as a very efficient way of identifying hotspots or topics. As shown, the first burst in this study began in 2013, caused by multiple research， most of which are studies of point-of-care lung ultrasound[26-28]. And the latest reference citation burst was detected in 2020 and last until now due to the outbreak of Covid-19[29]. Currently, significant references are still regularly cited, which means that the study of LUS is still likely to remain a hot research topic in the coming years.

Keywords co-occurrence analysis is one of the frequently used methods in bibliometrics to recognize the trending topic, which can reflect the changing process of research topics in the whole field and better grasp the research hotspots. And the purpose of co-occurrence is to evaluate the link between the items that have been recorded. As shown, “lung ultrasound” “covid-19” and “pneumonia” were the most frequently occurring keywords. Moreover, “covid-19”, “SARS-CoV-

2", "PoCUS", "deep learning", "lung ultrasound score" et al, are hot research topics in recent years. The application of LUS has become the current hot spot in the field and is expected to stay hot in the future. Also, scholars interested in the field who wish to publish papers are encouraged to conduct applied research on LUS.

Keywords burst detection showed that the latest burst began in 2018, including the following keywords: "society", "of care ultrasonography", "consolidation", and "thoracic ultrasound", suggesting that these research topics had received extensive attention in recent years. Currently, "pneumonia" and "Cocid-19" appeared frequently in articles published in recent years and are expected to cause the next burst.

Our research in the form of bibliometric analysis offered more quantitative focus, trends, and collaboration on research findings compared to traditional reviews, providing a more thorough insight into the evolving field of LUS. Compared to traditional reviews, our bibliometric analysis provided a more quantitative emphasis, trends, and collaboration on research findings, giving a more detailed insight into the developing area of LUS. Still, this study does come with a few limitations. Firstly, the data from SCI-expanded were only included for articles and reviews in English, which may lead to publication bias. Secondly, the data were only included in the past decade, which may also cause publication bias. It could cause the fact that some potentially influential papers published earlier could not be included due to the short duration. Thirdly, because VOSviewer and Citespace cannot analyze the complete text of the publication, certain information may be ignored.

This study provides a new insight and perspective on the trends of LUS research. It revealed the current trend of global LUS research in the past and current state. A growing interest in LUS is observed globally and an increasing trend of scientific production in this field in the next few years will enlighten this point.

New insight and perspective on the trends of LUS research is available from this study. It revealed the current trend of global LUS research in the past and current state. There is a growing global interest in LUS and the increasing trend of scientific production in this field in the coming years is worth looking forward to.

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FIGURE 1(A). Publications of publications in LUS research from 2013 to 2022. The red curve represents the annual publication number and the green curve represents the expected number of publications

FIGURE 1(B). Global geographical distribution of LUS publications

FIGURE 1(C). Top 10 countries in terms of the number of publications cited in LUS research

FIGURE 2(A). The international collaboration relationship networks

FIGURE 2(B). A Network visualization map of Journal analysis generated by VOSviewer

FIGURE 2(C). A Network visualization map of co-cited authors generated by VOSviewer

FIGURE 3(A). A Network visualization map of co-cited reference generated by VOSviewer

FIGURE 3(B). Top 25 References with the strongest citation bursts

FIGURE 4(A). A Network visualization map of keywords generated by VOSviewer

FIGURE 4(B). Top 25 Keywords with the strongest citation bursts

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Global research trends and focus of Lung Ultrasound: A Bibliometric Analysis

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Ethical Approval

Institutional Review Board approval was not required because the subjects were not humans.

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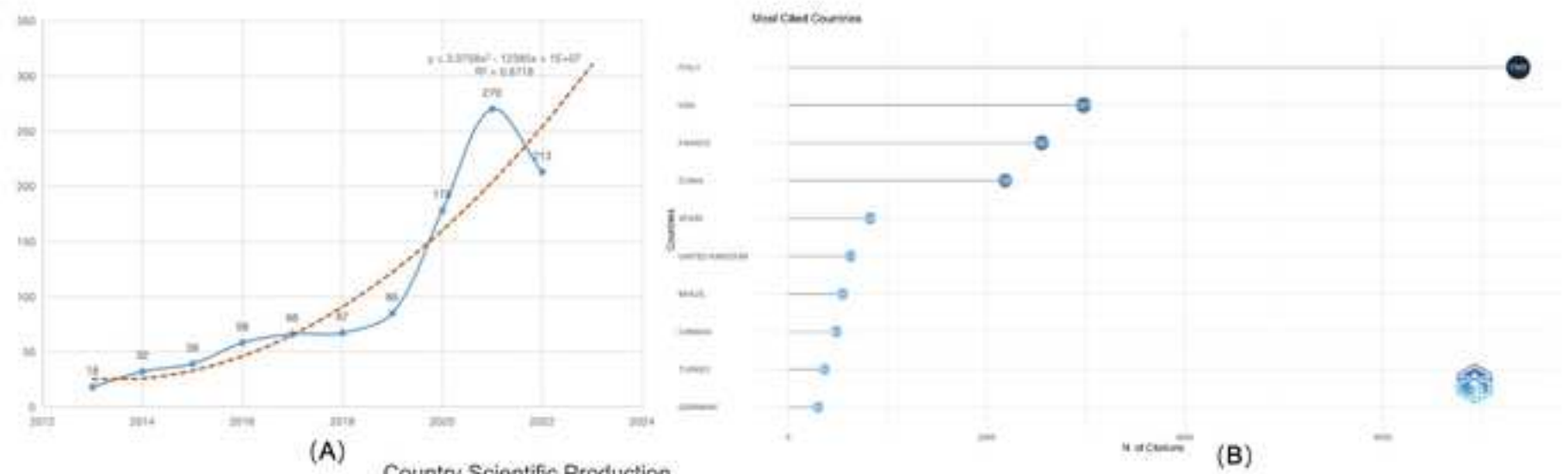

figure2

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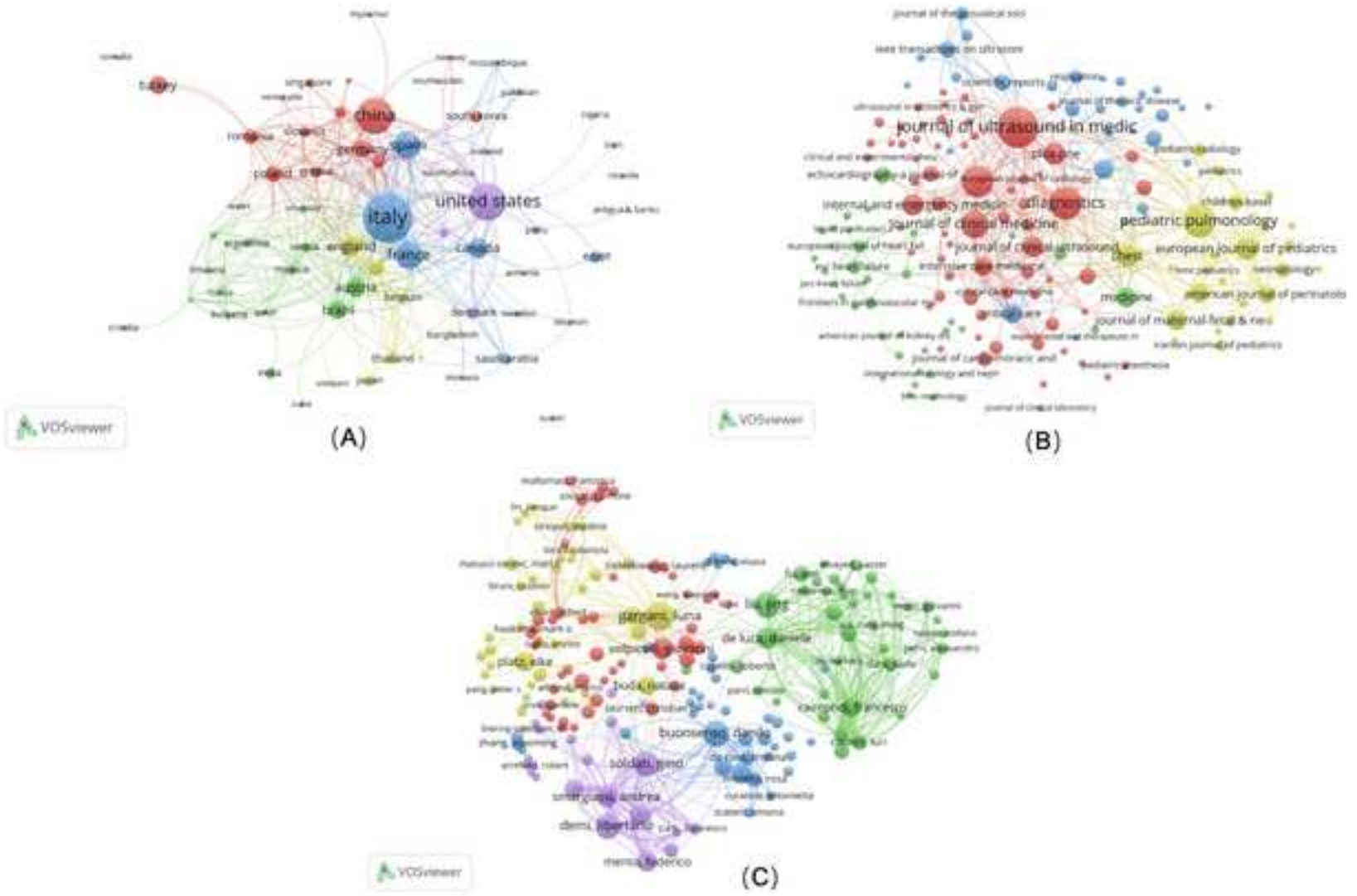

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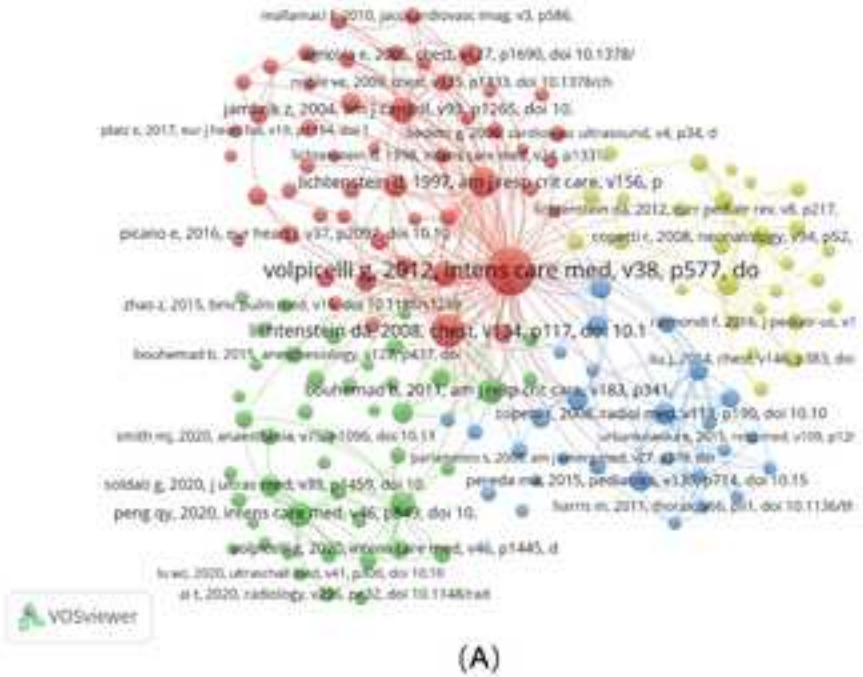
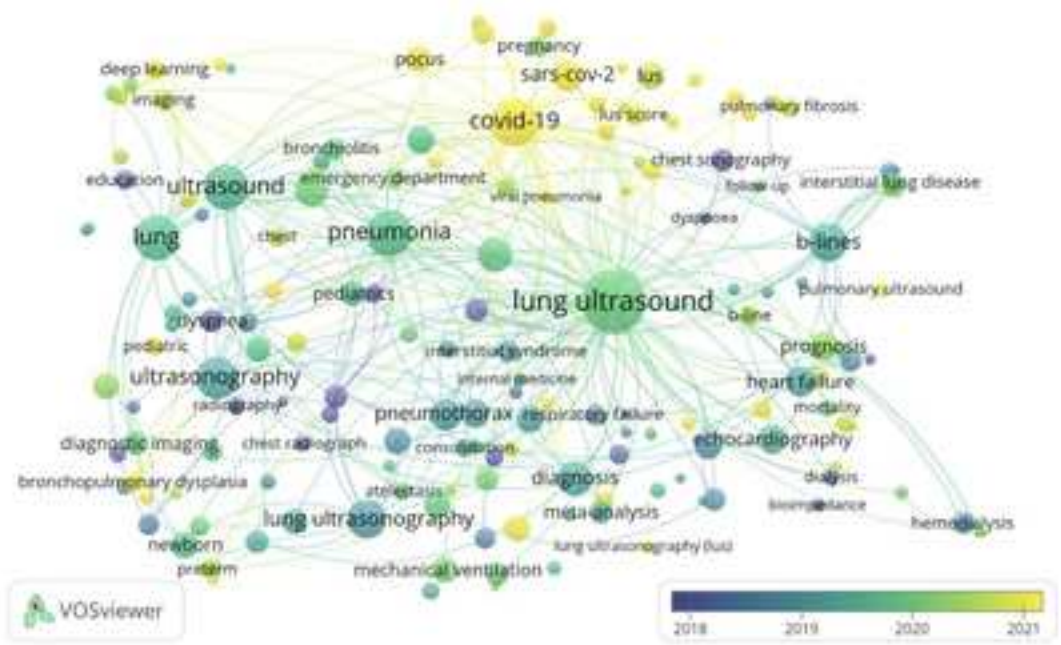


(A)

(B)



(A)

Top 25 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2013 - 2022
sign	2013	7.17	2013	2015	
alveolar interstitial syndrome	2013	6.3	2013	2017	
ultrasound sign	2013	6.12	2013	2016	
natriuretic peptide	2013	5.62	2013	2018	
comet tail artifact	2013	5.56	2013	2018	
chest sonography	2013	5.15	2013	2015	
chest radiography	2013	4.83	2013	2016	
alveolar consolidation	2013	3.94	2013	2016	
comet	2013	3.85	2013	2017	
follow up	2014	4.28	2014	2015	
respiratory distress syndrome	2013	3.01	2014	2016	
end expiratory pressure	2014	2.91	2014	2015	
pulmonary embolism	2014	2.7	2014	2017	
chest ultrasonography	2014	2.66	2014	2015	
predict	2015	3.06	2015	2016	
brain natriuretic peptide	2015	2.54	2015	2017	
radiography	2015	2.48	2015	2017	
intensive care unit	2016	2.69	2016	2018	
protocol	2017	4.19	2017	2019	
prognostic value	2017	3.31	2017	2019	
chest ultrasound	2013	2.44	2017	2018	
society	2018	3.46	2018	2020	
of care ultrasonography	2018	3.46	2018	2020	
consolidation	2016	3.06	2018	2019	
thoracic ultrasound	2014	2.76	2018	2020	

(B)

Table 1 Top 10 productive countries in LUS research

Rank	Country	Publications	Proportion of publications	Citations	Citations per publication
1	Italy	251	23.7%	7365	29.3
2	China	161	15.2%	2189	13.6
3	USA	129	12.2%	2979	23.1
4	Spain	65	6.1%	826	12.7
5	France	60	5.7%	2557	42.6
6	Turkey	38	3.6%	368	9.7
7	Brazil	30	2.8%	550	18.3
8	Canada	28	2.6%	486	17.4
9	Germany	26	2.5%	303	11.7
10	Australia	24	2.3%	236	9.8

Table 2 Top 10 productive institutions in LUS research

Rank	institutions	Publications	Proportion of publications	Country
1	UNIV MILAN	46	4.4%	Italy
2	UNIV CATTOLICA SACRO CUORE	43	4.1%	Italy
2	UNIV PAVIA	43	4.1%	Italy
4	AIX MARSEILLE UNIV	42	4.0%	Franc
4	UNIV BARCELONA	42	4.0%	Spain
6	INST CLIN PHYSIOL	39	3.7%	Italy
7	UNIV PISA	33	3.1%	Italy
7	UNIV TURIN	33	3.1%	Italy
9	FDN POLICLIN UNIV A GEMELLI IRCCS	29	2.7%	Italy
10	HARVARD MED SCH	28	2.6%	the US

Table 3 Top 10 productive journals in LUS research

Rank	Journal	Publications	IF	Total citations	JCR
1	JOURNAL OF ULTRASOUND IN MEDICINE	59	2.754	1011	Q2
2	DIAGNOSTICS	37	3.992	136	Q2
2	PEDIATRIC PULMONOLOGY	37	4.090	457	Q1
4	ULTRASOUND IN MEDICINE AND BIOLOGY	35	3.694	564	Q1
5	JOURNAL OF CLINICAL MEDICINE	27	4.964	75	Q2
6	CHEST	18	10.262	2040	Q1
6	EUROPEAN JOURNAL OF PEDIATRICS	18	3.860	257	Q1
8	PLOS ONE	17	3.752	280	Q2
9	INTERNAL AND EMERGENCY MEDICINE	16	5.472	216	Q2
10	JOURNAL OF CLINICAL ULTRASOUND	15	0.869	90	Q4

Table 4 The 10 most productive authors and top 10 co-cited authors in LUS research.

Rank	Author	Publications	Rank	Co-cited author	citations
1	Luna Gargani	36	1	Luna Gargani	612
2	Jing Liu	33	2	Giovanni Volpicelli	516
3	Danilo Buonsenso	30	3	Jing Liu	484
4	Libertario Demi	27	4	Libertario Demi	467
5	Gino Soldati	25	5	Daniele De Luca	420
6	Giovanni Volpicelli	22	6	Gino Soldati	419
7	Daniele De Luca	20	7	Danilo Buonsenso	413
7	Riccardo Inchingolo	20	8	Eugenio Picano	395
7	Andrea Smargiassi	20	9	Riccardo Inchingolo	377
10	Eugenio Picano	18	9	Andrea Smargiassi	377

Table 5 Top 10 original articles in LUS research.

Rank	Title	Journals	First author	Year	Citations
1	Proposal for International Standardization of the Use of Lung Ultrasound for Patients With COVID-19: A Simple, Quantitative, Reproducible Method	Journal of Ultrasound in Medicine	Gino Soldati	2020	330
2	BLUE-protocol and FALLS-protocol: two applications of lung ultrasound in the critically ill	Chest	Daniel A Lichtenstein	2015	302
3	Lung ultrasound in the critically ill	Annals of Intensive Care	Daniel A Lichtenstein	2014	275
4	Lung ultrasound for the diagnosis of pneumonia in children: a meta-analysis	Pediatrics	Maria A Pereda	2015	256
5	Lung Ultrasound-Implemented Diagnosis of Acute Decompensated Heart Failure in the ED: A SIMEU Multicenter Study	Chest	Emanuele Pivetta	2015	228
6	Lung ultrasound for the diagnosis of pneumonia in adults: a systematic review and meta-analysis	Respiratory Research	Miguel A Chavez,	2014	228
7	Deep Learning for Classification and Localization of COVID-19 Markers in Point-of-Care Lung Ultrasound	IEEE Transactions on Medical Imaging	Subhankar Roy	2020	219
8	Lung Ultrasound for Critically Ill Patients	American Journal of Respiratory And Critical Care Medicine	Francesco Mojoli	2019	195
9	Point-of-care lung ultrasound in patients with COVID-19 - a narrative review	Anaesthesia	M J Smith	2020	190
10	How I do it: lung ultrasound	Cardiovascular Ultrasound	Luna Gargani	2014	183