Infection and Drug Resistance

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ORIGINAL RESEARCH

Trends and Development in the Antibiotic-Resistance of *Acinetobacter baumannii*: A Scientometric Research Study (1991–2019)

This article was published in the following Dove Press journal:
Infection and Drug Resistance

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Objective: Data visualization software were used to display and analyze the research status, hotspot and development trend of the antibiotic-resistance of *Acinetobacter baumannii* objectively and comprehensively, so as to provide guidance and reference for the research of the antibiotic-resistant *Acinetobacter baumannii*.

Materials and Methods: The data of relevant publications on antibiotic-resistant *Acinetobacter baumanii* from 1991 to 2019 were retrieved from Web of Science (WOS) Core database. VOSviewer and CiteSpace software were used to conduct co-citation visualization network rendering and cluster analysis on the publications' years, authors, countries, institutions, keywords and citations.

Results: A total of 3915 valid records on the study of antibiotic-resistant *Acinetobacter baumanii* were retrieved. The number of relevant publications was increasing year after year. The United States is the most influential country in the field, which works closely with other countries and publishes most of the papers. University of Sydney is the leading institution in this area. Bonomo Robert A publishes most of the papers. There are the highest number of publications in the research areas of antimicrobial agents and chemotherapy. "Nucleotide sequence" and "outbreak" were once the hotspots in this field, but recently "bacteriophage", "biofilm" and "colistin resistance" have become the research hotspots.

Conclusion: Since 1991, the number of publications on antibiotic-resistant *Acinetobacter baumannii* has grown rapidly, and various countries and institutions have paid close attention to the problem of antibiotic resistance. Countries, institutions and researchers, which have strong influential power, collaborate with each other closely. The future research direction of antibiotic-resistant *Acinetobacter baumannii* should lie in the further breakthrough of antibacterial peptides, bacteriophage therapy, CRISPR system and various combined therapies.

Keywords: *Acinetobacter baumannii*, antibiotic resistance, CiteSpace, visualized analysis, scientometric

Introduction

Acinetobacter baumannii (*A. baumannii*) is a non-fermented gram-negative bacillus, which is widely found in natural water and soil, hospital environment and human skin, respiratory tract, digestive tract and urogenital tract, which is a conditional pathogenic bacterium.[1] *A. baumannii* can still live after being dried for several weeks in the living environment, which promotes its spread in hospitals through pollutant contamination.[2,3] *A. baumannii* is an important pathogen of nosocomial infection, mainly causing respiratory infections, which can also cause

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DovePress
http://doi.org/10.2147/IDR.S264391

bacteremia, urinary tract infection, secondary meningitis, surgical site infection, ventilator-associated pneumonia, etc.[4,5] The isolation of *A. baumannii* in hospitals is very dangerous, especially the patients in the ICU, because of their low immunity, which is conducive to *A. baumannii* infection.[6]

In recent years, mainly because of the extensive antibiotic resistance spectrum of *A. baumannii*, it has been designated as a human "red alarm" pathogen, causing vigilance in the medical community.[7,8] The Infectious Disease Society of America (IDSA) said in 2008 that the United States and other countries were at risk of pathogens developing resistance to antibiotics.[9] The emergence of high antibiotic-resistance has become one of the biggest challenges to human health.[10,11] With the abuse of antibiotics and the increase of various invasive tests, the problem of antibiotic-resistance of *A. baumannii* is becoming more and more serious.[12] Up-regulation of congenital resistance mechanisms and exogenous resistance are the main causes of multi-drug resistant (MDR) *A. baumannii*.[13–16] Various drug-resistance mechanisms can be combined with each other to lead to the development of highly resistant and widely resistant strains.[15] The diversity and complexity of antibiotic-resistant mechanisms and the undetermined mechanisms of drug resistance pose a great challenge to solve the problem of antibiotic-resistance of *A. baumannii*. In response to the emergence of more and more MDR *A. baumannii*, clinically commonly used combination drugs have been unable to control all strains. In conclusion, antibiotic-resistant *A. baumannii* has attracted research's attention worldwide.

CiteSpace, a Java application for analysis and visualization, was invented by professor chaomei Chen in early 2004.[17] Knowledge mapping is a novel analytical tool, which combines theories and methods of mathematics, as well as graphics and other disciplines with bibliometrics methods such as citation analysis and cocitation analysis to reveal the core structure, development history, hot spots and overall knowledge structure of the filed.[18,19] The VOSviewer is efficient and powerful in building and viewing bibliographic metrographs which can reveal another aspect of the research on antibiotic-resistant *A. baumannii* from microscopic and quantitative perspectives.[20,21] However, bibliometric analysis of the resistance of *A. baumannii* studies has never been done.

Therefore, CiteSpace 4. 0. R5 SE and VOSviewer 1. 6. 10 were used in this study to analyze data from WOS database. Since the earliest articles on this study were published in 1991, there were continuous publications in this field with totally 3915 valid records on antibiotic-resistant *A. baumannii* studies collected from 1991 to 2019 for analysis. We have completed the national co-occurrence map, the organization co-occurrence map, the author co-occurrence map, the periodical co-occurrence, the document co-occurrence and the keyword co-occurrence map cocitation. These results were analyzed to understand the cooperation among various countries, institutions and authors, while the analysis was also to obtain visual information of research results and find out research hotspots and trends. The research provides a new way and ideas to solve the problem of antibiotic-resistance of *A. baumannii* for its further study.

Materials and Methods

Data Source and Search Strategy

The literature acquisition strategy of this study in WOS database is the time span (1991–2019), topic (*Acinetobacter baumannii* OR *A. baumannii*) AND (drug resistance OR drug-resistant OR antibiotic resistance OR antibiotic-resistant OR antimicrobial resistance OR antimicrobial resistant OR multi-drug resistance OR multi-drug resistant OR pan-drug resistant OR pan-drug resistance OR extensively drug-resistance OR extensive drug-resistance OR extensively drug-resistant). There was no limit to the type of literature which excluded republished and unrelated articles. Finally, 3915 articles that met the requirements were included. Each data was downloaded in "full record plain text format". However, due to the time limit of data collection, 2019 data was incomplete (the data was collected till July 18, 2019).

Statistical Analysis

The software used in this study was CiteSpace 4. 0. R5. Parameters setting: time span was from 1991 to 2019, and 1 year was a time slice. Cited references were selected for co-cited analysis. The keywords were selected for co-occurrence analysis and burst analysis, and the remaining settings were kept as default. And the corresponding visualized map was drawn. VOSviewer1. 6. 10 was used to select authors, institutions and conduct cooperative network analysis to draw the visualized map. The following parts were included in the analysis parameters.

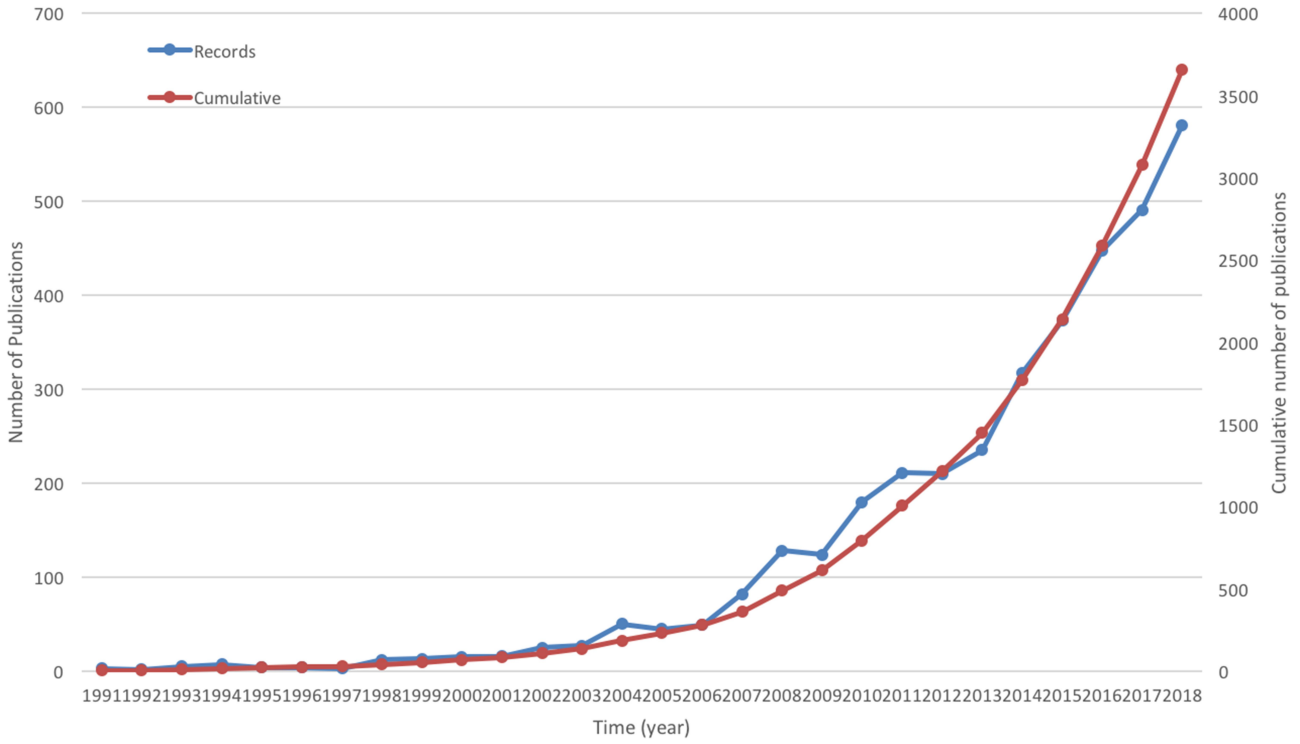

Figure 1 Annual trends in the number of antibiotic-resistant *A. baumannii* related publications from 1991 to 2018. The blue line is the number of annual publication. The red line is the cumulative number of publication.

Modularity: modularity values evaluated network modularity on a scale of 0 to 1. The higher the value, the better the clustering obtained by the network. When the module degree value was greater than 0.3, the network community structure obtained was significant.[22]

Silhouette: the silhouette value measured the homogeneity of the network. The closer the value from 0 to 1, the better the homogeneity of the network.

Frequency: the number of times that the subject appeared.

Centrality: it reflected the influence of the object in the whole research field. The threshold value was 0–1, and the centrality value was <1, indicating that the object was meaningful and recognized by researchers. The centrality value >1 was not significant.[23]

Results

The Annual Trends of Publications

According to the statistics of WOS, the number of published literature from 1991 to 2019 was 3915. Since the data of 2019 is partial, the overall data of 2019 was not considered for the time being. The number of published articles was mainly divided into three stages. As shown in Figure 1, from 1991 to 1999, the number of annually published articles was changed from 3 to 53; from 2000 to 2012, the number of published articles increased, reaching 211 in 2011, and the cumulative number of published articles increased rapidly; from 2013 to 2018, the number of published articles increased significantly every year. In 2018 alone, 581 articles were published. The cumulative

Table 1 Data Type Statistics of Research on Antibiotic-Resistant *A. baumannii*

Rank	Types	Counts (%)	Rank	Types	Counts (%)
1	Article	3280(83.78)	7	Editorial material	30(0.766)
2	Review	496(12.669)	8	Early access	7(0.179)
3	Proceedings paper	75(1.916)	9	Correction	4(0.102)
4	Meeting abstract	44(1.124)	10	Note	1(0.026)
5	Letter	42, 1.073)	11	Retracted publication	1(0.026)
6	Book chapter	36, 0.92			

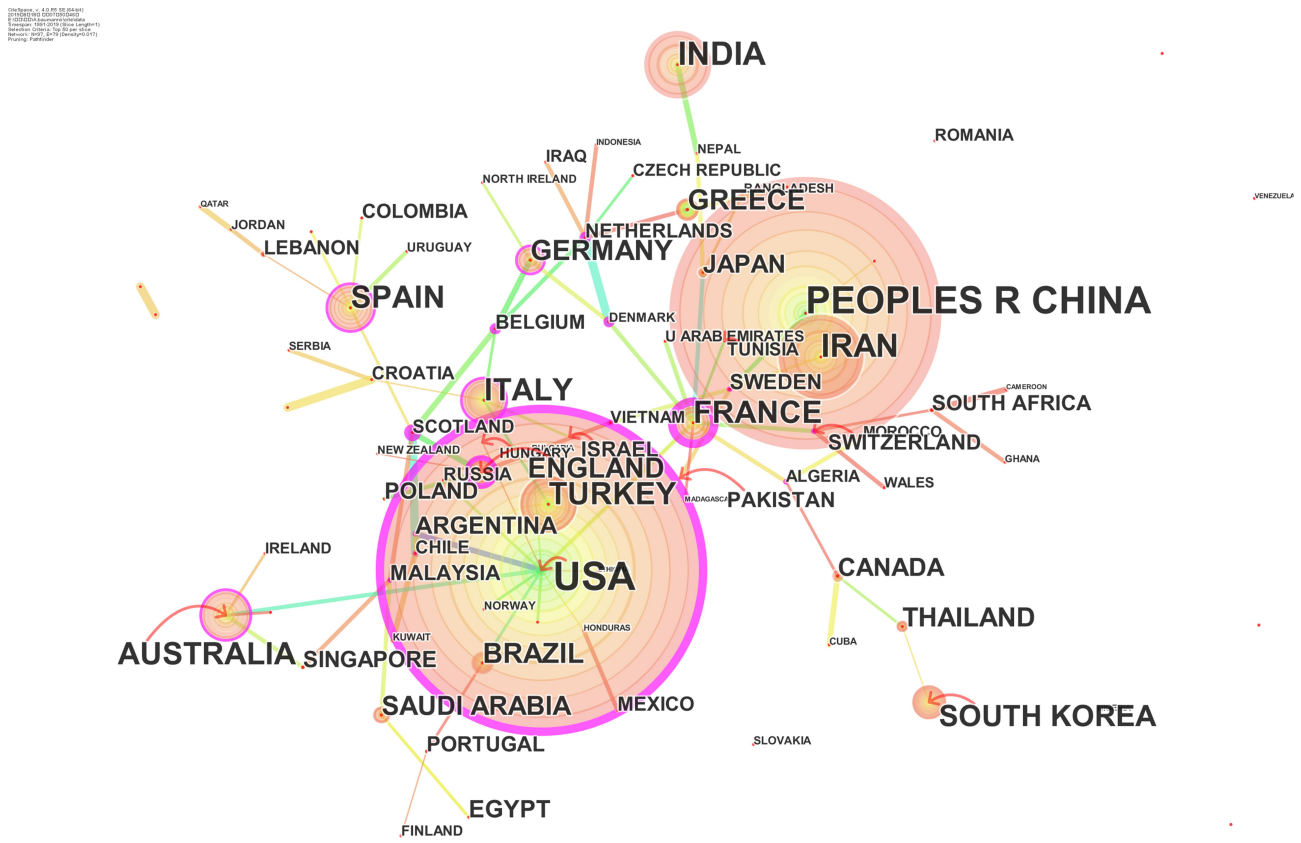

Figure 2 The country co-occurrence network of antibiotic-resistant *A. baumannii* related publications from 1991 to 2019. A node represents a country, and node size represents frequency.

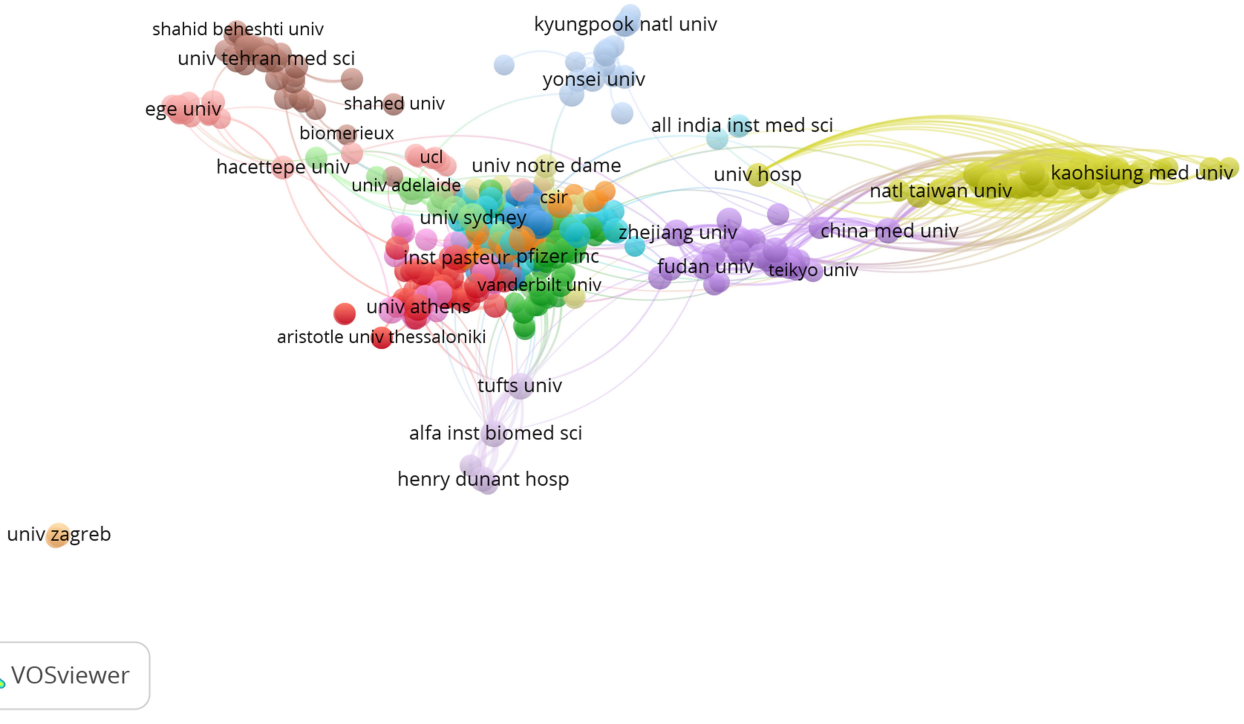

Figure 3 The institution co-occurrence network of antibiotic-resistant *A. baumannii* related publications from 1991 to 2019. A node represent an institution, and node size represents frequency.

Abbreviations: univ, university; sci, sciences; hosp, hospital; med, medical; inst, institution

Table 2 Top 10 of Countries and Institutions That Published Antibiotic-Resistant *A. baumannii*-Related Articles from 1991 to 2019

Rank	Country	Counts (%)	Institute	Counts (%)
1	USA	758(19.36)	University of Sydney (Australia)	69(1.76)
2	Peoples republic of China	654(16.70)	National Taiwan University (China)	63(1.60)
3	Iran	229(5.84)	Tufts University (USA)	61(1.55)
4	India	195(4.98)	University Tehran Medical Sciences (Iran)	58(1.48)
5	Spain	174(4.44)	Zhejiang University (China)	50(1.27)
6	France	166(4.24)	National Taiwan University Hospital (China)	49(1.25)
7	Turkey	155(3.95)	Case Western Reserve University (USA)	48(1.22)
8	Australia	151(3.85)	Alfa Institute Biomed Sciences (Greece)	46(1.17)
9	Italy	150(3.83)	University Athens (Greece)	46(1.17)
10	South Korea	144(3.67)	Monash University (Australia)	42(1.07)

number of published articles increased by leaps and bounds. In general, the publications have been keeping increasing since 1991. The results also showed that the study on antibiotic-resistance of *A. baumannii* had been one of the research focuses in many countries around the world.

There were 11 types of documents in 3915 results data, among which 3280 records were the most common type of scientific research articles accounting for 83.78% of the total records in Table 1. The second was the review (496), accounting for 12.669% of the total records. The remaining were proceedings paper (75, 1.916%), meeting abstract (44, 1.124%), letter (42, 1.073%), book chapter (36, 0.92%), editorial material (30, 0.766%), early access (7, 0.179%), correction (4, 0.102%), note (1, 0.026%) and retracted publication (1, 0.026%). The diversity of data types indicated that antibiotic-resistance of *A. baumannii* has received extensive attention and the high proportion of research papers reflected the depth of the research.

Analysis of Countries and Institutions

Co-occurrence analysis was carried out on the countries, and the network map was created by CiteSpace. The size of nodes in the figure reflects the relative amount of publications of countries. The lines between the nodes represent the collaboration between countries, and the line thickness reflects how close the collaboration is.[24] As shown in Figure 2, 96 countries contributed to the study, and 81 countries were connected with each other. The United States was the largest contributor, with 758 publications. The United States was in the center of the picture, with close ties to other countries. Eighty-one countries made up seven clusters, and there were active collaborations among the countries within these clusters.

The VOSviewer was used to draw an institution's network map. A total of 575 research institutions participated in the research of this field, with 169 links between them (Figure 3). Among them, University of Sydney was the institution with the most publications (63), followed by Alfa Institute Biomed Sciences (44) and Zhejiang University (40). The different color of the node indicates the different cluster. There were 10 clusters of 575 research institutions, and they were active collaborations among them, especially the close collaborations between universities and hospitals, which is the main type of collaboration in this research field. Cooperation among institutions within the same cluster of institutions is very intensive.[25] Chinese institutions accounted for three of the top 10, indicating that antibiotic-resistant *A. baumannii* is a serious problem in China and that the country attaches great importance to this field (Table 2). Among the top 10 institutions, University of Sydney published the most articles for 63 times. The top 10 institutions which published the most are from the United States (2), China (3), Australia (2), Greece (2) and Iran (1). It can be seen that cooperation and communication in the research of antibiotic-resistant *A.baumannii* was essential, especially in cooperation with research-based institutions.

Analysis of Author

Author co-occurrence analysis was conducted on 3915 pieces of data through CiteSpace. Nine hundred and thirty-three authors participated in the study, with the majority of small nodes and only a few nodes in the center of the map were large (Figure 4). It indicates that the majority of authors published only a few relevant studies, on the contrary, a few authors followed the study continuously and did in-depth research., Bonomo Robert a. (49, 1.25%) has the largest number of published articles, while Hall

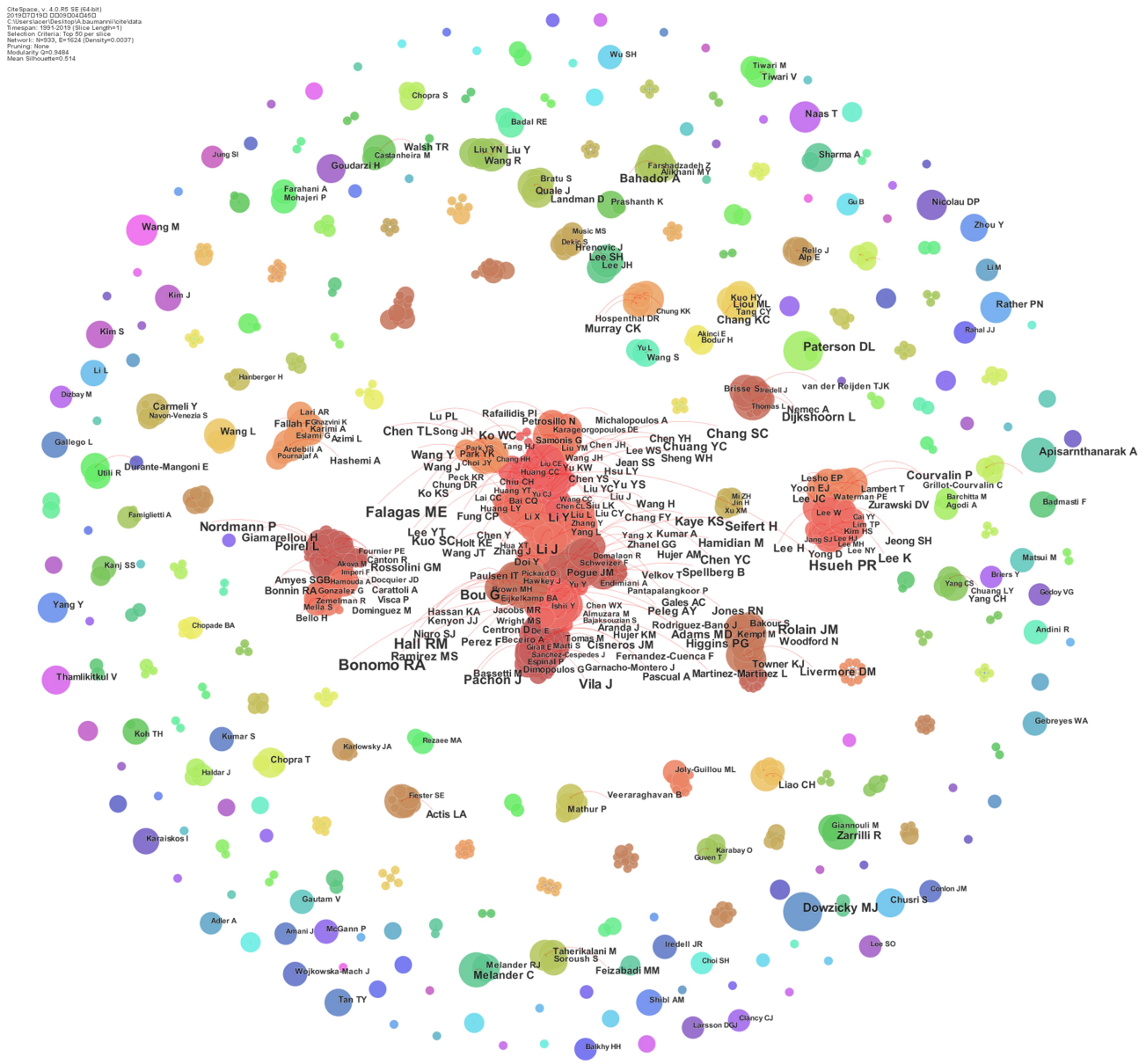

Figure 4 The author co-occurrence network of antibiotic-resistant *A. baumannii* related publications from 1991 to 2019. A node represent an institution, and node size represents frequency.

Ruth (46, 1.17%) and Falagas M. e. (46, 1.17%) tied for the second place (Table 3). The total number of publications by the top 10 authors accounted for only 7.92% of total publications. It means that many researchers there are, but few productive authors. The mutual collaboration among authors should be encouraged to accelerate the pace and increase the depth of research in this field.

Analysis of Journals

In order to find out the journals with large publications and high citations in this field, CiteSpace is used to list the top 10 journals in the publication volume. *Antimicrobial Agents and Chemotherapy* with the most publications, and its impact factor (IF) is 4.30 (2019), while the average IF of the top 10 journals is 3.52 (2019) (Table 4). It is clear that *Antimicrobial Agents* and *Chemotherapy* has the most publications and the higher IF (higher than an average IF of 3.52, 2019), which paid extreme attention to the field.

Analysis of Highly Cited and Co-Cited References

The co-occurrence analysis of literature is helpful to understand the most authoritative literature in this field

Table 3 Top 10 of Author and Co-Cited Author That Published Antibiotic-Resistant *A. baumannii*-Related Articles from 1991 to 2019

Rank	Auther	Counts (%)	Co-Cited Author	Citations
1	Bonomo, Robert a.	49(1.25)	Falagas, M. e.	5136 (5.78)
2	Falagas, M. e.	46(1.17)	Livermore, Dm	2066(2.33)
3	Hall, Ruth m.	46(1.17)	Bonomo, Robert a.	1960(2.21)
4	Hsueh, Po-ren	32(0.81)	Towner, Kj	1483(1.67)
5	Bou, German	30(0.76)	Nordmann, Patrice	1362(1.53)
6	Rolain, Jean-marc	23(0.58)	Spellberg, Brad	1320(1.48)
7	Li, Jian	22(0.56)	Poirel, Laurent	1265(1.42)
8	Vila, Jordi	21(0.53)	Paterson, David l.	1220(1.37)
9	Pachon, Jeronimo	21(0.53)	Rolain, Jean-marc	1204(1.35)
10	Nordmann, Patrice	20(0.51)	Courvalin, Patrice	987 (1.11)

Table 4 Top 10 Journal That Published Antibiotic-Resistant *A. baumannii*-Related Articles Most from 1991 to 2019

Rank	Journal	Count%	IF(2019)
1	Antimicrobial Agents and Chemotherapy	188(4.80)	4.30
2	International Journal of Antimicrobial Gents	145(3.70)	4.30
3	Journal of Antimicrobial Chemotherapy	134(3.42)	5.07
4	Plos One	105(2.68)	2.80
5	Frontiers in Microbiology	93(2.37)	4.07
6	Microbial Drug Resistance	66(1.68)	2.39
7	Clinical Microbiology and Infection	58(1.48)	6.42
8	Journal of Medical Microbiology	56(1.43)	1.37
9	American Journal of Infection Control	51(1.30)	1.97
10	BMC Infectious Diseases	49(1.25)	2.56

and lays a foundation for subsequent research. Seven hundred and seventy-five articles were cited in a total of 3915 articles (Figure 5). The total number of the first 5 references exceeds 200 times (Table 5). The article with the highest number of citations is,[26] with 449 citations, followed by.[13] While the centrality of the co-cited articles is[27] the highest, which is 0.32,[12] has the highest cited frequency as high as 2743 times, as an article of guiding significance in this field (Table 6). This article mainly defines multi-drug resistance, pan-drug resistance and widespread drug resistance, and also the corresponding testing standards were developed to provide a unified standard for the follow-up research.

Analysis of Keyword

The key words are extracted from the title and abstract. The keywords provide a reasonable description of the research hotspots and can be used to clearly understand the research status.[28] There are 310 nodes which means 310 keywords in the 3915 literature and there are also 150 links in total (Figure 6). The two central keywords in the figure are "Acinetobacter baumannii" and "antibiotic resistance". The most frequent keyword is "Acinetobacter baumannii" (centrality 0.02), followed by "pseudomonas aeruginosa" and "antibiotic resistance", "infection", etc. (Table 7). The keyword with the highest centrality is "intensive care unit" (frequency was 479, ranked no. 8), where antibiotic-resistant *A.baumannii* was most often infected. *Pseudomonas aeruginosa*, which are also gram-negative bacteria, also often show antibiotic-resistance.

Keywords Cluster Analysis

Hot topics can be reflected by the map of the co-occurrence of keywords. The cluster analysis (MI algorithm) of keywords is displayed in Figure 7. The mean silhouette value was 0.4383. The modularity is 0.8962, with its values greater than 0.3, was a significant result. A total of 310 keywords formed 27 keyword clusters, and there are 13 major clusters. Here are the first three of the largest clusters:

The largest cluster (cluster #0): It included 24 keywords with a Mean Silhouette value of 0.375. This cluster was labeled intensive care unit; multidrug resistance;

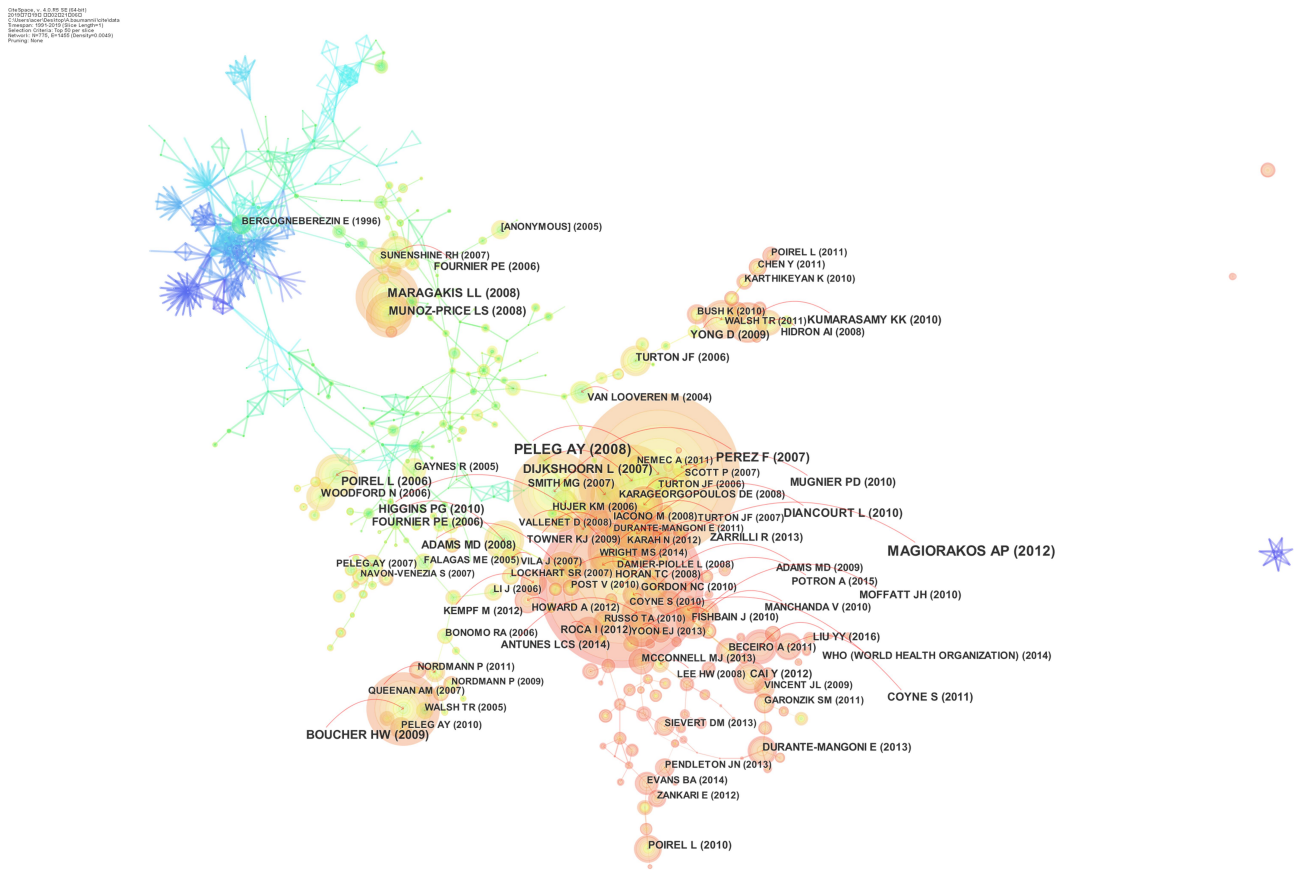

Figure 5 The reference co-occurrence network of antibiotic-resistance *A. baumannii* related publications from 1991 to 2019. A node represent an institution, and node size represents frequency.

bla (oxa 58) gene; medical center; evolution; sequence; strain; plasmid; algorithm; diversity by MI algorithm.

cluster #1: It included 23 keywords and a mean silhouette value of 0.422. This cluster was labeled *acinetobacter baumannii*; biofilm; multidrug-resistant; pseudomonas aeruginosa by MI algorithm.

cluster #2: It included 23 keywords and a mean silhouette value of 0.522. This cluster was labeled carbapenem; antimicrobial resistance; time series analysis; group 2 carbapenem; intraabdominal by MI algorithm.

Therefore, the research on drug-resistance mechanism accounts for the vast majority of the research on antibiotic-resistant *A. baumannii*, followed by the research on the treatment of it.

Analysis of Burst Keyword

The so-called "burst keywords" refer to the frequently quoted words in a period of time, which are considered as the indicators of research frontier topics.[29] In order to understand the trend of antibiotic-resistant *A. baumannii* research, all data were analyzed by burst keywords. "Calcoaceticus" and "nucleotide sequence" are the earliest prominent words, which all end in 2003 (Figure 8). "Bacteriophage", "biofilm" and "colistin resistance" have been the burst keywords in recent years. It indicates that the recent research hotspots are "bacteriophage", "biofilm" and "colistin resistance". Research hotspots from the beginning of research on drug-resistance mechanisms to more attention now on the treatment.

Discussion

For countries, the United States is definitely a leader in the research of antibiotic-resistance *A. baumannii*, which has a large collection of publications, as many as 758 articles. In addition, the United States is at the center of the country collaboration map and has more connections with other countries. The United States, a developed country with strong economic foundation supports the in-depth study on antibiotic-resistant *A. baumannii*. Clinical and Laboratory Standards Institute (CLSI) is the standard for clinical bacteria testing for most

Table 5 Top 5 Co-Cited References Related to Antibiotic-Resistant *A. baumannii* Research from 1991 to 2019 in Terms of Frequency and in Terms of Centrality

Rank	Frequency	Centrality	Time	Reference	Centrality	Frequency	Time	Reference
1	449	0	2012	Multidrug-resistant, extensively drug-resistant and pandrug-resistant bacteria:an international expert proposal for interim standard definitions for acquired resistance	0.32	7	1995	A novel integron-like element carrying the metallo-beta-lactamase gene blaIMP
2	444	0.01	2008	*Acinetobacter baumannii*: emergence of a successful pathogen.	0.31	16	1999	Spread of amikacin resistance in *Acinetobacter baumannii* strains isolated in Spain due to an epidemic strain.
3	226	0	2007	Global challenge of multidrug-resistant *Acinetobacter baumannii*.	0.28	105	2008	Comparative genome sequence analysis of multidrug-resistant *Acinetobacter baumannii*.
4	203	0.01	2009	Bad bugs, no drugs: no ESKAPE! An update from the Infectious Diseases Society of America.	0.27	24	2001	Identification of epidemic strains of *Acinetobacter baumannii* by integrase gene PCR
5	202	0.02	2007	An increasing threat in hospitals: multidrug-resistant *Acinetobacter baumannii*.	0.25	6	1997	Activity of selected beta-lactams, ciprofloxacin, and amikacin against different *Acinetobacter baumannii* biotypes from Chilean hospitals.

Table 6 Top 5 Cited References Related to Antibiotic-Resistant *A. baumannii* Research From 1991 to 2019 in Terms of Frequency

Rank	Cited	Reference
1	2743	Multidrug-resistant, extensively drug-resistant and pandrug-resistant bacteria: an international expert proposal for interim standard definitions for acquired resistance
2	1579	Origins and Evolution of Antibiotic Resistance
3	1217	AntimicrobialResistantPathogensAssociated With Healthcare-AssociatedInfections: AnnualSummary of DataReported tothe NationalHealthcareSafetyNetwork at the CentersFor DiseaseControl and Prevention, 2006-2007
4	1088	*Acinetobacter* spp, as nosocomial pathogens: Microbiological, clinical, and epidemiological features
5	869	The epidemic of antibiotic-resistant infections: A call to action for the medical community from the Infectious Diseases Society of America

countries including China.[30] The most cited literature and most research institutions of the publication belong to the United States. Among the top 10 countries in terms of the number of publications, 60% are from developed countries and 40% from developing countries, indicating that the problem of antibiotic-resistant *A. baumannii* attracts more attention in developed countries. The main reason is that the developed countries have more capital and better research base to support such a study. Furthermore, antibiotics are more

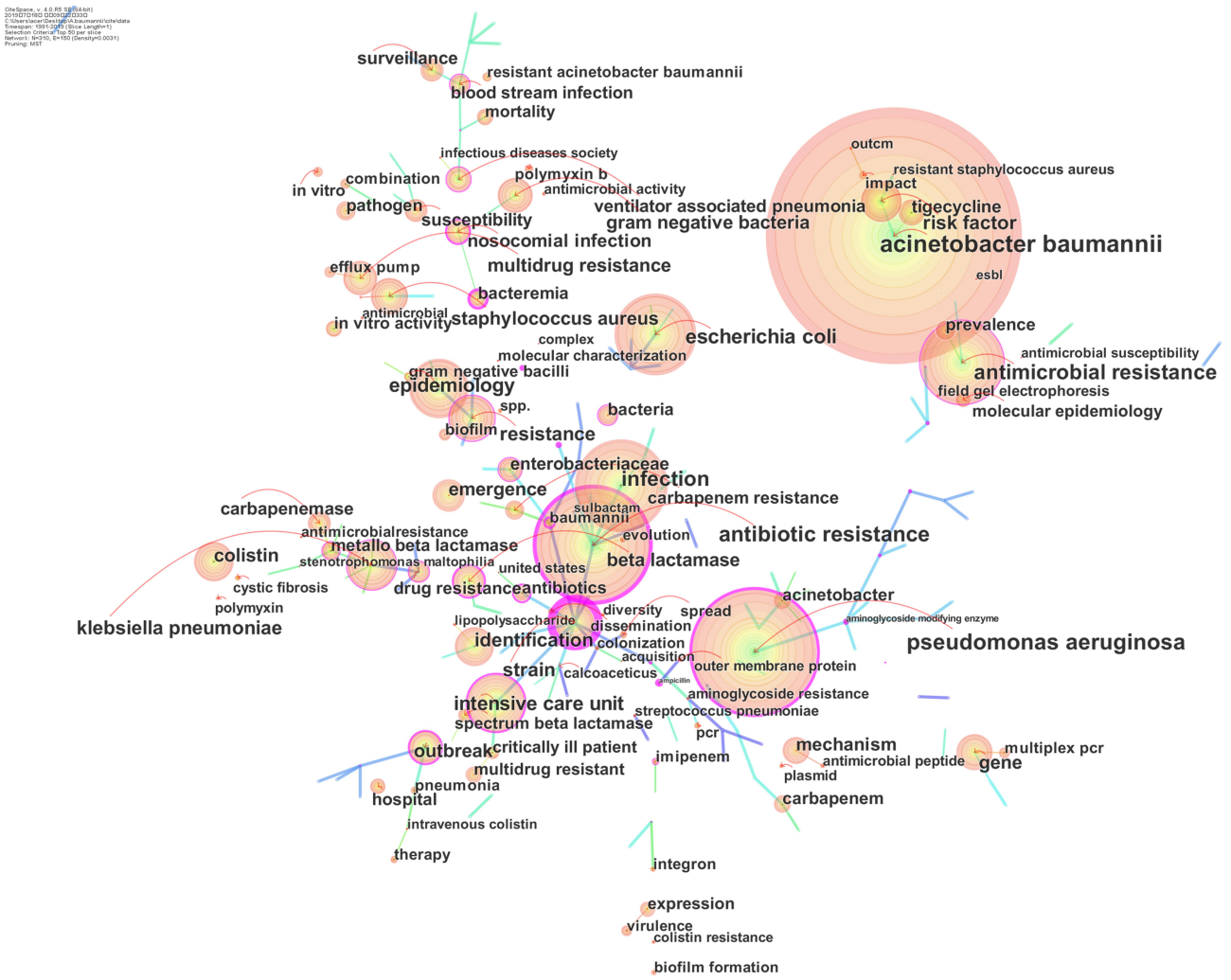

Figure 6 The keywords co-occurrence network of antibiotic-resistant *A. baumannii* related publications from 1991 to 2019. A node represents an institution, and node size represents frequency.

widely used in developed countries, and the abuse of antibiotics has accelerated the evolution of drug-resistant strains.[31] Developing countries should closely collaborate with other developed countries to generate sparks of ideas and promote the research advance on antibiotic-resistant *A. baumannii*.

Table 7 Top 10 Keywords Related to Antibiotic-Resistance *A. baumannii* Research from 1991 to 2019 in Terms of Frequency and in Terms of Centrality

Rank	Frequency	Centrality	Keywords	Time	Centrality	Frequency	Keywords	Time
1	1890	0.02	*Acinetobacter baumannii*	1994	0.24	479	Intensive care unit	1992
2	961	0.04	*Pseudomonas aeruginosa*	1991	0.24	351	Strain	1991
3	879	0.2	Antibiotic resistance	1991	0.2	879	Antibiotic resistance	1991
4	728	0.02	Infection	1992	0.13	426	*Klebsiella pneumoniae*	1993
5	673	0.08	Antimicrobial resistance	1997	0.13	303	Outbreak	1992
6	648	0.12	*Escherichia coli*	1991	0.12	648	*Escherichia coli*	1991
7	499	0.09	Epidemiology	1993	0.12	255	Nosocomial infection	1994
8	479	0.24	Intensive care unit	1992	0.09	499	Epidemiology	1993
9	426	0.13	*Klebsiella pneumoniae*	1993	0.09	344	Identification	1993
10	396	0.06	Resistance	1994	0.08	673	Antimicrobial resistance	1997

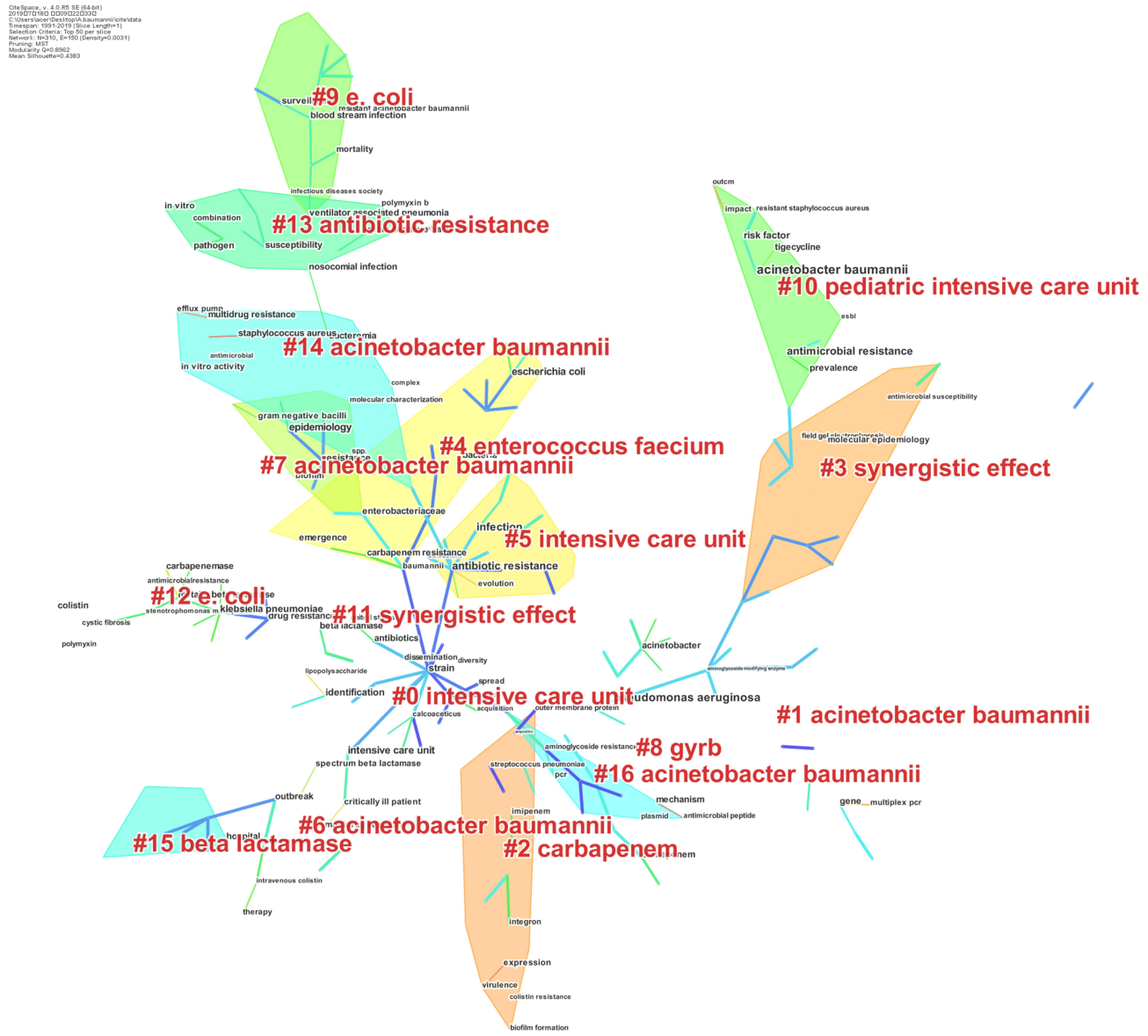

Figure 7 The clusters visualization network of keywords of antibiotic-resistance *A. baumannii* related publications from 1991 to 2019.

At the beginning of the 20th century, the burst keywords were "nucleotide sequence" that the research focus was on the study of drug-resistance mechanisms. Antibiotic-resistant *A. baumannii* began to break out, and drug resistance continued to increase. From carbapenem resistance to tigecycline resistance to now colistin resistance.[11,32] For different types of drugs, the resistance mechanism is different. The resistance mechanism of *A. baumannii* is divided into two categories, enzymatic mechanism and non-enzymatic mechanism, of which the non-enzymatic mechanism is mainly activation of the efflux pumps, decreased membrane permeability, changing the target site.[33]

"Bacteriophage", "biofilm" and "colistin resistance" had become the recently bust keywords. It also means that the research hotspot in recent years were "bacteriophage", "biofilm" and "colistin resistance". Bacteriophages had also been used to treat bacterial infections since the 19th century.[34] This method had some limitations, so it had not been widely used.[35] On the one hand, bacteriophages were specific to bacteria, a phage can kill only some strains of the same bacteria;[36] on the other hand, the presence of resistance genes in bacteriophages can also lead to drug resistance.[37,38] Due to the widespread emergence of multidrug-resistant bacteria, or even "superbugs", use various

Keywords	Strength	Begin	End	1991 - 2019
calcoaceticus	18.3397	1991	2003	
nucleotide sequence	5.3686	1991	2003	
colonization	5.9077	1992	2003	
outbreak	12.7683	1992	2009	
hospital outbreak	8.5658	1994	2007	
multiresistant acinetobacter baumannii	6.9617	1998	2008	
nosocomial infection	10.4498	1999	2009	
united states	7.611	2000	2012	
nosocomial pneumonia	7.4458	2002	2011	
feature	7.1081	2002	2007	
metallo beta lactamase	5.2496	2002	2007	
nosocomial outbreak	5.6186	2003	2009	
nosocomialinfection	5.9167	2003	2012	
antimicrobial surveillance program	7.9199	2003	2012	
gram negative bacilli	7.6693	2004	2011	
gar 936	5.355	2004	2011	
surveillance program	5.2551	2005	2012	
intensive care unit	9.5117	2005	2007	
ventilator associated pneumonia	5.9109	2005	2008	
cystic fibrosis	7.6123	2006	2011	
in vitro activity	5.9387	2007	2008	
methicillin resistant	6.2486	2008	2012	
bacteriophage	5.5024	2016	2019	
biofilm	5.6859	2016	2019	
colistin resistance	6.6317	2017	2019	

Figure 8 The keywords with the strongest citation bursts of antibiotic-resistant *A. baumannii* related publications from 1991 to 2019. The time interval is indicated by the green line, and the time interval of burst keywords is highlighted in red, indicating the beginning and end of the time interval of each burst.

methods in combination, such as the combined treatment of antibiotics and bacteriophages.[39,40] A study by Yang has isolated and identified the virulent AB1 bacteriophage, which is effective against *A. baumannii* and has certain therapeutic potential.[41] Bacteriophages therapy began to revive.[42] Since 2016, the research of "biofilm" has become a hot topic. The formation of biofilm is one of the reasons for the survival of *A. baumannii* in a harsh environment for a long time. The results show that there is an important correlation between drug resistance and biofilm formation of *A. baumannii*.[43] Colistin, being called the last line of defense in clinical antibiotic treatment, however, colistin-resistant *A. baumannii* has also been reported.[44,45] As the resistance to colistin *A. baumannii* continued to increase, the researchers proposed some other solutions. The Tammar Wallaby cathelicidin WAM1 has been shown to be effective against *Acinetobacter*.[46] Antimicrobial peptides are believed to have an antibacterial activity to limit the spread of *A. baumannii* strains, thereby reducing infection rates and mortality.[47] Some studies have proposed using the CRISPR system to combat antibiotic resistance and achieved certain research results.[48–50] Now the focus of the research is to solve the limitation of therapy in clinical treatment, then apply it to the clinical widely.

The combination of antibiotics and phages is based on the treatment of antibiotic-resistant *A. baumannii*, while the study of biofilm is based on the control of the transmission of antibiotic-resistant *A. baumannii*.51 Both of them are to solve the problem of antibiotic-resistance of *A. baumannii*, but the control of transmission is to prevent the problem at the source, which is more effective to solve the problem. Controlling the transmission of antibiotic-resistant *A. baumannii* will be the future research trend.

Conclusion

This paper should be the first application of visualized analysis software to comprehensively analyze the study about antibiotic-resistant *A.baumannii*. In this study, a series of data were collected from WOS, including sci-expanded, SSCI, A&HCI, cpci-s, cpci-ssh, bkci-s, bkci-ssh, ESCI and ccr-expanded. At the end of the data collection, a total of 3915 pieces of data were collected. And 933 researchers from 575 research

institutions in 96 countries contribute to the study of antibiotic-resistant *A. baumannii*. The number of scientific publications reflects developments in specific fields based on bibliometrics.[52] The United States was in the lead, followed by China. The most influential journals are *Antimicrobial Agents and Chemotherapy*, which paid close attention to the latest development of the field. Falagas M. e. is influential in this field with high publication volume and citation frequency. Therefore, close collaborations between authors should be strengthened to bring research outcomes more effectively and quickly. As the treatment options for antibiotic-resistant *A.baumannii* infection are limited, it will be the future research trend to develop or discover new treatment methods and combine existing treatment methods. It is important to pay attention to the prevention and control of antibiotic-resistant *A. baumannii*.

Acknowledgment

The authors would like to express their appreciation to Professor CM Chen, who invented CiteSpace, which is free to use.

Disclosure

This work was supported by the National Natural Science Foundation of China (NO.31870135), Opening Project of Zhejiang Provincial Preponderant and Characteristic Subject of Key University (Traditional Chinese Pharmacology), Zhejiang Chinese Medical University (No.ZYX2018035), and Project of Health and Family Planning Commission of Zhejiang province (2018KY831). The authors report no conflicts of interest in this work.

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