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Mapping international collaboration in tuberculosis research from 1998 to 2017

A scientometric study

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Abstract

Background: TB is one of the top 10 causes of death and the leading cause from a single infectious agent. The study characterize the developmental trends and collaboration features in the field of tuberculosis (TB) at the national level and identify high-impact countries.

Methods: Scientometrics and social network analysis methods were used to analyze the research situation and collaboration behaviors based on TB research indexed in Web of Science from 1998 to 2017.

Results: The publication output, national collaborative rate, and collaborative level have steadily increased from 1998 to 2017. However, domestic publications still account for a substantial proportion of a nation's publications. Over time, the numbers of national publications and international collaborative publications have increased in total, but the growth trend of their share as a proportion of total national publications is not significant. The United States of America has the largest number of highly cited publications, while Denmark, the Netherlands, Switzerland, and Sweden have higher values of average relative citation than do other countries. Notably, the United Kingdom and South Africa have established the strongest and most stable collaboration.

Conclusions: There was increasing research activity and collaboration in the field of TB during the period 1998 to 2017, but growth shows wide variability between countries. Further comprehensive and full collaboration should be promoted.

Abbreviations: ARC = average relative citation, BC = betweenness centrality, BRICS = Brazil, Russia, India, China and South Africa, ICD = international classification of disease, SCI-E = Science Citation Index Expanded, SSCI = Social Sciences Citation Index, TB = tuberculosis, UK = United Kingdom, UN = United Nations, USA = United States of America, WHO = World Health Organization.

Keywords: scientific collaboration, scientometrics, social network analysis, tuberculosis

1. Introduction

Tuberculosis (TB) is a chronic infectious disease that seriously affects human health in the long term.[1] As reported by the World Health Organization (WHO), in 2017 there were an estimated 1.3 million TB deaths and 10.0 million people fell ill with TB. The WHO's End TB Strategy and the United Nations' (UN) Sustainable Development Goals, share a common goal: to end the global TB epidemic sometime between 2016 and 2035. On 26 September 2018, the UN hold first high-level meeting on TB. The meeting highlights the need to accelerate progress towards the goal of ending the TB epidemic.

With the prevalence of HIV-associated TB and drug-resistant TB in recent years, the latest picture is still one of a serious epidemic of disease, slow progress and high disease burden, which seriously restricts the social and economic development of countries. The disease burden caused by TB is falling in most countries, but not fast enough to reach the first (2020) milestones of the End TB Strategy.[2] Without more effective tools, and innovative approaches to prevention, diagnosis, treatment, and care, this goal would not be achieved. To break the bottleneck calls for growth in scientific research and innovation, relying on the full participation and collaboration of countries around the world.

With collaboration playing an increasingly prominent role in promoting scientific production capacity, it has become an important way to conduct scientific research.[3] Previous scholars have conducted some bibliometric research based on TB publications. Ramos et al conducted a bibliometric analysis of TB publications indexed in PubMed from 1997 to 2006, and found that the countries with more estimated cases of TB produced less research in TB than industrialized countries;[4] A study carried out using scientometric and density equalizing methods to analyze all publications related to TB research listed in the Web of Science database between 1900 and 2012.[5] As a high-TB-burden country, some scholars have also conducted bibliometric analysis of Indian TB research papers. Based on Web of Science data from 1987 to 2012, the study analyses the collaboration pattern and identifies the major institutions, prolific authors and preferred journals carried on mycobacterial TB and leprosy in India. The study found that India needs to pay

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attention to TB related research.[6] Chen et al used the bibliometric resources of the Web of Science to identify the 100 most cited studies published on TB.[7] Vaidehi Nafade et al based on TB publications from 2007 to 2016, conducted a bibliometric analysis of TB research and found that collaborations appeared more frequently between high-income countries and low/medium income countries.[8] However, there is still a lack of knowledge about scientific collaboration in this field. The present study characterized the research situation and collaboration behaviors in TB research at the national level.

2. Source and methods

2.1. Data source and process

It was suitable for this study to select the Science Citation Index Expanded (SCI-E) and Social Sciences Citation Index (SSCI) of the Web of Science as the data source. The search strategy was: subject = tubercul * OR scrofula * OR mantoux OR pott's disease AND publication year = 1990 to 2017.[9–13] The search was restricted to the document type "article or review". Due to the lack of address information in the early bibliographic data, we selected a total of 88,422 documents from 1998 to 2017 for analysis. We removed the documents missing address information or that were irrelevant to the topic, and we finally obtained a total of 87,792 papers. Then, England, Wales, Scotland, and Northern Ireland were unified into the United Kingdom (UK). The People's Republic of China, Hong Kong, Macau, and Taiwan were viewed as independent entities in this study.

2.2. Analysis methods

The author's address defines the country of origin of each paper. If a paper has 3 co-authors who are from three different countries, thus this paper belongs to three countries. This study used the full counting method to calculate the number of co-authored publications from each country. Moreover, in order to identify the changes in research situation and collaboration on TB, the growth of the discipline is divided into 1 period every 5 years. This study used 2 indicators, the number of highly cited publication and average relative citations (ARC), to evaluate the citation performance of each country.[14] VOSviewer (Leiden University, version 1.6.4) mapped the collaboration network and used betweenness centrality (BC) to identify high-impact countries. The collaborative strength was calculated with Salton's cosine formula.[15] The ethical approval was not required for this study.

2.3. Related definitions and indicators

2.3.1. Collaborative level. Collaborative level is an indicator for measuring scientific collaboration, reflecting the depth of collaboration. It refers to the ratio of the total number of countries to the total number of publications in a certain research field.[16]

2.3.2. Collaborative rate. Collaborative rate is an indicator for measuring scientific collaboration, reflecting the breadth of collaboration. It refers to the percentage of publications by 2 or more countries out of the total publications in a certain research field.[16]

2.3.3. Internationally collaborative publication and domestic publication. A paper co-authored by 2 or more countries is defined as an international collaborative publication. A paper is defined as a domestic publication when author addresses include only 1 country.

2.3.4. Highly cited publication. A highly cited publication is a paper that ranks in the top 10% of citations for field and year.

2.3.5. Betweenness centrality (BC). BC is the extent to which a particular node falls on the shortest paths between other pairs of nodes in the network. A node with a higher BC is more important for information communication than other nodes.[17] This study calculate the values of BC using Pajek (Andrej Mrvar and Vladimir batagelj, version 5.03).

2.3.6. Average relative citation (ARC). The values of ARC above 1 mean that a country's publications are cited more frequently than the world average level. This indicator is the average of the relative citation scores of the publications belonging to the country. The relative citation score is calculated as the number of citations of a publication divided by the average number of citations of all publications published the same year in the same field. The standardization by year removes variations in the citations of papers owing to differences in their citation window.[14]

2.3.7. Collaborative strength. The strength of collaboration between countries A and B is measured as defined in Eq. (1) (Salton's cosine):

$$\text{Strength of collaboration AB} = \text{CoPubsAB}/\sqrt{(\text{PubsA} \times \text{PubsB})}$$

CoPubsAB refers to the number of co-publications between country A and country B, PubsA and PubsB refers to the total number of publications by Country A and B.[15]

3. Results

3.1. Analysis of output of scientific research and country collaboration trends

It can be seen that there was a rapidly increasing trend from 2325 papers in 1998 to 6738 papers in 2017 (Fig. 1). The number of papers before 2015 was exponentially increasing, and then the growth trend became relatively flat. Over the 20-year period, the

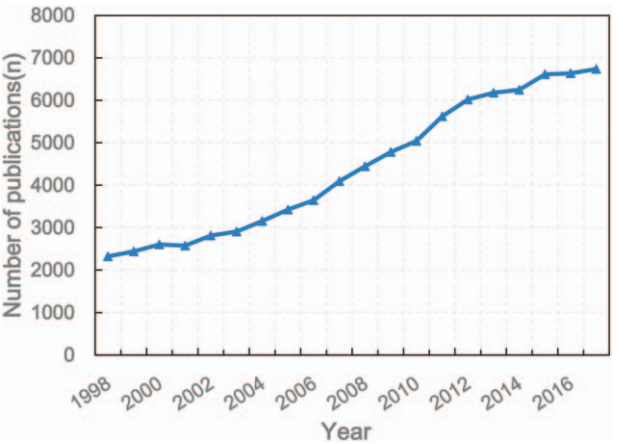

Figure 1. Total number of TB research publications between 1998 and 2017.

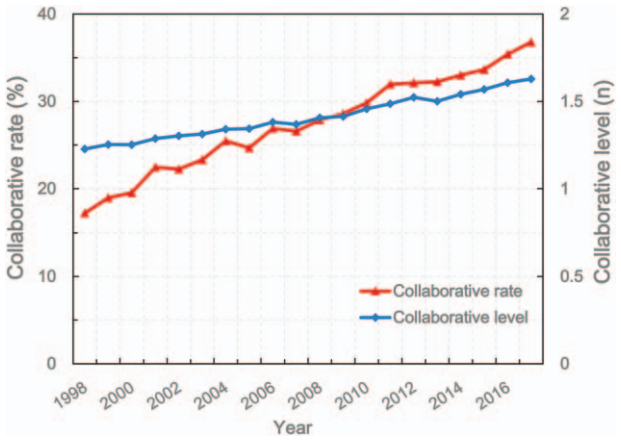

Figure 2. The national collaboration rate and collaboration level in TB research between 1998 and 2017.

collaborative rate of countries increased from 17% to 37% (Fig. 2). The average number of countries per publication showed an overall growth trend from 1.23 to 1.63 countries per publication. Figure 3 presented the trend of the number of multi-country authorship publications as a percentage of the total number of publications over time. Although the share of single-country authorship of publications decreased from 82% to 63%, it still accounted for a substantial proportion of a nation's publications. There was a substantial increase in the share of publications produced by 2 or 3 countries.

3.2. Journal and discipline of publication

We observed that publications were primarily published in the specialty journals focused on TB, microbiology, immunology, and biochemistry (Table 1). *The International Journal of Tuberculosis and Lung Disease* was the journal with highest number of TB publications. According to the discipline category of Web of Science, we found that ninety-four percent of the research papers were related to the top 10 disciplines (Table 2).

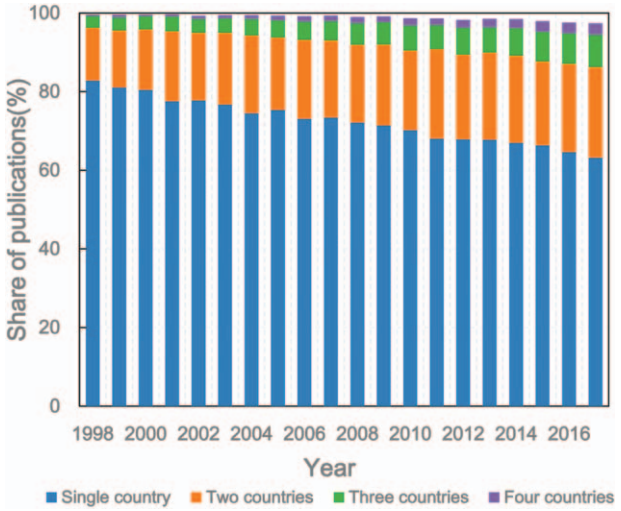

Figure 3. The share of multi-country authorship of publications on TB between 1998 and 2017.

Table 1

The 10 journals with the highest number of tuberculosis publications and their 5-year impact factors in 2017.

Journal	Number of publications (%)	2017 5-year impact factors
International Journal of Tuberculosis and Lung Disease	3971 (4.50%)	2.459
PLOS One	3187 (3.61%)	3.352
Journal of Clinical Microbiology	1393 (1.58%)	3.962
Tuberculosis	1274 (1.44%)	2.686
Infection and Immunity	1074 (1.22%)	3.603
Antimicrobial Agents and Chemotherapy	988 (1.12%)	4.505
Journal of Immunology	816 (0.92%)	4.99
BMC Infectious Diseases	814 (0.92%)	2.949
Journal of Biological Chemistry	808 (0.91%)	4.254
Journal of Bacteriology	727 (0.81%)	2.837

The discipline of infectious diseases had the largest number of TB publications.

3.3. Country of publication

Over the 20-year period, the 15 most prolific countries saw an increase generally in the number of publications (Fig. 4). The right of Figure 4 showed the share that the number of these countries' publications accounted for total number of publications worldwide fluctuated over time, but overall growth in their share of worldwide publications was not obvious. The United States of America (USA) was the most productive country with the highest number and share of TB publications, but its share of publications declined from 34% to 28%. The UK ranked 2nd after the USA before 2012. However, the more prominent increase in number and share by time period was from India and China. India had a higher number and share of publications than the UK in 2012. Moreover, the number and share of publications from China surpassed those from the UK in 2015. Also notable is that the share of publications in France, Italy, Japan and Spain decreased.

3.4. Internationally collaborative publication

The distribution of the number and share of internationally collaborative publications shows that the number of international publications in these countries increased steadily over time

Table 2

The 10 discipline catrgories with the highest number and share of tuberculosis publications.

Discipline catrgories	Number of publications	Share of publications
Infectious Diseases	15486	17.64%
Microbiology	13947	15.89%
Immunology	12954	14.76%
Respiratory System	8971	10.22%
Biochemistry& Molecular Biology	7884	8.98%
Medicine, General & Internal	5266	6.00%
Pharmacology& Pharmacy	5226	5.95%
Public, Environmental& Occupational Health	5028	5.73%
Multidisciplinary Sciences	4765	5.43%
Chemistry, Medicinal	3248	3.70%

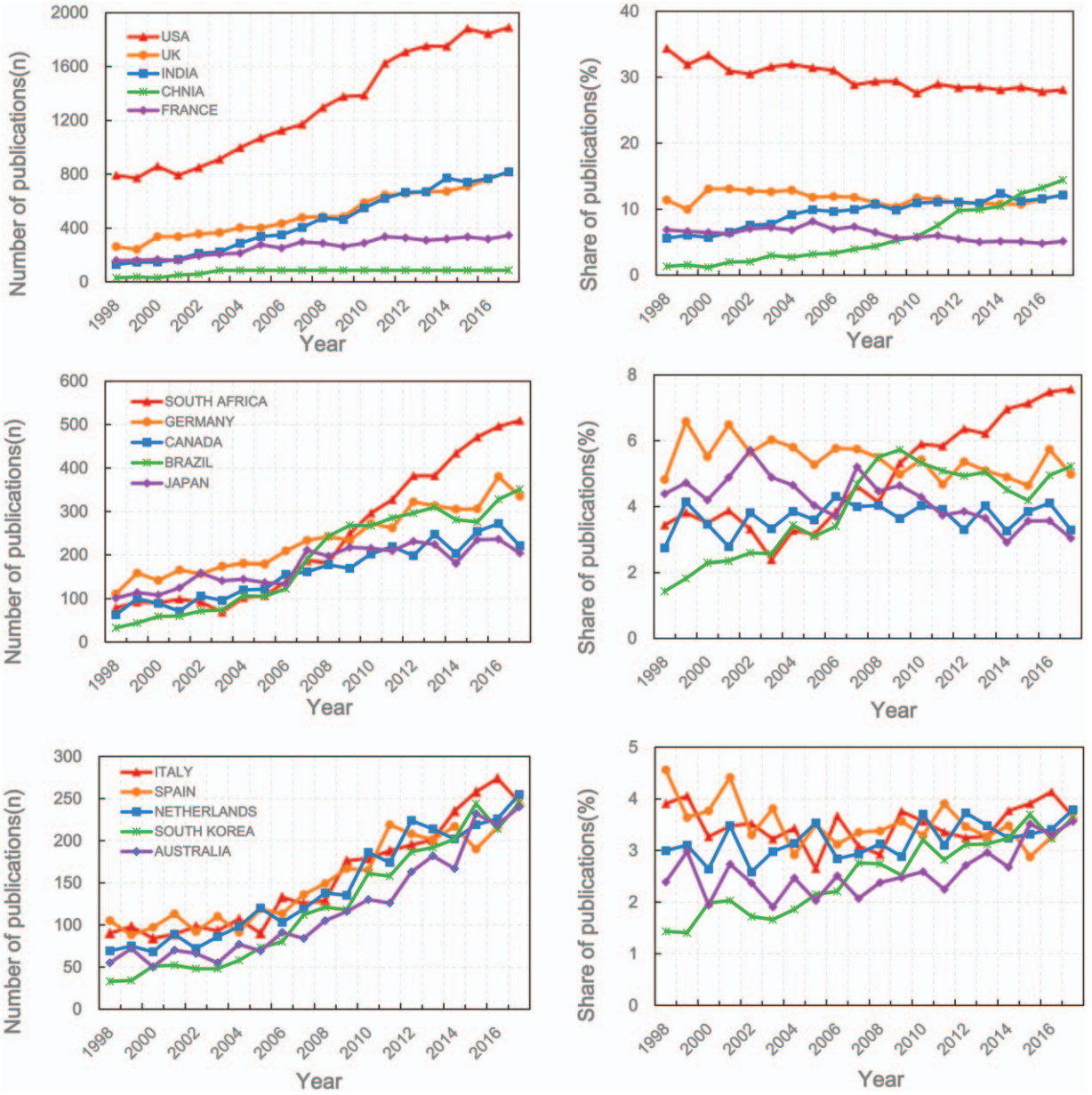

Figure 4. Numbers (left) and shares (right) of publications by 15 most prolific countries in TB between 1998 and 2017.

(Table 3). Nevertheless, the growth of the share of international publications was not significant. The USA produced the largest number of international publications, followed by the UK. In terms of the share of international publications, China, India and South Africa experienced a relatively rapid increase. While the share of international publications in the UK, Germany, Canada, France, the Netherlands, and Sweden declined. Table 3 also lists the percentage of international publications within each country's total publications (IP(%)B). Except in Brazil, the growth trend of the percentage was remarkable over time. The highest percentage in the Netherlands, Switzerland and Sweden was up to about 80%. We next examined whether there is a difference between the international publication and the domestic publication in terms of citation impact, and found that the international publications for all countries obtained a higher values of ARC than domestic publications for four time periods. Of note, the ARC of domestic publications in most countries is less than 1, which means that the citation impact of their own was lower than the global average.

3.5. Country of the share of publications and the disease burden

The burden of TB disease can be measured in terms of incidence, prevalence and mortality.[2] This study used 2 indicators, incidence rate and mortality rate, to measure the burden of TB. The mortality of TB excludes the death from TB among HIV-positive people, for consistency with the international classification of diseases (ICD-10) that death from TB among HIV-positive people are classified as HIV death.[2] We selected 17 most prolific countries with the larger number of publications or internationally collaborative publications and 30 high-TB-burden countries

Table 3

The numbers and shares of internationally collaborative publications and ARC values of their international and domestic publications by the top 15 countries in four time periods.

	1998–2002					2003–2007					2008–2012					2013–2017				
Country	IP	IP (%)A	IP (%)B	ARC (IP)	ARC (DP)	IP	IP (%)A	IP (%)B	ARC (IP)	ARC (DP)	IP	IP (%)A	IP (%)B	ARC (IP)	ARC (DP)	IP	IP (%)A	IP (%)B	ARC (IP)	ARC (DP)
USA	**1162**	45.50	28.61	1.99	**1.34**	**2020**	46.11	38.32	1.60	**1.32**	**3678**	47.01	49.78	1.75	**1.39**	**5197**	46.48	57.02	1.55	**1.32**
UK	**673**	**26.35**	43.99	1.84	**1.03**	**1142**	**26.07**	54.93	1.61	**1.14**	**1909**	**24.40**	66.79	1.80	**1.03**	**2662**	**23.81**	73.29	1.81	**1.18**
S AFR	165	**6.46**	36.50	1.35	0.68	338	**7.72**	55.96	1.80	0.78	995	**12.72**	69.29	2.38	0.75	1689	**15.11**	73.69	1.77	0.77
FRA	345	**13.51**	41.12	2.17	0.77	657	**15.00**	52.69	1.52	0.72	957	**12.23**	63.8	1.78	0.82	1138	**10.18**	70.07	1.64	0.88
GER	267	**10.45**	36.33	1.93	0.95	489	**11.16**	50.10	1.64	0.98	829	**10.60**	62.28	2.10	0.93	1143	**10.22**	69.74	1.91	0.96
IND	106	**4.15**	13.27	0.94	0.54	295	**6.73**	18.46	1.37	0.60	599	**7.66**	21.62	2.11	0.60	1120	**10.02**	29.74	1.29	0.67
CHN	48	**1.88**	23.41	1.34	0.53	164	**3.74**	29.44	1.48	0.64	547	**7.00**	31.35	1.79	0.61	1016	**9.09**	25.88	1.30	0.63
CAN	200	**7.83**	46.62	2.0	1.16	354	**8.08**	53.96	1.69	1.02	558	**7.13**	57.70	2.44	1.08	791	**7.08**	66.08	1.97	0.95
NET	218	**8.54**	**58.44**	1.66	**1.30**	356	**8.13**	**67.68**	1.58	**1.43**	620	**7.92**	**72.35**	2.32	**1.16**	910	**8.14**	**81.54**	1.72	**1.34**
SWI	124	4.85	**55.61**	1.82	0.67	187	4.27	**60.52**	1.91	1.41	546	6.98	**78.67**	2.15	1.30	812	7.26	**82.86**	2.20	1.49
BRA	113	4.24	**42.16**	1.08	0.38	193	4.41	**32.22**	1.14	0.48	386	4.93	**28.40**	1.83	0.47	594	5.31	**38.42**	1.21	0.56
ITA	147	5.76	32.03	1.33	0.65	228	5.20	41.61	1.47	0.94	464	5.93	53.52	2.44	0.90	727	6.50	59.88	2.05	0.91
SPA	91	3.56	18.38	1.50	0.46	160	3.65	28.12	1.52	0.82	424	5.42	46.70	2.14	0.67	602	5.38	56.47	1.76	0.75
AUS	123	4.82	39.30	1.52	0.72	201	4.59	53.46	1.42	0.82	381	4.87	59.53	2.41	0.98	727	6.50	69.90	1.70	1.03
SWE	125	**4.89**	**69.83**	1.32	**1.26**	163	**3.72**	**82.74**	1.27	**1.21**	315	**4.03**	**72.92**	3.02	**1.11**	508	**4.54**	**80.76**	3.02	**1.23**

IP = number of international publications, IP (%) A = the percentage from IP of each country in total international publications worldwide, IP (%)B = the percentage of IP within each country's total publications, ARC(IP) = average relative citation of international publications, ARC(DP) = average relative citation of domestic publications, USA = the United State of America, UK = the United Kingdom, S AFR = South Africa, FRA = France, GER = Germany, IND = India, CHN = China, CAN = Canada, NET = Netherlands, SWI = Switzerland, BRA = Brazil, ITA = Italy, SPA = Spain, AUS = Australia, SWE = Sweden.
Bold fonts indicate changes or meaningful values.

as dataset. The abscissa of Figures 5 and 6 represents the share of publications issued by these countries, the ordinate represents the share of internationally collaborative publications. The circle size in Figure 5 indicates the incidence rate of TB, while the circle size in Figure 6 indicates the mortality rate. The lower left corners of Figures 5 and 6 are a large group of high-TB-burden countries with fewer publications. On the whole, most countries with high incidence and mortality rate have fewer publications, both in terms of share of publications and international publications. Most countries with higher share of publications and international publications have lower morbidity and mortality rates, except India, South Africa, China and Russia.

3.6. Country of citation

The impact of a country is not only reflected in the number of publications, but citation performance is also an essential part of evaluating impact. It can be seen that the number of highly cited publications from most countries increased steadily over time (Table 4). The USA had the largest number of highly cited publications (4402), the UK came second (1735), and South Africa had the highest number of highly cited publications in high-TB-burden countries (790). Except for the USA, France, Japan, and Denmark, the share of highly cited publications from other countries has increased with time. Among the remaining countries, South Africa, India, and China had rapid growth. In

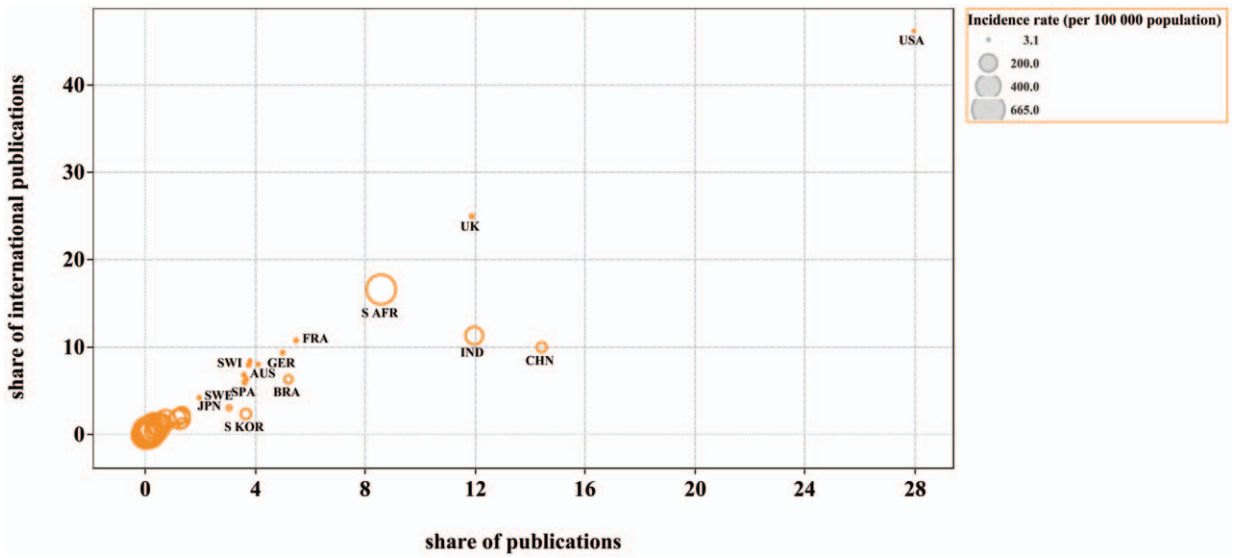

Figure 5. The scatter plot of the share of national publications and incidence rate in 2017. USA = the United State of America, UK = the United Kingdom, S AFR = South Africa, FRA = France, GER = Germany, IND = India, CHN = China, SWI = Switzerland, BRA = Brazil, SPA = Spain, AUS = Australia, SWE = Sweden, JPN = Japan, S KOR = South Korea.

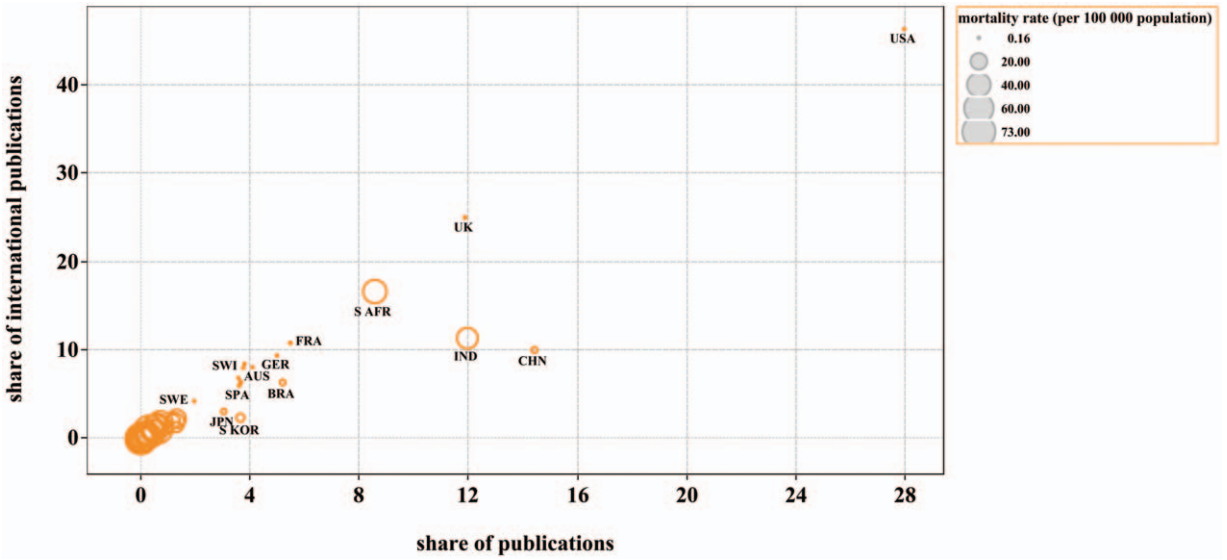

Figure 6. The scatter plot of the share of national publications and mortality rate in 2017. USA = the United State of America, UK = the United Kingdom, S AFR = South Africa, FRA = France, GER = Germany, IND = India, CHN = China, SWI = Switzerland, BRA = Brazil, SPA = Spain, AUS = Australia, SWE = Sweden, JPN = Japan, S KOR = South Korea.

terms of the ARC, the ARC values of eleven countries were greater than 1 for 4 time periods, while the ARC values of China, Brazil, and South Korea were less than 1 in the 4 time periods. Denmark had the highest values of ARC for the first 3 time periods, and the Netherlands, Switzerland and Sweden had higher values of ARC for 2 of the time periods. Of note, although the ARC value in the USA was not the highest one, it was very stable over time.

3.7. Collaboration network

As shown in Figure 7, the n in the brackets indicates the number of vertices in the network. The size of the node corresponds to the country's number of publications, a line indicates a collaborative relationship and it is resized linearly based on collaboration frequency. A green node represents high-TB-burden countries, and red represents the countries with low-TB-burden. For the sake of clarity, in the first 2 periods, only the countries and

Table 4

The numbers and shares of highly cited publications and ARC values of total publications by the top 20 countries in four time periods.

	1998–2002			2003–2007			2008–2012			2013–2017		
Country	**HCP**	**HCP(%)**	**ARC**	**HCP**	**HCP(%)**	**ARC**	**HCP**	**HCP(%)**	**ARC**	**HCP**	**HCP(%)**	**ARC**
USA	683	**54.00**	1.43	854	**49.97**	1.43	1326	**51.56**	1.57	1539	**47.57**	1.45
UK	225	17.79	1.39	308	18.02	1.4	497	19.32	1.55	705	21.79	1.64
S AFR	39	**3.08**	0.92	95	**5.56**	1.35	281	**10.93**	1.9	375	**11.59**	1.51
GER	96	7.59	1.31	147	8.60	1.31	242	9.41	1.66	287	8.8	1.5
FRA	102	**8.06**	1.34	170	**9.95**	1.14	203	**7.89**	1.43	245	**7.57**	1.41
IND	31	**2.45**	0.59	104	**6.09**	0.74	182	**7.08**	1.12	286	**8.84**	0.86
CAN	71	5.61	1.55	89	5.21	1.38	165	6.42	1.88	199	6.15	1.62
NET	64	5.06	**1.51**	90	5.27	1.53	152	5.91	**2**	210	6.49	1.65
SWI	31	2.45	1.31	70	4.10	**1.71**	160	6.22	1.97	246	7.60	**2.07**
ITA	33	2.61	0.87	64	3.74	1.16	149	5.79	1.73	221	6.83	1.59
CHN	11	**0.87**	**0.72**	36	**2.11**	**0.89**	108	**4.20**	**0.98**	261	**8.07**	**0.84**
SPA	26	2.06	0.65	43	2.52	0.88	101	3.93	1.44	154	4.767	1.32
AUS	37	2.92	1.03	39	2.28	1.25	83	3.23	1.83	163	5.04	1.5
JPN	40	**3.16**	0.75	53	**3.10**	0.83	98	**3.81**	1.29	86	**2.66**	0.95
SWE	26	2.06	1.38	28	1.64	1.25	89	3.46	**2.51**	132	4.08	**1.99**
DEN	41	**3.24**	**2.56**	44	**2.57**	**1.83**	69	**2.68**	**2.93**	77	**2.38**	1.6
BEL	21	1.66	1.19	48	2.81	1.41	70	2.72	1.75	81	2.50	1.99
BRA	15	1.19	**0.67**	31	1.81	**0.7**	61	2.37	**0.86**	107	3.31	**0.81**
S KOR	23	1.82	**0.95**	24	1.40	**0.79**	64	2.49	**0.95**	85	2.63	**0.9**
RUS	10	0.79	0.80	19	1.11	0.99	28	1.09	1.93	51	1.58	1.14

HCP = number of highly cited publications, HCP (%) A = the percentage of HCP of each country in total highly cited publications in the time period, ARC = average relative citation of total publications, USA = the United State of America, UK = the United Kingdom, S AFR = South Africa, FRA = France, IND = India, CAN = Canada, NET = Netherlands, SWI = Switzerland, ITA = Italy, CHN = China, SPA = Spain, AUS = Australia, JPN = Japan, SWE = Sweden, DEN = Denmark, BEL = Belgium, BRA = Brazil, S KOR = South Korea, RUS = Russia.
Bold fonts indicate changes or meaningful values.

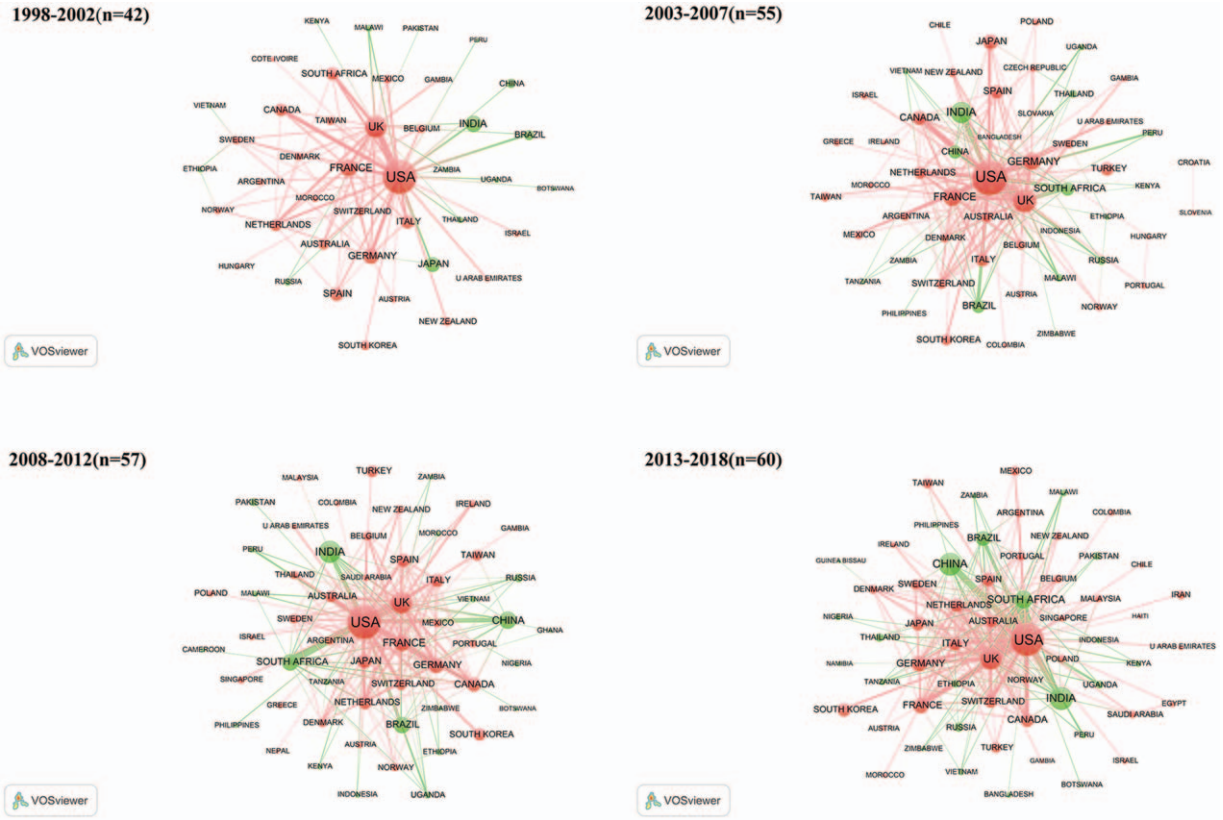

Figure 7. Evolution of the country collaboration network in four time periods.

relationships are presented in which the number of papers is not fewer than 20 and the line values are not less than 10. In the last 2 periods, the countries and relationships are presented in which the number of papers is not fewer than 30, and the line values are not less than 20. With time, the number of vertices and lines in the network increased and the width of lines became thicker. The USA, located in the center of the collaborative networks, played a vital role in the collaboration network. Furthermore, high-TB-burden countries increasingly appeared in the networks and built collaborations with many other countries. Notably, compared with the collaboration relationships between low-TB-burden countries, there were fewer collaborations between high-TB-burden and low-TB-burden countries.

3.8. Centrality analysis of the collaboration network

This study used the indicator of BC in social network analysis to identify the influential nodes in the network. The BC values for most countries have decreased over time (Table 5), which implies that the number of countries participating in the collaboration and the frequency of collaboration between countries has gradually increased with time. That is, countries have weakened their ability to control other countries accordingly. The USA, the UK, and France had high values of BC in all 4 time periods, which means that they are important bridges and intermediaries in the network and control the communication of information.

Table 5

Top 10 countries in TB research ranked by betweenness centrality in four time periods.

1998–2002	2003–2007	2008–2012	2013–2017
USA (0.1933)	USA (0.1881)	USA (0.1120)	USA (0.1131)
France (0.0801)	France (0.1066)	UK (0.0823)	UK (0.0712)
UK (0.0793)	UK (0.0733)	France (0.0688)	France (0.0448)
Germany (0.0460)	Germany (0.0611)	Switzerland (0.0561)	India (0.0273)
Belgium (0.0446)	Belgium (0.0465)	Germany (0.0330)	Australia (0.0270)
Netherlands (0.0381)	India (0.0427)	Brazil (0.0317)	Netherlands (0.0260)
Austria (0.0300)	Netherlands (0.0394)	Netherlands (0.0312)	Switzerland (0.0247)
Italy (0.0291)	Turkey (0.0342)	South Africa (0.0306)	Japan (0.0237)
Switzerland (0.0261)	Spain (0.0251)	Canada (0.0286)	Germany (0.0232)
Japan (0.0221)	Canada (0.0211)	Australia (0.0282)	Canada (0.0204)

Table 6

Top 10 strongest country-pair collaborations in each time period was presented.

1998–2002	2003–2007	2008–2012	2013–2017
UK-S AFR (0.095)	UK-S AFR (0.123)	UK-S AFR (0.205)	USA-S AFR (0.204)
USA-UK (0.087)	USA-UK (0.104)	USA-UK (0.156)	UK-S AFR (0.200)
USA-CAN (0.078)	FRA-BEL (0.095)	UK-SWI (0.151)	USA-UK (0.177)
UK-NET (0.072)	USA-CAN (0.083)	USA-S AFR (0.148)	UK-NET (0.144)
UK-FRA (0.064)	USA-SWI (0.080)	USA-SWI (0.137)	USA-SWI (0.138)
USA-GER (0.049)	FRA-SWI (0.078)	FRA-SWI (0.120)	UK-SWI (0.131)
FRA-ITA (0.047)	GER-SWI (0.077)	FRA-BEL (0.119)	UK-GER (0.125)
USA-FRA (0.047)	UK-FRA (0.076)	UK-AUS (0.107)	ITA-SWI (0.121)
FRA-GER (0.047)	UK-SWI (0.075)	UK-GER (0.103)	GER-SWI (0.120)
UK-AUS (0.046)	UK-GER (0.074)	UK-FRA (0.101)	NET-S AFR (0.118)

USA = the United State of America, UK = the United Kingdom, S AFR = South Africa, FRA = France, BEL = Belgium, GER = Germany, CAN = Canada, NET = Netherlands, SWI = Switzerland, ITA = Italy, AUS = Australia.

3.9. Analysis of collaborative strength

We next examined the strength of collaboration between countries. Collaborations with fewer than 30 co-publications or countries that had fewer than 300 publications during the time period, were excluded to maintain statistical stability. The collaborative strength of country pairs has increased gradually across time (Table 6). The UK, and the USA had the greatest number of strong collaborations with other countries. Of note, the strong collaborations in all four time periods exist between the UK and South Africa, followed by the UK and the USA.

4. Discussion

The TB field overall has seen a rapid growth in output from 1998 to 2017 with increased participation worldwide. Domestic publications still account for a substantial proportion of national publications. This result may be explained by the fact that there are many obstacles to international collaboration which require a relatively large cost of manpower, material, and financial resources. Progress towards ending TB will require all countries to reach a consensus on goals, work together to overcome obstacles, increase investment in scientific research funds, and fully engage in collaboration to fight against TB jointly.

When analyzing the TB research performance of different countries, it is unsurprising that the USA has the highest number of publications; our results are in line with a previous study.[4] Nevertheless, its share of publications has decreased over time. This may be owing to the global growth in research trend and visibility of publications added to Web of Science from other countries. The growth trend of the international publications' share was not significant, suggesting that collaboration between countries is not extensive enough. The ARC values of international publications for all included countries were higher than the domestic publications for 4 time periods. It can be inferred from the present data that collaboration has contributed to increased citation impact. In terms of the citation impact of individual countries, the USA experienced the largest number of highly cited publications. Denmark, the Netherlands, Switzerland, and Sweden stand out in citation performance, and the higher ARC values of the latter three are supported by the high percentage of international publications in their own total papers. The citation impact of the USA is not to be underestimated, as evidenced by the higher and stable ARC values in terms of its domestic publications.

The USA and the UK have always retained a dominant position in the TB research. While the performance of research in the high-TB-burden countries is in stark contrast to the reality of their situation. A bibliometric analysis of TB research indexed in PubMed from 1997 to 2006 concluded same result.[4] Except for India, China, South Africa and Brazil, the research productivity of other high-TB-burden countries was low. This result is due to the large amount of funds invested by the Brazil, Russia, India, China, and South Africa (BRICS) countries in scientific research.[8] Moreover, the number of the international publications in India, China, and Brazil accounted for a low percentage of their own total publications, indicating that collaboration has not yet become the preferred method for high-TB-burden countries to conduct research. Notably, the citation impacts in India, China, and Brazil were below average. On the whole, other countries, especially high-TB-burden countries, should find their own gaps and deficiencies using high-impact countries as the benchmark, accelerate research on TB in light of their own conditions, and strive to improve their research strength and academic impact.

When analyzing the features of the country collaboration network, we find there exists regional concentration as well as a certain amount of unbalanced and insufficient collaboration, as evidenced by the high-TB-burden countries having fewer strong collaborations with other countries and the majority of the strongest collaborations existing between closely neighboring countries. The strong collaborative relationships have remained stable for a period of time and cannot easily disappear. The main implication of these results is that more support should be provided to promote strong collaborations between high-TB-burden countries and other countries, especially high-impact countries.

The present study seeks to shed light on the increasing research activity and collaboration between different countries in the field of TB during the period 1998–2017. Further comprehensive and full collaboration should be promoted.

This study has several limitations, a major limitation of our study is that fewer non-English publications are indexed in the Web of Science. In addition, although some results have been tentatively explained, they cannot be further verified and follow-up study is still needed.

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